Supplying resilience through assessing diversity of responses to disruption

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Abstract

Purpose – The purpose of this paper is to contribute to the theory and practice of supply chain management in terms of how an organisation should structure its supply base to be resilient to supply uncertainties and disruptions. An empirical assessment of supplier response diversity is demonstrated, and the following research question posed: Is response diversity of suppliers positively associated with supply chain resilience, more positively than mere supplier diversity is?

Design/Methodology/Approach – Resilience is operationalised as the maintenance of sales of two food products in 27 southern Finnish retail stores during two distinct disruptions. Response diversity is operationalised as 1) diversity in the personnel sizes of slaughterhouse suppliers of pork under domestic strikes and as 2) evenness in the proportions of imports and domestic supply of food oil under global price volatility. A five-step quantitative assessment is performed.

Findings – Response diversity is positively related to the maintenance of sales, more positively than diversity of individual suppliers is.

Research limitations/Implications – Response diversity is an advancement to the theory of supply chain resilience and supply base management, and access to big data increases practical potential.

Practical implications – Empirical assessments of response diversity of suppliers provide buyer companies an effective means to enhance their supply base management for resilience.

Social implications – The proposed approach is useful for teaching and for authorities to enhance food security.

Originality/value – This first assessment of response diversity of supply chain operations presents an important advancement in the theory and practice of supply base management for resilience.

Keywords Empirical, Food, Purchase category, Supply chain resilience, Supply base complexity, Response diversity

Paper type Research paper

1. Introduction

Climatic extremes, market volatility and political instability create uncertainties and disruptions in supply chains, and globalisation has made anticipating and managing adverse events challenging (Van der Vegt *et al.*, 2015). Consequently, there is an increasing demand for supply chain resilience. Supply chain organisations can manage risks through structuring the supply base (Choi and Krause, 2006; Ates *et al.*, 2015), but past research

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has led to inconsequent advice; thus, theoretical advancements and empirical tools are needed.

Supply chain disruptions have severe effects on the financial, operational and market performance of firms (Heckmann *et al.*, 2015; Kim *et al.*, 2015), and food supply chains are especially challenged (Stone and Rahimifard, 2018). Consequently, risk management capability significantly enhances competitive advantage (Kwak *et al.*, 2018). Current risk management strategies mainly relate risk to the probability of occurrence of disruptive events (Heckmann *et al.*, 2015) and to the business impact of disruptions (Brindley, 2014). Such strategies present 'predict-and-adapt' approaches to maintaining good performance, whereas building supply chain resilience implies preparing for inherent, aleatory (variation) and epistemic (lack of knowledge) uncertainty, where the probability of disruptions cannot be assessed (Aven, 2016; Fiksel *et al.*, 2015; Scholten *et al.*, 2018). The resilience perspective (Kim *et al.*, 2015) thus represents a conceptually distinct 'capacity-oriented' approach (Aven, 2016; Kahiluoto *et al.*, 2014; Van der Vegt *et al.*, 2015) where the characteristics of the supply chain (Heckmann *et al.*, 2015), such as the supply base structure (Choi and Krause, 2006; Atek *et al.*, 2015), are important. A firm and a supply chain might be able to structure their supply base to be more resilient towards plausible types of disruptive events.

Despite the increasing number of publications on principles of supply chain resilience, there is limited empirical understanding of how firms can build resilience in supply chains (Blackhurst *et al.*, 2011; Fiksel *et al.*, 2015; Jüttner and Maklan, 2011; Kamalahmadi and Parast, 2016). Scholten *et al.* (2018) conclude that 'we know very little about, what constitutes supply chain resilience beyond top-level generic supply chain strategies; . . .and how supply chain resilience can be measured before the unexpected happens'. While 'much of the literature is conceptual, theoretical and normative' (Tukamuhabwa *et al.*, 2015), studies focusing on theory-based operationalising and empirically assessing supply chain and enterprise resilience are nearly non-existent (Kamalahmadi and Parast, 2016; Ribeiro and Barbosa-Povoa, 2018; Tukamuhabwa *et al.*, 2015). Therefore, new knowledge and analytical means for resilience management are needed (Carvalho *et al.*, 2012; Knemeyer *et al.*, 2009) to raise risk management in supply chains 'to the next level' (Aven, 2016). In this respect, a special challenge is faced by food-security-providing agri-food supply chains regarded 'as complex social, economic and environmental constructs where the priority goes far beyond the company specific focus of supply chain management works and would conceivably benefit from including more diverse academic disciplines' (Stone and Rahimifard, 2018).

Sourcing strategy is an important driver of a firm's financial performance (Shi, 2013). 'Complexity', that is, the number of suppliers, the degree of the differentiation (diversity), and the interrelations of the suppliers, are important aspects of the supply base (Choi and Krause, 2006). The buyer manages the supply base by concentrating contracts and purchases on one wholesaler or distributing them among a diversity of suppliers. Diversified 'balanced' sourcing is traditionally preferred for reducing vulnerability to seller opportunism (Chatterjee *et al.*, 1995), and redundancy has often been mentioned as one principle of supply chain resilience (Christopher and Peck, 2004; Kamalahmadi and Parast, 2016). Supplier diversity may even enhance national food security (Marchand *et al.*, 2016). On the other hand, a reduction in complexity through fewer suppliers may lead to lower transaction costs (Handfield and Nichols, 1999) as well as increased supplier responsiveness. According to Sheffi and Rice (2005), 'while some redundancy is part of every resiliency strategy, it represents sheer cost with limited benefit unless it is needed due to a disruption'. Indeed, building diversity in supply chains not aligned with plausible disruptions or main vulnerabilities may 'erode profits without improving resilience' (Pettit *et al.*, 2019).

It is, however, possible to build more resilience with less redundancy through targeted diversity (Kahiluoto *et al.*, 2014; Kahiluoto *et al.*, 2018), thus combining resilience and (economic) efficiency, as demanded by the academic and practitioner community (Christopher and Peck, 2004; Kamalahmadi and Parast, 2016). Relative to supplier 'type diversity', which refers to any diversity of suppliers (Page, 2010), diversity in responses of suppliers to disruptions targets diversity effectively with regard to resilience. Therefore, such 'response diversity' has the potential to reduce or avoid the trade-offs between efficiency and redundancy. The value added by response diversity relative to type diversity in building resilience has been shown for natural (Elmqvist *et al.*, 2003; Nyström, 2006) and managed ecosystems (Kahiluoto *et al.*, 2014; Mäkinen *et al.*, 2015). Response diversity also has relevance for social systems because different actors respond differently to disruptions and opportunities (Leslie and McCabe, 2013). To the best of our knowledge, response diversity has not been previously proposed or empirically assessed for supply chain management.

While theoretical propositions and common practices have been presented to employ supplier diversity in managing for risk and resilience, diversity has been defined and operationalised too vaguely to lead to coherent conclusions; the literature is inconclusive with conflicting arguments. Choi and Krause (2006) concluded that supply base complexity in terms of size and heterogeneity would aggravate management of supply chain risk. Also, the few empirical studies have offered divergent conclusions (e.g. Hendricks *et al.*, 2009). Thus, there appears a knowledge gap regarding theory-based empirical operationalisation of supply diversity as a strategy towards resilience (e.g. Choi and Krause, 2006; Ates *et al.*, 2015; Schmitt *et al.*, 2015). We responded to this gap by drawing on the theory of diversity within the resilience literature in ecology and social–ecological systems and applying the theory to supply chain management. The aim of the study was to separate various kinds of diversity as determinants of resilience, to alleviate theoretical and empirical confusion. Consequently, the following research question was posed: Is response diversity of suppliers positively associated with supply chain resilience, more positively than type diversity is? If so, response diversity assessments by supply chain companies such as retailers would be an appropriate means in the management of their supply base structure (Choi and Krause, 2006; Atek *et al.*, 2015) and thus supply chain resilience.

The assessment was exemplified in two available empirical cases by validating the results through triangulation of data from two different (product) supply chains, each with a different relevant disruption and, consequently, a different criterion for the response diversity structure. The assessment, while borrowing theory from adjacent disciplines relative to food supply chain management, such as ecology and agroecology, also responds to calls to explore different types of event studies on supply chain resilience (Ambulkar *et al.*, 2015) and for the use of secondary and archival data (Calantone and Vickery, 2010; Fisher, 2007; Roth *et al.*, 2008).

The next section presents the theoretical grounding and the operationalisation of supply chain resilience, response diversity and supply base structure in relation to purchase category strategy, to ground the proposed approach in the knowledge gaps. Section 3 introduces the five generic analytical steps of the proposed assessment approach, the case events and the data. Section 4 reports and illustrates the findings and tests the hypotheses. In the sections that follow on, we discuss and conclude about the validity and generalisability of the findings and the implications to the theory and management.

2. Theoretical framework

2.1 Supply chain resilience

Resilience has been defined with regard to engineering systems (Aven, 2016), social–ecological systems (Folke *et al.*, 2010) and supply chains (Kim *et al.*, 2015; Scholten *et al.*, 2014; Stone and

Rahimifard, 2018). General resilience refers to resilience of '. . .any and all parts of a system to all kinds of shocks, including novel ones', whereas specified resilience – 'of what, to what' – refers to resilience of 'some particular part of a system, related to a particular control variable, to one or more identified kinds of shocks' (Folke *et al.*, 2010). Supply network resilience, in addition to (retail-) firm-wise node/arc resilience, is considered an important part of supply chain resilience (Kim et al., 2015). According to these definitions, the resilience in supply chains refers to the capacity to withstand, recover from and adapt to a disruption, volatility or change, or even to 'move to a new, more desirable state after being disturbed' (Christopher and Peck, 2004) to maintain the supply function. This 'requires actively understanding the risk landscape, determining where those risks are best owned and managed' and strengthening the components that help in confronting those risks (Van der Vegt *et al.*, 2015). Supply disruptions have been defined as 'unforeseen events that interfere with the normal flow of goods and/or materials' (Craighead *et al.*, 2007; Scholten *et al.*, 2014) and 'imply. . .turbulence and uncertainty in the supply chain' (Jüttner and Maklan, 2011). Disruptive events can appear within a firm or supply chain, that is, internally (Wu *et al.*, 2007) or as externally driven disruptions (Jüttner *et al.*, 2003).

We built on the state of the art of supply base management and complexity (Choi and Krause, 2006) by adopting the purchase category (Ates *et al.*, 2015) as the unit of analysis, thus responding to recent calls (Hesping and Schiele, 2015). We also related our analysis to risk pooling (Schmitt *et al.*, 2015) where the response diversity approach implies a theoretical contribution, and the empirical, quantitative assessment provides a practical means.

2.2 Supply base structure and purchase category strategy

Choi and Krause (2006) conceptualised the complexity of supply base, building on previous work (e.g. Choi *et al.*, 2001). They defined supply base as the 'portion of the supply network that is actively managed by the focal company through contracts and purchasing of parts, materials, and services', and complexity as the overall number of suppliers, the degree to which they interrelate and the degree of differentiation of the focal firm's suppliers in terms of, for example, organisational culture, size, location and technology. According to Choi and Krause (2006), while the degree of complexity of the supply base reflects in the level of transaction costs and supplier responsiveness, it also reflects in supply base risk and innovation. Further, each dimension of supply base complexity can be focused and managed separately. Choi and Krause propose that 'given a fixed number of suppliers, there is a positive curvilinear relationship between the level of *differentiation* and supply risk' based on the opportunity to substitution among suppliers. They do not consider *response differentiation* to disruptions within a group of suppliers providing the same function (i.e. 'purchase category').

Structuring the supply base in line with the purchase category strategy is of primary importance for purchase performance (Kraljic, 1983), but there is little knowledge about the relationship between supply base structure and purchase category strategy (Ates *et al.*, 2015). Purchase category is defined as homogenous sets of products with similar spend characteristics and from the same market (Cousins *et al.*, 2008). Ates *et al.* (2015) performed a multi-case study about dependence of successful supply base structure on purchase category strategies of cost leadership and innovation (Ates *et al.*, 2015), but did not consider a risk-averse purchase category strategy or resilience management. Ates *et al.* (2015) dealt with risk as a category characteristic but considered the category a single homogeneous entity, whereas response diversity implies targeted heterogeneity within each purchase category.

While purchase category strategy provides an important theoretical step towards applying response diversity in supply base management for resilience, the approach of inventory pooling demonstrates the potential of diversification. The inventory pooling ('risk pooling') approach was classically applied when supply is constant and demand uncertain,

and it can then stabilise costs through choice of suppliers. However, Schmitt *et al.* (2015) demonstrated numerically that in the case of supply uncertainty, the risk diversification effect occurs when 'inventory is held at a decentralized set of locations, which allows the effect of each disruption to be reduced, resulting in a lower cost variance'. The authors conclude that a decentralised system is, in most cases, optimal when supply uncertainty, or both supply and demand uncertainty, occurs. Risk diversification in inventory systems demonstrates diversity within purchase categories.

2.3 Supplier response to disruptions

Responses of a firm's suppliers to disruptions are decisive for supply chain resilience. Suppliers that are more resistant to disruptions or recover quickly enhance resilience. However, there is no particular supplier that is resistant to all plausible supply disruptions. Therefore, a portfolio of suppliers with different supplier responses (different reactions) to disruptions (Markowitz, 1952), that is, implying response diversity, ensures that some of the suppliers maintain the supply despite a certain disruption, whereas in the case of another kind of disruption, other suppliers in the portfolio may be able to maintain the supply.

In supply chains, suppliers appear in several tiers depending on the perspective. In food supply chains, the tiers are represented by input suppliers such as fertiliser or fodder producers, primary producers or farmers, food processors, wholesalers and (from the viewpoint of consumers) by retailers. Supplier response is the reaction of a supplier, such as an import agency used by a food retailer, to disruptions such as, in this example, yield loss due to extreme weather in the exporting country, or to an export embargo due to conflict or to new customs duties caused by unsuccessful trade negotiations, all of which hinder sourcing. A strike in a domestic supply chain is another example of supply disruption, which may interrupt the supply of an industrial bakery, whereas family bakeries may be capable of maintaining their supply, thus creating diversity in supplier responses (i.e. response diversity, within the supplier portfolio of each purchase category).

As another example of a supply chain such as for a retailer in the clothing industry, for example, Zara, suppliers can be fabric manufacturers or service suppliers such as designers or photographers. Supplier response could then embody the inability of a subcontractor in a developing country to provide fabrics in response to a new EU directive controlling child labour in textile supply chains for European markets. A supplier in another country with more restrictive labour legislation would respond differently; it could maintain supply, having already excluded the use of child labour. Hence, supplier responses to plausible disruptions may depend on supplier response diversity (in this example based on targeted diversity in supplier locations) of a firm's suppliers within a purchase category.

2.4 Response diversity as a determinant of resilience

Diversity is considered a key determinant of resilience (Folke, 2006) because redundancy within a group of actors providing one function ('functional group', in analogy to a 'purchase category' in supply base management) reduces the probability that the group, and thus the function, disappears. Therefore, systems with a broader range of resources potentially provide access to more means available to withstand and respond to disturbances (Page, 2014). Diversity and variation increase resistance, recovery and adaptability, as well as transformability and innovativeness that are required for resilience in case the current system fails in providing its function in a new situation or if the current system is not sustainable (Folke *et al.*, 2010; Geels, 2002). Diversity is commonly assessed through richness (number of types) and evenness (distribution among the types) (e.g. Shannon and Weaver, 1949).

For resilience, the key is not diversity as such, but response diversity. Response diversity implies diversity within a functional group or purchase category, in their responses to the changes, variabilities (Elmqvist *et al.*, 2003; Nyström, 2006) and uncertainties, which are most

critical to the function (Lambert *et al.*, 2012). Response diversity ensures that at least some of the actors providing the same function continue to perform well during and/or after disruptions (perhaps even expanding their activity to compensate for the lost actors) thus maintaining the function (Nyström, 2006). While type diversity refers to supply being balanced among a greater number of suppliers, response diversity refers to supply being balanced among suppliers that can respond differently to plausible, critical disruptions. When applying response diversity relative to mere diversity (e.g. diversity of individual suppliers) or 'type diversity' (Page, 2010), less diversity is required to enhance resilience within a unit (Kahiluoto *et al.*, 2014). Response diversity can also be latent, that is, it may become active only in certain circumstances; for example, existing connections to additional suppliers might be activated or expanded during a strike.

Purchase category strategy (Kraljic, 1983; Atek *et al.*, 2015) provided a significant advancement in supply base management (Choi *et al.*, 2001; Choi and Krause, 2006) through a more structured approach. Response diversity approach and assessments can further provide a critical advancement relative to purchase category strategies by identifying the diversity in responses to supply uncertainty and disruptions within each purchase category. Identifying, within each purchase category, the supplier structure which most effectively reduces the variance of the response variable would also reduce the number of diversity units needed and thus enhance efficiency as well (Kahiluoto and Kaseva, 2016). The diversity units in supply chain management refer to inventories, suppliers, marketing channels and more, and the response variables refer to cost, sales, price and so on. Response diversity assessments have the potential to provide an empirical, quantitative, targeted means for effective and efficient 'risk decentralisation' (Schmitt, 2015) for enhancing resilience to supply uncertainty. Consequently, we propose the following hypotheses to be empirically tested:

H1. Resilience is positively related with supplier response diversity.

H2. Resilience is more positively related with supplier response diversity than with supplier type diversity.

3. Material and methods

3.1 Operationalisation

To empirically test our hypotheses using a multi-case approach, we implemented the following to operationalise the key concepts. *Supply chain resilience* was operationalised as the maintenance of food supply within a purchase category (food product) during disruption relative to food supply before the disruption; sales (monetary sales as well as sales of product quantities) was a measure of the core *function* of supply chains, for example, supplying food and food security (Stone and Rahimifard, 2018), and therefore, the maintenance of sales during disruption serves as a measure of resilience in food supply chains.

The food supply chain was selected as the case supply chain due to the greatly increased turbulence of its operational environment and its critical importance to societal security. Retail stores were the focus, defined as 'focal companies' by Choi and Krause (2006), due to their role as key managers of food supply and demand chains. Two recent but different *disruptions* faced by the Finnish food supply chain served as 'real-life experiments' (i.e. two different cases) from which it was possible to extract empirical quantitative data for validating the findings by data triangulation and for generalisability. Of the cases employed, one was a domestic, conflict-related disruption within a supply chain (i.e. strikes) and the other, a global-market-related disruption within the operational environment (i.e. price spikes). The case *products* were selected to maximise the probability of identifying the occurring dependence of maintenance of sales during the disruptions on response diversity.

Response diversity was operationalised based on hypothetically diverting responses (i.e. sensitivity) among suppliers to the disruptions. Regarding strikes, response diversity was

operationalised as diversity in personnel sizes of slaughterhouse suppliers. Increasing response diversity implied an increase in number of small suppliers, including family enterprises, which are usually less exposed to strikes, as also reported in the media regarding the studied case (archival data). Regarding the global market price spikes, response diversity was operationalised as evenness in the proportions of imports and domestic supply. Since imports dominate the market, an increase in response diversity implied an increase in the proportion of the domestic supply, which is less exposed to global price volatility (Liu, 2012).

Consequently, to empirically test hypotheses H1 and H2 using the multi-case approach (i.e. two different cases), maintenance of supply under disruptions was specifically operationalised as sales in terms of monetary value and product quantity. The purchase category was operationalised as food, specifically as pork and food oil. We focused on one of the complexity dimensions of the supply base (Choi and Krause, 2006) – the diversity of suppliers as a strategy to enhance supply resilience – and applied size and location as the hypothetically important differentiators of suppliers within the purchase category. While testing H2, we compared the significance of differentiation to the significance of the other dimension of complexity in supply base, namely the number of suppliers. The targeted diversity (i.e. diversity of responses to disruptions) has the potential to provide supply resilience with a lower number of suppliers compared to mere supplier diversity, thus lowering transaction costs and reduced risks relative to a higher number of suppliers (Choi and Krause, 2006; Handfield and Nichols, 1999).

3.2 The cases and the data

3.2.1 The case supply chains/networks. The Finnish food supply chain is extensively consolidated, even when compared to other European food supply chains. For example, two national grocery store chains comprise 82.5 per cent of the total Finnish grocery store market (PTY, 2018) and are usually responsible both for the wholesale and the retail activity. Furthermore, industries involved in the manufacturing of foods, such as animal slaughter and food oil industry, are largely represented by large national cooperatives. Although representing a minor market share, small and medium-sized enterprises, partly family enterprises, complement the centralised industries. Most consumers get their food products in supermarkets, and other channels are available only in limited numbers.

Two prominent supply disruptions occurred during the period of data availability. Pork supply suffered due to the strikes and showed the most variation among the 27 retail stores studied for supplier diversity. Food oil saw a relatively high volatility in price among food products due to direct linkage between food oil and the global biofuel market (Liu, 2012). Pork fillet and food oil each represent a separate purchase category (Atek *et al.*, 2015). Pork for Finnish consumption is mostly produced and processed in Finland, whereas most food oil for Finnish consumption is imported by grocery store chains. In contrast to pork fillets, domestic food oils are differentiated from most imported food oils through different oil crop origins, turnip rapeseed oil representing the major share of domestic food oil.

3.2.2 Data. The primary data sources comprised of a Finnish retail chain, FAOSTAT food price indices, public reports – accessible through the Internet – of supplier companies, and media regarding the enterprises encompassed and actions during disruptions (archival data). The stores of the single nationally coordinated retail chain varied little in management and store size, thus offering a data set with few potentially interfering variables for the analysis. To ensure generalisability of the findings, stores were randomly selected by the chain's management to represent its stores within southern Finland, especially in terms of the range of supplier diversity. The suppliers of the case products to retail stores included in the study comprised local, national and international producers, importers and distributors.

The primary data presented the weekly purchases and sales in monetary value per supplier and trademark for each of the 27 stores. The data set received from the retail chain

included 40,400 observations of weekly monetary sales (euro) and sales of product quantity (pieces) of oil, meat, bread and cheese products. The number of observations for pork and food oil sales was 6,624 and 20,449, respectively. A 13-week time period (from week 10 to 22) of each year from 2006 to 2011, totalling six years, was studied. The unit of analysis was the week's sale of each product. The weeks included those before and during the strikes, and the years were those before and during the high global food price volatility ('food crisis'). The weekly pork and food oil price indices were obtained from the FAO Food Price Index data base (FAO, 2016) and added to our database.

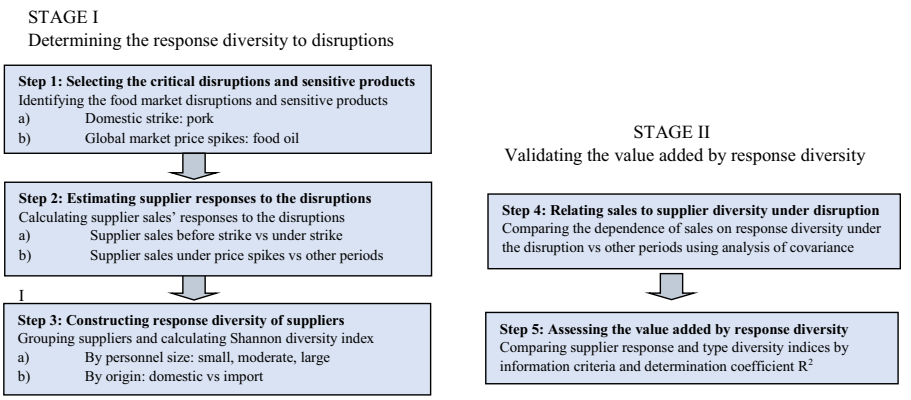
With regards to *the case of pork supply during strikes in the food industry*, information was sourced from public media to determine the period and encompassed enterprises by the strikes. The strikes began on April 7, 2010, and expanded stepwise, with the first three days encompassing 12 large-scale slaughter, bakery and convenience food manufacturing units of five enterprises and 4,500 persons. The following strike began on April 21, 2010, lasted for two days and included 57 production units with 9,300 employees. In their entirety, strikes were staged over weeks 14, 16, 17 and 18 of the calendar year (April 5–11, April 19–May 5, 2010), therefore, weeks 10–13 (March 8–April 4, 2010) were considered representative of the preceding situation in the data. In addition, weeks 19–23 were considered as the post-strike period. Thus, the period studied in total was 13 weeks, and this was repeated for each year (see above). The number of pork suppliers varied from one to seven per retail store ($\bar{x} = 3.2$) compared to other products affected by the strike in the data, such as bread (1–3, $\bar{x} = 1.6$) and cheese (1–4, $\bar{x} = 3.2$). The annual number of pork suppliers per retail store varied from one to three (2006, 2011), and four (2007, 2009) and five (2010), while achieving the maximum number of seven (2008). The FAOSTAT global market price indices of meat for April (the month of the strike) for all the years studied were as follows: 115 in 2006, 125 in 2007, 154 in 2008, 135 in 2009, 156 in 2010 and 187 in 2011 (FAO, 2016).

With regards to *the case of food oil supply during exceptional global market price spikes*, this disruptive event in the food market was represented by unforeseen global market price volatility between 2006 and 2011. Prior to this, the FAO Food Price Index had been approximately 100 since the early 1980s. After the disruption, the index has shown a declining trend till 2015, and thereafter varied less. The global food market disruption was due to several factors, including yield losses in several important export areas, rapid increases in cultivation of dedicated energy crops, lack of buffer storages, and aggravation of the crisis through speculation (Tadesse *et al.*, 2016). The FAOSTAT global market price indices of oil crops and derived products for the observed months of each year were used to characterise the price volatility. While the vegetable oil price index was 100 in 2002 to 2004 and even lower the previous years, the index was 106 in 2006, 149 in 2007, 276 in 2008, 151 in 2009, 176 in 2010 and 265 in 2011 (FAO, 2016). The number of food oil suppliers varied among the retail stores from one to seven suppliers per retail store ($\bar{x} = 3.8$).

3.3 The analytical steps

Five generic steps were proposed as an empirical, quantitative assessment of response diversity for the management of supply chain resilience (Figure 1). These steps were further divided into two stages: first, response diversity is determined; and second, the value added of response diversity is validated. The steps were exemplified in two different cases of Finnish supply chains and their respective disruptions, to triangulation testing of the hypotheses.

3.3.1 Step 1: selecting the critical disruptions and sensitive products. Most critical disruptions can be quantitatively identified based on empirical data for supplier responses to various political, market and climatic disruptions in the past, if sufficient data are available. Here, two critical market disruptions faced by Finnish food supply chains during the last ten years were utilised as the empirical cases. Two food products were selected based on 1) the hypothetical sensitivity to one of the two disruptions and 2) the presence of a notable



Note: The steps of the generic procedure are presented in bold. The procedure applied to the cases is specified for each step

Figure 1.
The proposed response diversity assessment for the management of the supply chain resilience

variation in supplier diversity among the 27 retail stores. Each of the stores made sourcing decisions independently.

Regarding the case of *pork supply disrupted by strikes*, a series of expanding strikes by the employees of food manufacturers and wholesalers in spring 2010 exemplified domestic political instability, with possibly deleterious within-country effects on consumers, retailers and suppliers. The strikes were expected to immediately influence the available selection of food products and sale of food products by retailers.

3.3.2 Step 2: estimating supplier responses to the disruptions. Given a sufficient number of observations, it is possible to estimate differences in responses of individual suppliers to various disruptive events such as global market price variation. Primary data on purchases and sales from the retail chain were used for model parameterisation. The maintenance of monetary sales and sales of product quantity during the disruptions was estimated depending on the supply of individual suppliers (type diversity) prior to or during disruptions. In the case of pork supply during the strikes, sales during the weeks prior to the strikes were compared to sales during the strike weeks. In the case of food oil supply, sales during the price spikes were compared to sales during the corresponding weeks in other years.

3.3.3 Step 3: constructing response diversity of suppliers. Supplier responses can be grouped and response diversity constructed using multiple methods when there is access to big data. For example, multivariate methods such as principal component analysis and cluster analysis have been found to be useful in classifying responses to disruptions (Mäkinen *et al.*, 2015).

In exemplary cases, suppliers were grouped according to hypothetically different responses of their sales to these studied disruptions. Regarding domestic disruption by a series of strikes, the suppliers of retail stores were grouped according to the number of personnel. These groupings were based on previous observations that support the hypothesis that the more personnel a food manufacturer employs, the more vulnerable it is to strikes than, for example, family enterprises or smaller manufacturers with fewer personnel, with a lower proportion of personnel typically participating in labour market conflicts. In smaller enterprises, the threshold for participating in the strike is higher due to personal relations, and the owner is more easily able to substitute for the personnel involved in the strike. Indeed, it was found that during the study period, employees of the large-scale food processing industry were on strike, whereas those of small- and medium-sized

enterprises, a notable portion of which are family enterprises, were not on strike. The response diversity units of pork suppliers were classified according to the number of employees using three naturally divergent size classes of suppliers: small (20 to 46), moderate (86 to 283) and large (>700). The increase in the Shannon index implied an increase in the proportion of those suppliers with a small number of employees; in other words, the greater diversity in the personnel sizes of slaughterhouse suppliers included a greater proportion of smaller or family enterprises.

Regarding the exceptional global price volatility, suppliers of food oil to retail stores were grouped according to richness and evenness of their proportion of imports and domestic sources, based on public information on the Internet, to reflect the hypothetical response diversity. The variable of response diversity was thus a continuous variable indicating the distance from the extremes of solely domestic and solely import suppliers in terms of number of suppliers (richness) and distribution of sales among the suppliers (evenness). Within an import-dominated market, such response diversity represents an ability to retard and alleviate the impact of global price volatility on food oil sales in the Finnish market. Therefore, when the Shannon index increased, the proportion of domestic sources generally increased. The proportion of domestic sources was greater than the proportion of imports in only 4 per cent to 6 per cent of *retail store x year* combinations.

The response diversity index was constructed through calculating the Shannon–Weaver diversity index [henceforth, 'the Shannon index'; Shannon and Weaver, 1949] (Eqn 1) using either the hypothetical response groups as diversity units (response diversity) or, as a comparison, individual suppliers (type diversity). The Shannon index provides an equal weight to each observation and is comparable among cases with different compositions (Jost, 2007). The Shannon index was used to describe the number (richness) and proportional sales distribution (evenness) among the diversity units for both response and type diversity. A Shannon index equal to zero indicates that the retail store has only one response group of suppliers (i.e. responses of all suppliers to the disruption are hypothetically similar) or, in the case of type diversity, only one supplier. The value of the Shannon index increases as the number of supplier response groups and/or the evenness of the proportions of sales among the supplier response group increases.

The Shannon index, H, was calculated according to Eqn (1):

$$H = -\sum_{s=1}^{S} \frac{w_{\mathrm{is}}}{W_i} \ln \frac{w_{\mathrm{is}}}{W_i} \quad \text{for } i = 1, \ldots n \tag{1}$$

where $s = 1,\ldots,S$ refers to the number of supplier groups; w_{is} is the sales of a supplier group s of a retail store i; W_i represents the total sales of the retail store i; and W_{is}/W_i is the proportion of sales covered by supplier type s. Finally, true diversities (Jost, 2007) calculated by exponential of H are presented to facilitate interpretation. The supplier diversity of individual stores should always be compared in linear scale. Thus, four times higher supplier diversity of one store can be interpreted as four times greater diversity. True diversity refers to the number of equally common components (diversity units) within a range from one to the total number of appearing components.

3.3.4 Step 4: relating sales to supplier diversity under disruption. The relationship of supplier response diversity to supply chain resilience (i.e. to the maintenance, recovery or adaptability) and of supplier performance under disturbance relative to other time periods can be quantitatively determined. The relationship of the constructed supplier response diversity to the maintenance of sales was assessed. The conditions were normalised by excluding the Easter weeks from the analysis for all years to avoid a potentially confounding factor: The demand, and thus sales, may have been different before and during the weeks of Easter, and the timing of Easter varies across years.

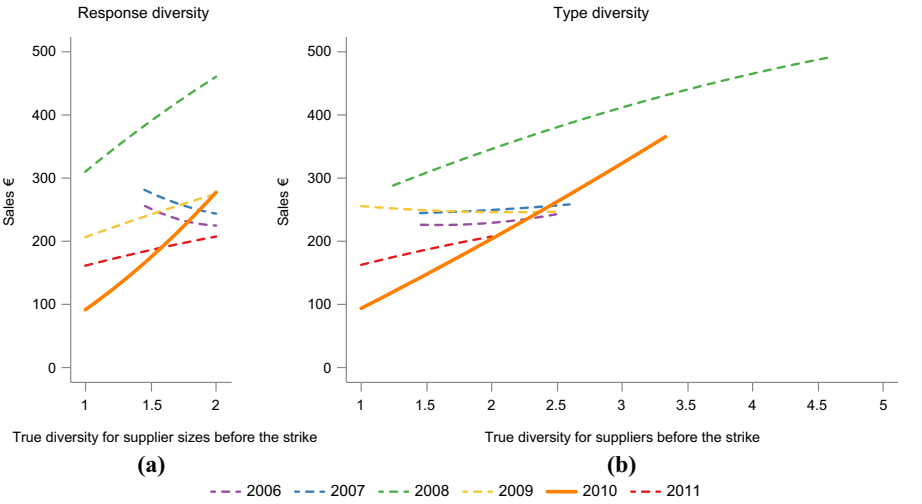
In the case of the strikes of 2010, the homogeneity of the regression slopes was investigated between the year 2010 and each of the other years. If the interaction term was not statistically significant, the effect of the covariate, in terms of true diversity, was assumed to be homogenous each year. The pairwise comparisons of the slopes between the strike year of 2010 and the other years was performed with the Westfall method, which is a stepdown multiple comparison correction used when several statistical tests are being performed simultaneously (Westfall, 1997). A significance level of $\alpha = 0.05$ was applied to all the analyses. To test the dependence of retail stores' annual sales on the diversity of suppliers, the repeated measures analysis of covariance (ANCOVA) was used to the year (from 2006 to 2011) as a fixed effect and the diversity index (diversity of suppliers) as a covariate. The homogeneity of the slopes for the dependent variable and the covariate in various years was tested by the interaction term (*year x covariate*) included in the model. The relationship between the dependent variable and the covariate was found to be linear.

All distributions of sales of oil and pork were positively skewed. Generalised linear mixed models (GLMMs) with log-normal distributions were used in the analyses. The models were fitted using the residual maximum likelihood (REML) estimation method. The effect of the year within stores was analysed as repeated measures having a heterogeneous compound symmetry (CSH) or a heterogeneous first-order autoregressive (ARH(1)) covariance structure. Covariance structures were compared by a likelihood ratio test and information criteria (AIC, AICC and BIC) (Pinheiro and Bates, 2000). Appropriateness of the models were examined using residual analyses. The residuals were checked for normality using boxplots and normal probability plots. The residuals were also plotted against the fitted values. These plots indicated that the assumptions of the models were adequate. Degrees of freedom were calculated using the Kenward–Roger method (Kenward and Roger, 2009).

3.3.5 Step 5: assessing the value added by response diversity. The dependence of supply chain resilience on response diversity vs. type diversity can be compared to determine the benefit of the response diversity assessment. In the cases utilised, dependence of maintenance of sales on supplier response diversity vs. on supplier type diversity was analysed. The hypotheses H1 and H2 were operationalised to be tested in the two empirical cases of specific products (i.e. pork fillet and food oil), each representing a specific purchase category and a relevant critical supply disruption.

H1 was tested in the case of pork sales (monetary sales and sales of product quantity) through analysing the dependence of sales on supplier response diversity during the strikes in 2010 (the strike year) relative to the corresponding weeks in the other years of the study period. In the case of food oil sales during global market price spikes, H1 was tested through the dependence of sales on supplier response diversity during the years with global market price spikes. H2 was tested in both cases by analysing if the maintenance of sales was more related to supplier response diversity than to diversity of individual suppliers.

Correspondingly, H2 was tested in both cases by analysing whether the maintenance of sales was more related to the supplier response diversity than to diversity of individual suppliers. This was done by comparing two similar sales models (presented in Figures 2 and 3) to each other, each with one of the diversity indices as part of the model. H2 was tested through variance explained using the coefficient of determination (R^2) as well as through information criteria and pseudo-R^2 values. The models of response and type diversities were compared using the Bayesian information criterion (BIC). The strength of the evidence against the model was evaluated by the higher BIC value as not worthy of more than a slight mention ($BIC_{diff} = 0–2$), positive ($BIC_{diff} = 2–6$), strong ($BIC_{diff} = 6–10$) or very strong ($BIC_{diff} > 10$) (Kass and Raftery, 1995). The coefficients of determination were calculated using Cox and Snell's R^2, which are based on the ratio of the likelihoods of the full model and the intercept model (Cox and Snell, 1989). All statistical analyses were performed using the



Note: Dependence of sales during the strike weeks on supplier diversity before the strike weeks was greater in the strike year of 2010 (continuous orange line) than during the corresponding weeks of the other years. The dependence was greater for response diversity (a) than for type diversity (b). Response diversity is indicated by the exponent of the Shannon diversity index (i.e., true diversity) and includes the richness (number) and evenness (distribution) of the supplier personnel size groups >700 (1), 86 to 283 (2) and 20 to 46 (3). Type diversity is indicated by the exponent of the Shannon diversity index for individual suppliers. The x-axis is shorter for response diversity than for type diversity because the theoretical maximum of diversity is the possible annual maximum of (a) the three supplier response groups or (b) the seven suppliers per store

Figure 2.
Dependence of pork sales on supplier response diversity and type diversity

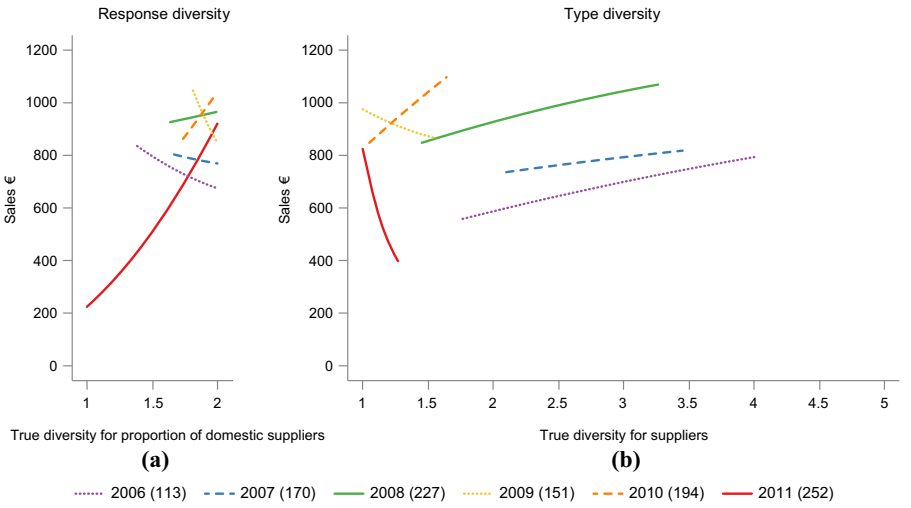
GLIMMIX procedure of the SAS system for Windows version 9.4 through the SAS Enterprise Guide version 6.1 (SAS Institute Inc., USA).

4. Results

4.1 Maintenance of pork fillet sales during domestic strike

The hypothesis H1, that a greater diversity in the size of supplier personnel (response diversity) is associated with maintenance of greater retail sales during a strike, was established by data for the monetary sales (Figure 2a,b; Tables Ia and IIa) and for the sales in product quantity (Figure A.1a,b). The findings did not differ between the two case product chains and disruptions. Dependence of pork sales on supplier diversity was greatest in the strike year 2010, and the dependence was greater for response diversity than for type diversity. This is shown by the following:

The sales in the strike year depended more, compared with the corresponding weeks of the other years, on the supplier size diversity prior to the strike weeks. The slope of the regression line for the dependence of the sales on supplier size diversity was greater for the strike weeks of 2010 than for the corresponding weeks in 2007 ($p = 0.052$) and 2008, 2009 and 2011 ($p < 0.05$; Figure 2a, A.1a; Tables Ia and IIa). The retail stores with a greater supplier diversity prior to the strikes maintained greater sales during the strikes than the retail stores with lower supplier diversity. The sales during the strikes correlated positively with the Shannon indices before the strikes (0.82, $p < 0.001$) and during the strikes (0.61, $p < 0.001$). Many retail



Note: Dependence of sales on supplier response diversity (a) was positive in the price peak years, contrary to type diversity (b), see the year 2011 with the highest price peak. Continuous lines indicate the years with highest, dash lines the years with intermediary, and the small dash lines the years with lowest FAO price indices given in the parentheses. Response diversity is indicated by the exponent of the Shannon diversity index (i.e., true diversity), including the richness (number) and evenness (distribution) of the proportions of the domestic and import suppliers. Type diversity (b) is indicated by the exponent of the Shannon diversity index for the individual suppliers. The x-axis is shorter for response diversity than for type diversity, because the theoretical maximum of diversity is the possible annual maximum of (a) the proportion of the two supplier response groups or (b) seven suppliers per store. Exclusion of the outlier (response diversity 0.0) would lead to a decline in the slope similar to 2008

Figure 3.
Dependence of food oil sales on supplier response diversity and type diversity

stores had only one supplier in 2010 before the strikes, whereas during the strikes, the stores had several suppliers each. The average true diversity for supplier size was 1.34 prior to the strikes and 1.72 during the strikes. Pork sales were clearly lowest during the strikes relative to the corresponding weeks of other years ($p < 0.007$ for 2010 vs. $p = 0.21$ for 2011). Pork sales were positively related to diversity in personnel sizes in years with price spikes (i.e., in 2011 and 2008) (Figure 2a). The FAO price index for meat varied less than for food oil (113 to 252), specifically, between 121 (2006) and 183 (2011), but the timing followed the variation in food oil price (Figure 3a).

Retailers prepared with a greater diversity of suppliers before the strike in regard to personnel size maintained diverse sourcing and higher sales during the strikes (Figure 2a, A.1a). This was because the smaller slaughter firms and wholesalers did not suffer from the strikes as much as those with personnel affiliated to labour market associations: The more diverse the personnel sizes of the suppliers of a retail firm were, the less the pork sales of retail firms declined in comparison with the same weeks of other years, as hypothesised.

Regarding retail sales under global price spikes, it seems that in 2008, a year marked by an exceptionally high market price for meat, and in 2006, with an exceptionally low global market price for meat, small slaughterhouses followed the global price level variation less closely and more slowly than large-scale national slaughterhouses. Consequently, the higher the supplier response diversity of a store, the higher the sales, a relationship that was strongest in the strike year (Figure 2a, A.1a).

Effect	Response diversity F value	Response diversity P value	Type diversity F value	Type diversity P value
a) Strikes (pork)				
Shannon index	$F_{1,59.9} = 1.90$	0.173	$F_{1,62.2} = 2.98$	0.089
Year	$F_{5,69.0} = 23.08$	<0.001	$F_{5,70.1} = 11.93$	<0.001
Shannon index * year	$\boldsymbol{F_{5,69.8} = 3.34}$	**0.009**	$\boldsymbol{F_{5,69.2} = 3.14}$	**0.013**
b) Global market price spikes (food oil)				
Shannon index	$F_{1,113.9} = 0.13$	0.715	$F_{1,79.0} = 3.21$	0.077
Year	$F_{5,99.1} = 7.20$	<0.001	$F_{5,92.4} = 3.00$	0.015
Shannon index * year	$\boldsymbol{F_{5,98.8} = 8.03}$	**<0.001**	$\boldsymbol{F_{5,89.6} = 5.27}$	**<0.001**

Note: Hypothesis tests of fixed effects of repeated measures analysis of covariance models to disruptions of (a) pork sales by strikes and (b) food oil sales by global market price spikes. The degrees of freedom were obtained by the Kenward–Roger method. The number of observations were 154 and 160, respectively

Table I.
Hypothesis tests

Year	a) Strikes Slope ± std err	b) Global price Slope ± std err
2006	−0.28 ± 1.26	−0.55 ± 0.50[a]
2007	−0.38 ± 0.84[°]	−0.23 ± .56
2008	0.57 ± 0.18**	0.22 ± 0.51[b,c]
2009	0.43 ± 0.37*	−2.13 ± 0.94[b]
2010	1.58 ± 0.28	1.34 ± 0.65
2011	0.37 ± 0.24**	2.06 ± 0.30[a,c]

Note: In the case of (a) strikes (pork), the statistically significant differences between slopes for the strike year 2010 and the other years are marked with asterisks. In the case of (b) global market price spikes (food oil), the statistically significant differences between the years with the highest (2008, 2011) and the lowest (2006, 2009) FAO food price indices are marked with the same character. The Westfall method was applied for the pairwise comparisons (Westfall, 1997). ([°]) $p < 0.10$, (*) $p < 0.05$, (**) $p < 0.01$, (***) $p < 0.001$.

Table II.
Annual variation in the dependence of sales on response diversity of suppliers

4.2 Maintenance of food oil sales during global market price spikes

The hypothesis H2, that the sales of food oil during global market price spikes shows a positive dependence on supplier response diversity, was established by data for both monetary sales (Figure 3a,b; Tables Ib and IIb) and for sales in product quantity (Figure. A.1c,d), similarly to the case of pork sales during strikes. This is shown by the following:

The dependence of food oil sales on response diversity (evenness of the distribution of suppliers among domestic suppliers and imports, that is, more domestic suppliers) varied across the years studied (Table Ib). It was found that the greater the Shannon index for response diversity of the suppliers of a retail store, the greater the sales in the price peak years (Figure 3a, A.1c). The strongest evidence for the benefit of response diversity was found in 2011, when the global market price was at its highest (Figure 3a,b, A.1c,d). Overall, the greatest benefit from response diversity was found in the years with the highest global market prices (2008, 2010 and 2011), and the most disadvantage from response diversity was obtained in years with the lowest global market prices (2006 and 2009) of the studied period. For retail stores with the lowest modelled supplier response diversity, the proportion of the domestic supply being 0–20 per cent of the sales (i.e. with the greatest proportion of imports), sales were lowest in 2011 when the global market price was at its highest (Figure 3a, A.1c).

One retail store clearly had the lowest supplier diversity in 2011, that is, only one single supplier (Figure 3a). If this outlier was excluded from the analysis, the slope for 2011 declined from 2.06 to 0.74 – below that of the slope for 2010, which also declined slightly (from 1.34 to

0.92). However, the exclusion of the outlier did not affect the above results regarding years with greatest benefits and disadvantages from supplier response diversity.

4.3 Difference between response diversity and type diversity

The hypothesis H2 that response diversity is more positively related to maintenance of greater sales than diversity of mere suppliers (type diversity) was established. Response diversity better explained the variation in sales than type diversity (BIC_{diff} = 2.6) and increased the coefficient of determination by 1 percent to 49 per cent. During the strikes of 2010, however, the difference in the benefit between response and type diversity was small, even if slightly in favour of response diversity, while both types of diversities were very positively related to sales (Figure 2a,b, A.1a,b). The difference between the slopes for the dependence of sales on diversity was in favour of response diversity (Table IIb).

Similarly, for global market price volatility, the relation of sales to response diversity was greater than to type diversity (Figure 3a,b, A.1c,d; Tables Ib and IIb). Comparison of BIC values showed strong evidence for the benefit of the response diversity model (BIC_{diff} = 17.8) relative to type diversity. Response diversity also explained 6 per cent more of the variation of sales than type diversity (48 per cent).

5. Discussion

Retail supplier diversity in responses to disruptions (response diversity) was found to be positively associated with maintenance of food sales, more positively than diversity of individual suppliers (type diversity).

5.1 Theoretical implications

The insights of this study stand in contrast to previous findings of supply base complexity: increased complexity appears to aid in dealing with supply uncertainty and disruptions. The shown critical role of diversity within a purchase category (Atek *et al.*, 2015; Kraljic, 1983) in responses to plausible supply uncertainties implies a major advancement in understanding and management of supply chain resilience (Kim *et al.*, 2015; Scholten *et al.*, 2018; Stone and Rahimifard, 2018).

The primary insight of response diversity for advancement of the theory relative to mere complexity of the supply base as identified by Choi and Krause (2006) in their theoretical contribution is that diversity, per se, does not enhance resilience, whereas diversity in responses to critical uncertainties and disruptions is the key. Second, the diversity of responses must appear within a group of suppliers providing the same function (i.e., within a purchase category). Such a targeted, resilience-producing diversification of suppliers with a similar function (Cousins *et al.*, 2008) provides the potential to consequent positive effects for resilience. The third critical advancement of the response diversity approach is allowing substitution among the diversity units because it appears within a purchase category. Such a triple superiority of response diversity to mere heterogeneity (Choi and Krause, 2006) or diversification (Schmitt *et al.*, 2015) implies the potential to avoid prior inconsequential empirical findings on the role of diversity in risk management (e.g. Hendricks *et al.*, 2009).

Consequently, the findings of the current study highlight the distinct differences between the two major components of complexity of the supply base, size and heterogeneity; the size of the supply base and the number of suppliers are not important. Our empirical findings are thus in accordance with the theoretical contribution of Kim *et al.* (2015): denser or merely more complex networks and redundancy do not necessarily lead to higher supply chain resilience. The chain structure clearly matters, and the choice of metrics is important. This leads to another major advancement in the theory: the effective complementarity of the diversity units (in terms of responses to various plausible disturbances) reduces the requirement for number

of diversity units (e.g. suppliers) for the impact on sales maintenance during disruption and thus provides efficiency in diversity. This increased efficiency of diversity addresses and overcomes major critics for the enhancement of resilience through diversity: the issue of combining resilience with (economic) efficiency (Kahiluoto and Kaseva, 2016; Aguila and ElMaraghy, 2019).

5.2 Practical implications

The current study demonstrated an approach and assessment to empirically reveal 'response diversity': the factors of change that are critical to the core functions of supply chains are identified, and the response diversity is determined based on the documented component (supplier) responses to these factors. The response diversity approach enables supply chain actors to manage rather than simply assess the supply chain resilience (Carpenter *et al.*, 2001) in comparison with 'general' resilience (Folke *et al.*, 2010; Himanen *et al.*, 2016; Stone and Rahimifard, 2018) which facilitates understanding the dynamics but hardly enables management by individual actors. The supplier portfolios compiled based on the empirical, firm-specific data on supplier-specific sales responses to supply uncertainties that occurred can form the groundwork. Retailers could, for example, import the same or compensatory products from various climatic regions or combine imports and domestic purchases to ensure access to food by consumers despite regional weather anomalies and yield losses. As another example, retailers might combine large-scale suppliers, which have a propensity for epidemics (Peck, 2006), such as salmonella or strikes, with small family firms, which are less vulnerable to such large-scale supply disruptions. Extensions to applications beyond supply uncertainty, such as to prepare for stochastic demand (Schmitt *et al.*, 2015), also offer options to practical managers. The initiation of export of pork from Finland to China by a Nordic slaughter cooperative as a response to Russian trade embargoes and negative demand prospects in Europe is one example.

To recognise resilience, we must move beyond suppliers and their locations and sizes (Choi and Krause, 2006). The empirical operationalisation of diversity in responses ('grouping') according to plausible disruptions is critical in achieving the benefit (see also Pettit *et al.*, 2019). For example, in the case of strikes, the value added appeared to depend on the specific grouping of personnel sizes; not all groupings were as effective. In addition, the role of the composition versus diversity of, in this case, suppliers, and as such warrants caution in the interpretation: which components increase along with the diversity is important for the effect and must be noted – in this instance exemplified by a set of suppliers with relatively few personnel in the case of a strike, and domestic suppliers in the case of global price volatility. Therefore, response diversity assessments must be based on an in-depth understanding of dynamics, and preferably be empirical and quantitative. Being in a key position between suppliers and consumers, retailers may manage the dynamics of the entire supply chain, but the demonstrated assessment tool is available to all the actors in various tiers of supply chains, as well as to, for example, coalitions of public, private (Ambulkar *et al.*, 2015) and civil society actors for a resilient society. Supplier diversity in the food retail industry to secure affordable food, the ultimate societal benefit of food supply chain resilience (Stone and Rahimifard, 2018), despite weather extremes and global price volatility, could represent one application.

In recent decades, firms have concentrated on improving efficiency by reducing slack and redundancy in supply chains while preparedness for perturbations has been given a low priority (Altay and Ramirez, 2010; Knemeyer *et al.*, 2009). Doubts of the possibility to combine resilience and diversity with economic efficiency have created major developments in specialisation in all tiers of supply chains during the last decades, not least in agri-food supply chains. This untested assumption of trade-off was unsupported by empirical evidence from Finnish commercial farms (Kahiluoto and Kaseva, 2016): practical managers who employ

diversity adapt their system for synergy with efficiency. In such an effort, the value added of the response diversity approach to enhancing efficiency of diversity is important for actors to produce the same insurance effect with less but better targeted redundancy.

5.3 Validity and generalisability of the findings

Regarding validity of the findings, the main question is whether the positive association observed between response diversity and the maintenance of sales could be due to an opposite cause–effect relationship. No theoretical basis or meaningful interpretation exists for a hypothesis that the maintenance of sales could lead to a greater diversity of suppliers other than as feedback through learning – which is part of supply chain resilience. Similarly, there is no obvious confounding factor that independently enhances both supplier diversity and maintenance of sales. The possible similar variation in diversity and sales caused by variation in size of the stores was avoided through a focus on changes (maintenance) in sales and not on overall sales. Thus, response diversity of retail suppliers indeed appears to increase the probability for maintenance of sales.

The findings of the exemplified cases demonstrate the general usability of response diversity as a means of managing resilience in supply chains. The potential of the approach is not specific to the food nor the disruptions studied. The two cases, each of a different food product and its respective supply chain, and a different disruption occurrence for each product, increased the generalisability of the findings. Using an additional data source for the product chains in focus as a supplementary step in the assessment (Stage 2) would further validate the conclusions.

The generic response diversity assessments were demonstrated with primary data from the recent past. While access to such retailer data has been extremely limited, the response diversity assessments are gaining potential owing to rapidly increased access to big data, especially within the retail sector. Larger data sets will enable a quantification in each of the five steps of the assessment such as in the identification of the critical disruptive events (Step 1) and the construction of the response diversity units and index based on clustered response groups (Step 3) (Mäkinen *et al.*, 2015). Empirical quantification targets the response diversity accurately increasing the probable benefits relative to the limitations of the hypothetical disruptions and response grouping used herein. Such quantifications would not influence current results and conclusions as the selection of diversity units and disruptions herein was supported by the results, but they could enable the identification of additional critical disruptions and corresponding response grouping of suppliers.

The demonstrated approach also has limitations. Some noise factors observed could be accounted for through access to bigger data. For example, while smaller pork suppliers were not on strike when the larger ones were, the latter started to substitute imported pork for domestic pork as a response to the strikes and is included in the current analysis. Such noise would be accounted for when grouping the suppliers in a quantitative analysis (Step 3). However, '. . .any tool we use needs to be treated as a tool. It always has limitations and these must be given due attention' (Avien, 2016). In accordance with this, empirical assessments can only reveal the dynamics of the past and emerging developments and need to be complemented with foresight exercises considering the current turbulent operational environment.

6. Conclusion

Response diversity implies an advancement to the theories of supply chain and supply base management and represents a novel structuring principle of supply base complexity within each purchase category to enhance resilience. The response diversity assessments provide a practical managerial means, demonstrated in supply chains for the first time herein. Firm- or chain-specific empirical assessments can be used to design the supplier composition for

minimising impacts of supply disruptions. The response diversity approach also shows novel theory and application potential beyond the supply base management, such as in the management of demand uncertainties and changes. Empirical assessments of response diversity hold increasingly promising potential for research and practice, if efforts towards market transparency make big data more accessible for firms across supply chains. The response diversity of suppliers also provides a means to enlighten the resilience perspective to supply chain actors by training and education, and a means for authorities to design interventions and incentives for food security and social stability.

By providing material for selection in new conditions or for new targets, response diversity also builds the capacity for successful transformations (Chapin *et al.*, 1997). This aspect of supply chain resilience and the specific characteristics of diversity effective for innovation warrant further research.

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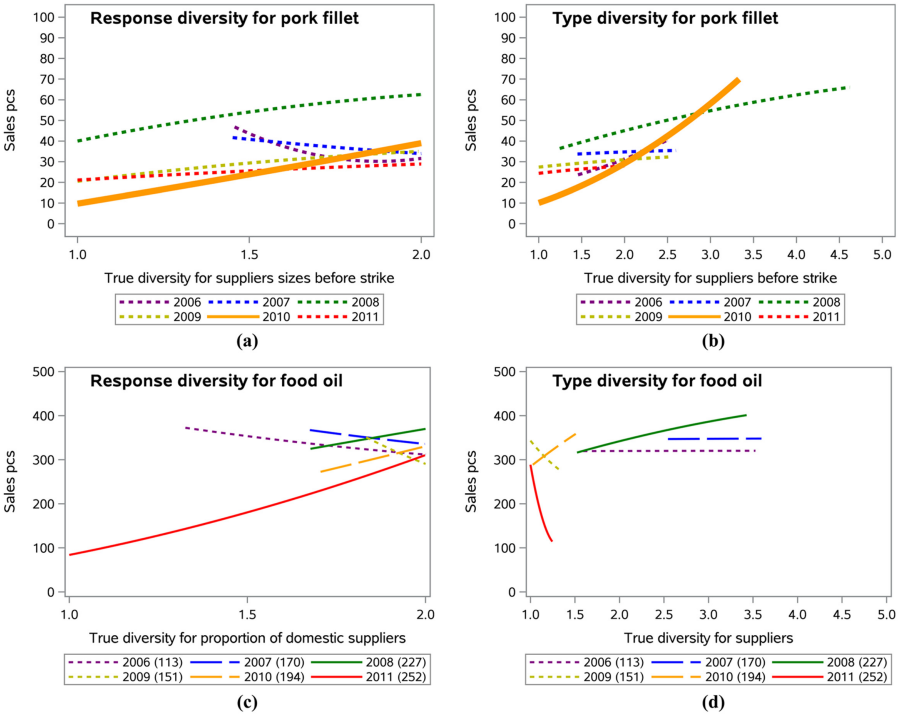
(The Appendix follows overleaf)

Appendix



Note: Dependence of sales during the strike weeks on supplier diversity before the strike weeks was greater in the strike year of 2010 (continuous orange line in a,b) than during the corresponding weeks of the other years. Respectively, the dependence in food oils was greater for response diversity (c) than for type diversity (d). Dependence of sales on supplier response diversity (c) was positive in the price peak years contrary to type diversity (b; see the year 2011 with the highest price peak). Continuous lines indicate the years with highest, dash lines the years with intermediary, and the small dash lines the years with lowest FAO price indices (c,d). Response diversity is indicated by the exponent of the Shannon diversity index (i.e., true diversity) and includes the richness (number) and evenness (distribution) of the supplier personnel size groups (>700 (1), 86 to 283 (2) and 20 to 46 (3)) (a,b) or of the proportions of the domestic and import suppliers (c,d). Type diversity is indicated by the exponent of the Shannon diversity index for the individual suppliers. The x-axis is shorter for response diversity than for type diversity because the theoretical maximum of response diversity is the possible annual maximum of (a) the three supplier response groups or (c) the proportion of the two supplier response groups and for type diversity (b,d) the seven suppliers per store

Figure A1.
Dependence of sales of pork (a,b) and food oil (c,d) quantities (in pieces=pcs) on supplier response diversity (a,c) and type diversity (b,d)

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