Operationalising resilience in tropical agricultural value chains

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Abstract

Purpose – The analysis of the concept of resilience in supply chain management studies mostly focuses on the downstream side of the value chain and tacitly assumes an unlimited supply of raw materials. This assumption is unreasonable for agricultural value chains, as upstream disruptions clearly have a material impact on the availability of raw materials, and indeed, are a common source of supply problems. This paper aims to present a framework for the operationalisation of the concept of socioecological resilience in agricultural value chains that incorporates upstream activities.

Design/methodology/approach – A citation network analysis was adopted to review articles. A conceptual framework is then advanced to identify elements of resilience and indicators relevant to tropical agricultural value chains.

Findings – There are limited studies that assess resilience in the food chain context. Flexibility, collaboration, adaptability and resourcefulness are key elements for assessing resilience at the individual chain actor level. However, the paper argues that adaptability is the relevant element for the assessment of resilience at an aggregate food system level because it considers the alteration of a system’s state of resilience.

Practical implications – The proposed framework and propositions accommodate stakeholder interactions in the value chain and could serve as a tool to guide the assessment of resilience in agricultural value chains.

Originality/value – This paper is one of the few to extend resilience to cover the socioecological interaction aspects for supply chains that yield the raw materials needed for continuity in channel-wide value creation processes.

Keywords Adaptability, Agricultural value chain, Socioecological resilience

Paper type Conceptual paper

Introduction

Disruptions occur daily in various parts of the world, destabilising the normal daily activities and causing economic losses (Hosseini and Barker, 2016). More frequent occurrences of disruptions of late have aroused interest in the idea of resilience (Petit et al., 2013; Soni et al., 2014). Resilience has become a popular concept for researchers, business, development organisations and governments because of the increased uncertainty arising from both natural and man-made disruptions (Hosseini and Barker, 2016).

At an organisational level, not every firm actively engages in building resilience. The concept of resilience is viewed as a strategic consideration, and this has become more prominent with the advent of globalisation, as organisations are no longer restricted to a single geographic location of operations (Wagner and Neshat, 2010). Firms that operate globally seek to benefit from the potential advantages of market expansion, risk diversification and lower sourcing and production costs associated with operating outside their original geographic location and national borders (Caniato et al., 2013; Gereffi et al., 2005). However, such global operations are accompanied by an axiomatic increase in risk and new challenges that do not always exist with local operations. Those that are not adequately prepared will inevitably suffer disruptions somewhere in their global value chain (Hohenstein et al., 2015; Jüttner and Maklan, 2011).

Food organisations like Barry Callebaut, Cadbury, Mars and Nestle, whose mainstream products hinge on raw materials derived from agricultural commodities produced in geographical-specific regions, face the problem of balancing the benefits and risks of globalisation. Globalisation does not necessarily mean that there are endless suppliers of inputs conveniently dispersed around the globe. Rather, while agricultural value chains have gone global, the source of supply is often concentrated into only a few preferential geographic areas or a few suppliers that can meet requisite standards. Therefore, risk has not really been mitigated by the dispersing of activities throughout the global value chain; rather, many commodity chains have actually become more vulnerable.

Commodities that are consumed globally, but grow profitably only in the tropics, are referred to as tropical commodities...
(Talbot, 2002). Some examples include cocoa, coffee, shea nut, cashew, oil palm. These commodities are often of interest to policymakers in producing countries as they are major earners of foreign exchange (Talbot, 2002). Tropical commodities have idiosyncratic weather requirements that make them susceptible to ecological and climatic disruptions, and their chains are often prone to deficiencies in governance that cause socio-economic disruptions (Niforou, 2015; Talbot, 2002; Gereffi et al., 2005).

As a result, the quest for resilience in tropical commodity chains transcends the actions of individual actors, and thus requires an assessment of the risks within the whole value chain. This paper defines resilience as the aggregate adaptive capacity of a system to become ready for, respond to and recover from disruptions without losing the system’s primary state (i.e. raw materials that flow through the chain).

Attempts to assess resilience in supply chains usually focus on activities in the processing, manufacturing and distribution stages of the chain (Datta et al., 2007; Munoz and Dunbar, 2015; Colicchia et al., 2010). However, resilience of an agribusiness value chain is multidimensional. It involves interactions between people, technical systems and the natural environment, and therefore has economic and socioecological dimensions that are upstream-focused (Folke et al., 2010). Moreover, resilience of agricultural value chains is largely determined by upstream activities in contrast with global manufacturing and retailing chains where resilience depends largely on downstream activities. This is because upstream disruptions are more critical in food supply chains (Pereira et al., 2014), as failures cascade down to midstream and retail actors when they do occur (Wang and Xiao, 2016). According to Leat and Revoredo-Giha (2013), there is limited research on supply chain resilience with a focus on upstream productive activities. Indeed, their review demonstrates that articles that analyse agricultural value chains and resilience of commodity production are rare in the literature.

To address this research gap, this conceptual paper attempts to operationalise a contextual definition of resilience for agricultural value chains. In addition, it proposes a framework for a future quantitative analysis of resilience from both economic and socioecological perspectives and addresses two main objectives:
1. to conceptualise resilience in the context of tropical commodity value chains; and
2. to propose and operationalise a conceptual model of agricultural value chain resilience.

This paper, therefore, provides two major contributions to the existing supply chain resilience literature. First, it develops a robust approach for operationalising the agricultural value chain resilience with an emphasis on upstream productive activities. This focus acknowledges the critical role that the supply of raw materials plays in the continuity of value chain processes. Indeed, the phenomenon of raw material scarcity is relevant in supply chains, but often ignored. In this regard, the paper provides a basis for extending the resilience analysis beyond the impractical assumption of infinitely available raw material. Second, the paper identifies appropriate elements of supply chain resilience. This process is based on the framework that extends the analysis of supply chain resilience from the viewpoints of individual economic units to the wider industry, thus necessitating an aggregate assessment of the system’s resilience.

To achieve these objectives, literature relevant to resilience in supply chains was reviewed and synthesised to identify elements and indicators relevant to the analysis of resilience in tropical agricultural value chains. The paper concludes by highlighting the salient issues to consider when analysing resilience in these chains, identifying future research gaps and noting the limitations of the proposed framework.

Methodology

A citation network analysis was adopted to give an objective approach for selecting research articles included in the literature review (van Eck and Waltman, 2014). The process involved four steps that are described in the subsections that follow.

Step 1: Database selection

Three databases (i.e. Science Direct, Scopus and Web of Science) were initially selected based on their multidisciplinary nature. The databases were compared based on the relevance of journal sources retrieved and the number of publications on the topic of interest found from the database. For Scopus and Science Direct, “supply chain resilience”, “food chain resilience”, “value chain resilience” were used as the search strings in the article title, abstract and keywords. For the Web of Science database, the same search words were used under the topic section because the database does not permit a search based on abstract and keywords. A preliminary search was conducted without restrictions on the timeframe. A trend analysis of the articles retrieved from the search, as shown in Figure 1, indicates that the interest in supply chain resilience heightened from the year 2000. Some of the earliest studies on supply chain resilience were conducted between 2001 and 2004 (Jüttner et al., 2003; Christopher and Peck, 2004; Sheffi, 2001). Therefore, the timeframe for the article search was set from 2000 to 2018. Inclusion criteria based on the language (articles in English) and document type (peer-reviewed articles) were applied to filter the results.

In total, 174 publications were retrieved from Science Direct. A similar search in Scopus and Web of Science yielded 453 and 684 articles, respectively. The database selection step also

Figure 1 A trend analysis of published articles on supply chain resilience in three databases
provided a first-hand indication of which journals contain most of the relevant publications with respect to supply chain resilience. The search also revealed the following seven journals in descending order of most publications: International Journal of Production Economics, International Journal of Production Research, Supply Chain Management: An Internal Journal, Sustainability (Switzerland), Journal of Cleaner Production, PLoS ONE and Transportation Research Part E – Logistics and Transportation Review. Figure 2 shows the top 20 journals with the highest number of peer-reviewed articles on supply chain resilience. The Web of Science and Scopus databases were selected for the citation network analysis (CNA), as they identified the largest number of papers, including 83 per cent of the articles retrieved by the Science Direct database.

Step 2: Citation network analysis

Although systematic literature reviews are comprehensive and replicable, they follow the pre-determined inclusion and exclusion criteria for article selection that can lead to a loss of important data (Weed, 2005). Rather, an CNA augments the procedure and permits a timely process that ensures that relevant publications are not ignored (van Eck and Waltman, 2014). Files containing relevant information of each publication (namely, authors, title of articles, indexed keywords, abstract, publication source and referencing link, DOI and citation frequency) were extracted from the two selected databases. The Vosviewer software was used for the CNA. The Vosviewer software created by Nees van Eck and Waltman focus on citation networks involving individual publications (van Eck and Waltman, 2014). For each publication, the software uses algorithms to generate an internal citation score that represents the frequency of citation in a citation network. It also yields a link strength for each publication based on the relationships with other publications in the citation network.

The citation network fulfils two rules. First, the relations between two publications are not forward-looking, meaning that a publication with a current date can cite another publication with a later date, but not the reverse. Second, the citation network is acyclic, that is, two publications cannot cite each other (van Eck and Waltman, 2014). The CNA generates connected component and clustering, which is an analysis that groups publications into clusters based on the strength of connection (citation relations) between the publications. The CNA also identifies core publications, which helps to eliminate publications of peripheral importance in the citation network. Core publications are publications with at least 10 citation relations with other core publications (van Eck and Waltman, 2014).

The CNA was conducted for the sets of publications generated from the Web of Science and Scopus databases in Step 1. The unit of analysis was the individual article publication. The CNA depended on the strength of connection in the title, keywords, abstracts and references of publications obtained from Step 1. Recent publications were expected to have fewer citations as compared to older ones; therefore, a minimum of zero citation was set as a threshold for selecting strongly connected publications. In determining the number of publications to be included in the literature review, a threshold for the top 100 publications with the strongest connection in the CNA was set using a minimum cluster size of 10 publications. For the Web of Science database, 98 publications were grouped in eight clusters and 99 publications in eight clusters were selected for the Scopus database. Visualisations of the CNA of publications from the two databases are presented in Figures 3 and 4. Articles shown in the same colour belong to the same cluster.

Step 3: Article selection

All publications in the two CNAs were ranked based on their total link strength. If a publication appeared in the CNA for the Web of Science, then \( X_w = 1 \), else \( X_w = 0 \). Likewise, if a publication appeared in the CNA for Scopus, then \( X_s = 1 \), else \( X_s = 0 \). The total link strength \( (L_s(\text{total})) \) for a publication was estimated as:

\[
L_s(\text{total}) = \sum (L_s(\text{core})X_s(\text{core}))
\]

After calculating the total link strengths, duplicate publications were merged into one publication. In total, 197 publications were ranked based on their link strength. Out of these, only five publications (Elleuch et al., 2016; Falkowski, 2015; Leat and Revoredo-Giha, 2013; Agigi et al., 2016; Umar et al., 2017) focused on supply chain resilience in the context of food chains. There is no precise number of publications accepted for literature review. However, Wee and Banister (2016) recommend a threshold of 30 publications as the minimum. Therefore, 50 publications with the highest link strength were selected for content analysis. In addition, four publications that focused specifically on food chains, but which were not ranked in the top 50, were included in the content analysis.

Step 4: Content analyses

The following questions were explored in analysing the selected research articles: (a) In what context was supply chain resilience examined? (b) How was the concept operationalised? (c) What indicators were used for measuring resilience? The selected research articles were organised into eight different clusters derived from the CNA as shown in Appendix 1. The commonalities in each cluster were analysed to give an overview of the key issues differentiating the research articles, as
The conceptualisation of resilience for tropical commodity value chains

A clear conceptualisation of the concept of resilience is important so that disruptions can be understood and mitigation efforts are appropriate to deal with disturbances that affect the system (Tendall et al., 2015). Holling (1973) identified resilience as one of the two properties shaping a system’s behaviour when faced with disturbance; the second is stability. Holling (1973, p. 14) defined resilience:

[... ] as a measure of how persistent a system is and how the system is able to absorb change and disturbance without losing the relationships between populations or stable variables.

Stability concerns the speed at which a system achieves equilibrium after disruptions. Holling (1973) further recommends the adoption of a management approach to study resilience. Subsequent definitions of resilience in management studies often refer to the system’s stability and rapidity of response.
Definitions of resilience proposed in the supply chain literature have been classified as either reactive or proactive (Ponomarov and Holcomb, 2009). Reactive definitions focus on a system’s responses to disruptions without emphasising its preparedness (Rice and Caniato, 2003; Christopher and Peck, 2004; Pettit et al., 2010). Proactive definitions of resilience are those regarded as precautionary and reflect the so-called “3Rs of resilience”: readiness, response and recovery of a system (Spiegler et al., 2016). Resilience focuses on unforeseeable disruptions (Pettit et al., 2010), and uncertainty about the probability of a disruption occurring puts resilience outside the domain of risk management and gives the proactive definition precedence over the reactive definition. Within a system, organisations may view resilience practices as either an operational or strategic capability (Brusset and Teller, 2017; Munoz and Dunbar, 2015). The reactive definition of resilience presents these practices as an operational capability, while the proactive definition treats resilience as a strategic and dynamic capability that enables the firm to adapt operating activities to achieve competitive advantage (Brusset and Teller, 2017; Manning and Soon, 2016). Notwithstanding these broad definitions of supply chain resilience, it is clear that the context of the analysis circumscribes the concept of resilience. Supply chain resilience will, therefore, be defined differently for different systems.
The context of tropical commodity value chains
Definitions of resilience have been criticised as vague, resulting in subjective applications of the concept across different disciplines (Fridolin and Jax, 2007). One such aspect associated with the subjective use of resilience concerns a system’s state post-disturbance. While Holling’s definition of resilience suggested a return to the system’s initial state (Holling, 1973), other authors argue that recovery need not imply a return to the original state, but rather the achievement of a new state (Christopher and Peck, 2004; Jüttner et al., 2003). What then is the “state” of a supply chain or food system that must be maintained in the face of disruption? Analysis of the system’s context determines the appropriate system state of resilience and should serve as a precursor for the operational definition and analysis of resilience.

The content analysis showed that, for most literature on supply chain resilience, the context of analysis relates to manufacturing, distribution and transportation systems. These systems are regarded as sociotechnical systems (Amir and Kant, 2018; Adrian and Andy, 2010). Indeed, Amir and Kant (2018) provide a fundamental distinction between sociotechnical and socioecological systems. They argue that, while sociotechnical systems capture the man–machine interactions, socioecological systems are strongly linked to man–nature interactions.

This paper posits that, in general, resilience of agricultural food systems comprises an integration of sociotechnical and socioecological aspects, with the latter being more relevant for upstream productive activities. However, the relative importance of sociotechnical resilience for upstream activities depends on the level of technology used in production activities. When production activities involve advanced technologies, as in plantation agriculture, then sociotechnical resilience becomes more relevant. In tropical commodity chains, socioecological resilience is important for two reasons. First, upstream activities play a crucial role in agricultural value chains because the nascent outcome of these activities is a central focus for supply chain continuity. Second, production activities for tropical commodity crops like cocoa have not been easy to mechanise due to small farm size and low capital investment.

The supply chain literature often neglects the socioecological aspect of resilience (Tendall et al., 2015). Rather, it focuses on downstream processing, manufacturing and distribution activities and assumes an unlimited supply of raw materials produced further up the chain (Datta et al., 2007). Such an assumption is unrealistic when the context of analysis includes upstream activities, as in the case of tropical commodity chains.

The state of resilience for tropical commodity chains
A vital aspect of resilience analysis is the identification of a system’s state (Carvalho and Cruz-Machado, 2011). Indicators of a sociotechnical system’s state of resilience proposed in the supply chain literature include its performance level, losses and recovery time (the resilience triangle) (Tukamuhabwa et al., 2015); connectedness, control over structure and function (Ponmarov and Holcomb, 2009); and operations (Jüttner and Maklan, 2011). For socioecological systems, Cumming et al. (2005) described the system’s state of resilience as the identity of the system that needs to be maintained in the face of disruption. For socioecological systems like agricultural food systems, ecosystem services act as the system’s state of resilience that needs to be maintained in the face of disruptions (Cumming et al., 2005). Resilient systems are those that can maintain the key attributes of ecosystem services that generate continuity in the system (Cumming et al., 2005).

Ecosystem services are the output of the interaction between human skill, technology and nature (ecology) (Biggs et al., 2015). Among the three categories of ecosystem services (i.e. provisioning, regulating and cultural services), the provisioning of ecosystem services (e.g. crops, fish, timber, etc.) fits well for agricultural food systems (Biggs et al., 2015). In tropical commodity chains, raw materials produced via upstream production activities are examples of these provisioning ecosystem services. The quantity and volumes of these raw materials flowing downstream serve as a reference point for gauging resilience levels, and these are determined by the stakeholders in their socioecological interaction (Cumming & Peterson, 2017). The notion of using the amount of inventory flowing through the supply chain as the basis for estimating resilience levels is highlighted by Torabi et al. (2015).

Further, Tendall et al. (2015) suggest three levels of enquiry for the analysis of resilience in food systems; the national or food systems level, discrete food value chain (either local or global) level and at the individual actor’s level. Policymakers and governments are most interested in resilience at the national or food systems level. For industry players, resilience is of interest at the level of individual food value chains. From the individual actor’s perspective, resilience is important at the level of individual firms or enterprises. A system’s state of resilience may be determined at any of these levels. Content analysis indicates that most supply chain resilience studies are conducted within the purview of the third, organisational, level.

Yet, this paper contends that resilience in tropical commodity chains like cocoa should, in the first instance, be approached from the national food system level. Cocoa is of national interest to the major producing countries because of its substantial contribution to the gross domestic product, 7.5 per cent and 3.4 per cent for Cote d’Ivoire and Ghana, respectively (Läderach et al., 2013). The governments of these two countries have considerable influence on the institutional environment that governs and guides actors in the value chain. They also set producer prices for the raw material (cocoa beans) traded by chain actors. This suggests analysis at the national or value chain level. Analysis at the aggregate level does not, however, prevent the inclusion of disaggregated levels of resilience for upstream actors.

In sum, the conceptualisation of resilience in agricultural food systems considers three issues. First, the context of analysis, as this determines whether the focus will be on socioecological or sociotechnical resilience. Second, the system’s state of resilience, as this foundation is required to determine the levels of resilience. Lastly, the level of enquiry, as this helps to establish a threshold level of resilience. The remaining sections of this paper seek to operationalise the concept.

Elements of agricultural value chains resilience
Measures of resilience in the supply chain literature have been partially subjective and usually considered within the specific context of the analysis (Tukamuhabwa et al., 2015). Indeed,
much of the literature positions resilience within the context of the processing, manufacturing and distribution of material in the value chain. As such, they adopt a sociotechnical view of the interactions between the behavioural and technical elements in determining resilience. Such views tend to be oblivious to the socioecological elements of an agricultural value chain (Tendall et al., 2015) and assume an unlimited supply of raw materials (Datta et al., 2007).

According to Jüttner and Maklan (2011), flexibility, velocity, visibility and collaboration are the four most frequently acknowledged elements of resilience found in the supply chain literature. Christopher and Peck (2004) combined visibility and velocity as sub-components of agility. Visibility refers the ability to see the flow of inventory in real time all along the value chain, while velocity measures the total turnover of material (inventory) in a set period (Christopher and Peck, 2004). The inclusion of visibility as an element of agility has been contested and linked to the concept of inter-organisational collaboration (Ponis and Koronis, 2012).

If the flow of material from one point of the value chain to another is facilitated via transactional terms between two or more chain actors, then visibility will not be a robust element. Visibility is enhanced when a dominant actor in the value chain facilitates the distribution of information to all the others (Ponis and Koronis, 2012). Conversely, visibility can be constrained when the flow of information is siloed at each level within the chain. For instance, a processor may know the inventory in its warehouse or those in the pipeline, while information on the level of a supplier’s outbound inventory may be opaque to the processor. Thus, visibility will be appropriate only when stakeholders collaborate and readily share information among themselves.

In a study that ranked different elements of resilience proposed in the supply chain literature, Ponomarov and Holcomb (2009) cited flexibility as the highest-ranked element of resilience, followed by collaboration and visibility. Alternatively, Pettit et al. (2013) presented collaboration as the highest-ranked element, followed by flexibility and adaptability. Despite these contrasting views, flexibility and collaboration have been consistently identified in the literature, and this is supported by the results of this analysis.

From the content analysis, 20 different elements of resilience were suggested. Evidently, there is a lack of consensus concerning these elements (Hohenstein et al., 2015). The content analysis revealed that the top seven elements often used for the operationalisation of supply chain resilience are flexibility, collaboration, redundancy, visibility, agility, efficiency and adaptability. This result resonates with other findings that show collaboration, flexibility and redundancy as the top three elements (Hohenstein et al., 2015). The different elements suggested in the supply chain literature and their usage frequencies in each cluster are illustrated in Figure 6.

The lack of consensus over the elements of resilience can be attributed to the differing contexts of analysis, and the tendency to delink peripheral elements from the core ones and the interchangeability of some elements of supply chain resilience. For instance, information sharing, connectivity, coordination, integration and visibility are regarded as components of collaboration (Scholten and Schilder, 2015; Ponis and Koronis, 2012). As such, proposing these as standalone elements of supply chain resilience reduces the concordance in literature. Indeed, these elements are often combined into one element (i.e. collaboration).

Although most of the selected articles in the content analysis assess supply chain resilience from the sociotechnical viewpoint, transformability (i.e. the capacity of a sociotechnical system to respond to disruptions by shifting from one configuration to another), which is the central element of sociotechnical resilience (Amir and Kant, 2018), is not profound in these articles. Instead, flexibility, which is considered as a prerequisite for transformation (Amir and Kant, 2018), is the most mentioned element of resilience in the supply chain literature.

Redundancy implies building extra or surplus capacity and capabilities as a proactive measure of disruption (Sheffi and Rice, 2005). However, having extra capacity/capability does not fully explain resiliency; balancing redundancy and efficiency is a prerequisite for building supply chain resilience (Sheffi and Rice, 2005). Yet, the two elements present a dilemma for resilient supply chains; while high redundancy can potentially increase resilience, there are cost implications that lower the efficiency of a system. This paper suggests a merger of the two concepts to form an element termed “resourcefulness”, and this is discussed in the next section.

Though velocity and visibility are among the most suggested elements of resilience (Jüttner and Maklan, 2011), they are regarded as constituents of agility (Christopher and Peck, 2004). Agility deals with responses to short-term changes in the supply chain (Eckstein et al., 2015), but resilience in tropical commodity chains suggests a longer-term view for two reasons. First, the perenniality of the tree crops that produce the raw material for long-term production suggests a need for a longer-term perspective, as actions taken today will not manifest until many years later. Second, the seasonality of raw materials that are critical for the continuity in the operations of midstream and downstream actors necessitates a strategic supply approach (Kraljic, 1983). Therefore, elements that deal with responses to long-term system changes are considered critical. Adaptability has been defined as an element that pertains to responses to long-term changes in socioecological systems (Fazey et al., 2007; Fiksel, 2003). In the following sections, the suitability of these four elements: flexibility, collaboration, resourcefulness
and adaptability is discussed in the context of tropical commodity chains.

**Flexibility**

Flexibility describes how well a system responds to disruptions to ensure continuity of its operations. Flexibility and agility are often used interchangeably in the literature. Nikookar *et al.* (2014) defined flexibility as the speed with which a system responds to disruption; this definition has also been ascribed to agility (Christopher and Peck, 2004). Rice and Caniato (2003) described flexibility as the creation of capabilities to respond to disruptions. This definition emphasises a system's capacity to respond to disruption and resonates with later studies in the supply chain literature (Chowdhury and Quaddus, 2016). According to Charles *et al.* (2010), flexibility is a precursor attribute that lays the foundation for other elements such as agility, and it is established via pre-event investment (Nikookar *et al.*, 2014). This investment allows for the development of internal capacities through mitigation and contingency strategies like flexibility in production, contracts, procurement and distribution (Chowdhury and Quaddus, 2016). Investments in resources and infrastructure have cost implications (Rice and Caniato, 2003; Spiegler *et al.*, 2016). The inclusion of costs in resilience assessment is a two-edged trade-off; the cost implications involved in developing strategies that will enhance flexibility (Christopher and Peck, 2004; Datta *et al.*, 2007; Rice and Caniato, 2003), and conversely, the costs from losses as a result of ignoring the investment (Spiegler *et al.*, 2016). Balancing the costs involved with being flexible and the goal of achieving effectiveness when dealing with resilience is crucial (Christopher and Peck, 2004; Datta *et al.*, 2007; Rice and Caniato, 2003) and requires astute trade-off analysis, which is often sadly neglected (Datta *et al.*, 2007).

The effectiveness of a system's adjustment to disruptions determines the response and level of recovery, and these depend on the level of preparedness via prior investment. For instance, a distributor who has a flexible transportation system can easily dispatch replacement vehicles for those vehicles in transit that break down. Such effective adjustments facilitate good response and recovery from a disruption. For an upstream-focused tropical commodity, a flexible farm could, for instance, invest in irrigation to ensure continuous productivity even in times of rainfall shortage. So, flexibility in the context of agricultural production activities concerns the ability for a food system to build capacities via investment to respond to disruptions and safeguard appreciable levels of the raw materials needed for continuity in the value chain processes.

**Collaboration**

Collaboration is the willingness of chain actors to work together to ensure the smooth running of chain activities. It is often linked to information sharing and visibility (Soni *et al.*, 2014; Ponis and Koronis, 2012) as means to increase the connectivity of chain actors and enable them to work effectively for their mutual benefit (Petit *et al.*, 2010). It concerns interactions among the socioeconomic components of a system, and it is the underlying element that facilitates flexibility, velocity and visibility (Scholten and Schilder, 2015). Collaboration is motivated by the mutual benefits attainable by all actors in a value chain, and it is undermined by self-interest seeking and short-termism.

It has been established earlier that the raw materials produced by upstream actors (i.e. provisioning ecosystem service) in tropical commodity chains are critical to ensuring continuity in the value chain processes and represent the system’s state of resilience. Kraljic’s purchasing portfolio matrix uses the supply risks in purchasing of such raw materials as a springboard to provide insights into the level of collaboration that chain actors can engage in (Kraljic, 1983). From Kraljic’s matrix, when the complexity of the raw material supply market is high and the importance of purchasing the raw material is also high due to its value-added profile, the commodity falls within the strategic quadrant (Kraljic, 1983). As such, the adoption of a strategic supply management approach is recommended. This involves establishing long-term contractual agreements with global suppliers to secure the long-term availability of the raw materials (Kraljic, 1983). The availability of these raw materials is naturally critical for continuous operations of actors at the midstream and downstream levels of the value chain. This dependence should stimulate midstream and downstream actors to take a greater interest in upstream production activities.

However, the backward integration of these actors is impeded by the complexity (vis-a-vis land tenure systems, governance structure necessitating political interference and natural physical monopolies where certain goods can only be produced in certain places) involved in engaging and owning land-based production activities in tropical commodity chains. Thus, in practice, collaboration is often low. Despite this complexity, midstream and downstream actors in tropical commodity chains have adopted certification and incentive schemes to boost on-farm productivity and ensure the availability and supply of biological raw materials (Elder *et al.*, 2012). Hence, collaboration is the binding force that stimulates symbiotic behaviour from different chain actors and motivates chain actors to act synergistically to mitigate disruptions that occur in the system and maintain the levels of raw materials flowing through the value chain.

**Resourcefulness**

Earlier, a merger of redundancy and efficiency to form resourcefulness was suggested. Resourcefulness is defined as the ability to identify problems, establish priorities and mobilise resources to deal with disruptions (Cimellaro *et al.*, 2010; Tierney and Bruneau, 2007), to ensure recovery of the functionality of the system (Tierney and Bruneau, 2007). Stakeholders take economic decisions to proactively prepare for disruption by developing their capacities to respond and or adapt to disruptions; such preparedness for disruption connotes investments. The capacities developed by these investments must be optimised to curtail wastes in operation. Therefore, it is important to balance the cost of investment in redundant capacities with efficiency (Scholten and Schilder, 2015). While redundancy captures pre-disruption decisions, efficiency is a post-disruption output of the latter. Resourcefulness looks at how the decisions have resulted in maintaining the system’s state of resilience.

This paper focuses on upstream disruptions in socioecological systems and investments related to agricultural production. If
production activities are being dominantly conducted by autonomous actors, then the decisions of these actors can severely influence resilience of tropical commodity chains. In these chains, the perennial nature of the tree crops that produce these commodities implies long-term recurring production activities that need to be efficiently managed to secure appreciable levels of productivity. Therefore, resourcefulness is defined as the prioritisation and efficient management of resources (i.e. the factors of production like land, inputs, labour) to ensure that the desired levels of productivity are not lost when the system is faced with disruption.

Adaptability
Adaptability is the capacity of a system to change its behaviour in response to the variation in its environment or to preserve, improve or achieve its goals (Ivanov et al., 2010). Adaptability deals with responses to long-term changes in the supply chain (Fiksela, 2003). Therefore, alteration of the system structure is required for developing such capacities (Eckstein et al., 2015; Ivanov et al., 2010). Systems that are adaptive can absorb shocks and “bounce back” after disruptions. Adaptability enables systems to learn and alter their behaviour (Fazey et al., 2007) and to retain their state of resilience (Cumming et al., 2005).

In the case of socioecological interactions, the social component of the system (i.e. human) alters the structure of the system via their behaviours (Cumming et al., 2005). When resilience analysis centres on upstream activities, the food system’s state of resilience is the continuity in the flow of the raw materials produced by the principal upstream actor (i.e. farmers). Thus, farmer behaviour takes primacy in determining the adaptability of the tropical commodity chain when the analysis is upstream production-focused. Indeed, in the face of disruptions, chain actors can act in a manner that is detrimental to other actors’ objectives. Individual actor responses to disruptions that deviate from achieving the system’s state of resilience or weaken the system’s ability to preserve its state of resilience are disregarded as adaptive strategies. In effect, adaptability reinforces collaboration among chain actors and transcends individual benefits; it deals with the shared aggregate benefits in a system. In view of this, adaptability is defined as the capacity of the tropical commodity chain to absorb disruptions and maintain its state of resilience, irrespective of structural and behavioural changes in the system.

Element for aggregate resilience in tropical commodity value chains
In identifying suitable elements of resilience, this paper views resilience from economic and socioecological perspectives. Ultimately, the raison d’être for building resilience in a system is to reduce losses arising from disruptions. This requires either pre-disruption investments when resilience analysis takes a proactive view or post-disruption investments when resilience analysis takes a reactive stance. Elements that capture these investment decisions, which act as antecedents for other elements and represent the economic aspects of resilience, are flexibility and resourcefulness. Elements that cover the socioecological components of resilience and focus on the system’s state of resilience are collaboration and adaptability. In the context of tropical commodity chains, resilience can be analysed from the viewpoint of policymakers at the national food system level or from the viewpoint of the value chain level or the individual chain actors.

The ensuing argument is presented as a basis for selecting elements suitable for analysing resilience at an aggregate level. An individual farmer’s adaptive strategy in the face of disruption (e.g. switching from producing crop A to crop B) can be an economically sound decision that creates the farm system’s new state of resilience (i.e. farm system X_B) and contributes to another system’s aggregate state of resilience (i.e. food system Y_B). However, the same adaptive strategy is not synergistic to food system A’s state of resilience, thereby reducing food system A’s aggregate state of resilience (food system Y_A). Alternatively, the investment decision of the farmer to build flexibility in the farm’s asset directly influences the farm system’s state of resilience (i.e. farm system X_A), which in turn feeds into the system’s aggregate state of resilience (i.e. food system Y_A). The same situation fits the farmer’s decision to collaborate with other chain actors or efficiently utilise the inputs.

Applying this logic, when building resilience, elements that do not reinforce the system’s aggregate state of resilience can be regarded as elements of an individual system’s resilience. Those that do are considered as elements of the aggregate system’s resilience. Therefore, when resilience analysis focuses on individual economic units in a food system, all four elements together can be used to determine resilience of the system. By contrast, when resilience analysis takes an aggregate outlook, adaptability is the key element that feeds into a system’s aggregate state of resilience. An illustration of the conceptual framework for analysing supply chain resilience in agricultural food value chains is presented in Figure 7.

Indicators for measuring resilience in tropical commodity chains
The content analysis points to two broad approaches that have been adopted to quantify supply chain resilience. The first approach determines a system’s state of resilience by developing measurable indexes (Brandon-Jones et al., 2014; Faulkner et al., 2010). Systems that do are considered as elements of the aggregate system’s resilience. Therefore, when resilience analysis focuses on individual economic units in a food system, all four elements together can be used to determine resilience of the system. By contrast, when resilience analysis takes an aggregate outlook, adaptability is the key element that feeds into a system’s aggregate state of resilience. An illustration of the conceptual framework for analysing supply chain resilience in agricultural food value chains is presented in Figure 7.

Figure 7 The conceptual framework for analysing resilience in agricultural value chains

![Conceptual Framework](image-url)
The second approach favours performance-based operationalisation. This focuses on the system’s outputs (e.g. supply lead time, cost) (Brandon-Jones et al., 2014; Spiegler et al., 2012) and construes supply chain performance measures as the state of resilience (Datta et al., 2007; Carvalho and Cruz-Machado, 2011; Colicchia et al., 2010). These performance measures then become the focus of analysis as they tend to be surrogate measures because there are no established indicators for measuring the actual elements of resilience (Cumming et al., 2005). Using performance measures as indicators for resilience assessment gives industry actors verifiable metrics to manage supply chain performance (Munoz and Dunbar, 2015). In this approach, a resilient system is the one that can maintain an acceptable threshold of performance (measured) after disruptions (Falkowski, 2015).

Studies that focus on midstream and downstream actors in a value chain often use performance measures related to customer service delivery (Spiegler et al., 2012). For instance, supply lead times have been used to represent the state of resilience for production and distribution systems (Datta et al., 2007; Colicchia et al., 2010). Some suggested indicators for flexibility include lead time ratio (Carvalho et al., 2012), increased sales or reduced costs (Sheffi and Rice, 2005), stock-out rate, inventory accuracy rate, percentage increase sales based on the flexibility design (Rajesh, 2016) and service delivery time (Ihsaq, 2012). For collaboration, indicators suggested in the literature include loss reduction (Chowdhury and Quaddus, 2016) and market share (Hohenstein et al., 2015). According to Ivanov and Sokolov (2013), an output performance measure is an appropriate indicator for assessing resilience.

Broadly, resilience analysis in tropical commodity chains focuses on two performance measures, socioecological and economic. The socioecological aspects focus on the minimisation of loss in a system’s state of resilience. This translates into the economic aspect of resilience that focuses on the minimisation of financial loss. In a tropical commodity chain, autonomous farmers are the chain actors whose structural or behavioural changes can significantly cause a loss of the food system’s aggregate state of resilience. Such autonomous actors can adapt well because they do not require mutual consent from other actors to adjust their production activities (Williamson, 1991) although peer effects may influence adaptability. Therefore, when the focus of analysis is on upstream activities, the indicator used to measure aggregate resilience in tropical commodity chains should accommodate the adaptability of each focal upstream actor (i.e. farmer) in the value chain. This means that an appropriate indicator for the aggregate resilience will capture:

- the proportion of focal upstream actors who switch-out from producing one commodity to another as an adaptation strategy to disruptions;
- the proportion of focal upstream actors who diversify part of their farms to produce other commodities as an adaptation strategy;
- the proportion that maintains the production of the same commodity despite the disruptions; and
- proportion of new entrants.

In such cases, the first two components of the indicator deal with losses in the system’s aggregate state of resilience resulting from the adaptive strategies of the focal upstream actors. The third and fourth components cover the gains in the system’s aggregate state of resilience resulting from the adaptive strategies used by the focal upstream actors. Thus, this paper proposes an indicator (called the farm adaptive ratio) that is an offshoot of the performance measure (i.e. system’s state of resilience) for measuring aggregate resilience. The farm adaptive ratio is expressed as:

\[
\text{Farm Adaptive Ratio } (i) = \frac{(\text{LossSsoR}(i))}{\mu(\text{SsoR}(j))}
\]

where \(\text{LossSsoR}(i)\) represents the loss in a system’s aggregate state of resilience (i.e. the quantity of raw materials) in cropping year\(_i\) resulting from adaptive strategies (i.e. switched-out farms and diversified farms), and \(\mu(\text{SsoR}(j))\) is a five-year moving average of a system’s aggregate state of resilience for previous cropping years. The major tropical commodities (i.e. cocoa, coffee, cashew and oil palm) start fruiting after an average of five years. Thus, a five-year moving average will capture the raw material contributions from new farm entrants and new trees. If the quantity of raw materials in cropping year\(_0\) (\(\text{SsoR}(0)\)) is greater or equal to \(\mu(\text{SsoR}(j))\), then \(\text{LossSsoR}(i)\) is zero, else \(\text{LossSsoR}(i)\) is the difference between \(\mu(\text{SsoR}(j))\) and \(\text{SsoR}(0)\).

The farm adaptive ratio (FAR) ranges from 0 to 1. A low FAR is expected for a value chain that has more focal upstream actors absorbing disruptions through their adaptation strategies without switching from producing the commodity under review. In contrast, a high FAR is expected for a value chain that has more focal upstream actors switching from producing the commodity being analysed. Therefore, an inverse relationship exists between the FAR and resilience, as shown in Figure 8. The lower the FAR, the higher the adaptive capacity and resilience of the value chain.

\[
\text{Figure 8 The inverse relationship between adaptability and resilience}
\]
Conclusion

The conceptualisation of resilience is an important step to present resilience as a calculable empirical concept, and it revolves around how the system’s state of resilience is determined. The system’s state can be based on performance measures and/or subjectively generated measures and indexes. This paper views the context within which resilience is assessed as a crucial influencer of the system’s state of resilience. Resilience analyses in agricultural value chains that are upstream-focused highlight the relevance of socioecological interactions in determining the system’s state of resilience. Therefore, conceptualisation of agricultural value chain resilience should reflect both the context of analysis and socioecological interactions that influence the system’s state of resilience.

Moreover, the operationalisation of agricultural value chain resilience depends on the level at which resilience is analysed. This dictates the suitability of elements suggested for the operationalisation of resilience. The paper reveals that, while adaptability and collaboration are suitable elements for assessing socioecological resilience, flexibility and resourcefulness are critical for the analysis of the economic aspects of resilience. These are applicable when the context of analysis is an individual economic unit. However, adaptability is the suitable element for determining a system’s aggregate state of resilience. This paper contends that, when agricultural value chains are viewed as socioecological systems and resilience analysis is upstream-focused, the chain actors whose activities primarily determine the system’s state of resilience are the focal actors. The behavioural changes of these focal actors in response to disruptions determine the adaptive capacity of the food system when resilience is assessed at an aggregate level.

The use of performance measures as indicators for assessing supply chain resilience gives a practical appreciation of a system’s resilience level. However, they become less usable when the concept of resilience is disaggregated into its different elements. For this reason, indexes are usually constructed to capture the different components of resilience and to present a single measure of resilience. In doing so, it is argued that indicators based on performance measures are appropriate and practical measures for the assessment of resilience.

Limitations and recommendations

Although the suggested conceptual framework for assessing resilience allows for trade-off analysis between the economic and socioecological dimensions of the concept, it has limitations in application. First, the framework views elements that capture responses to short-term changes in the agricultural value chain as peripheral. However, such elements can be appropriate when the context of analysis focuses on individual actors instead of the aggregate chain level. Therefore, the applicability of the proposed framework is limited to an aggregate scope of resilience analysis. Moreover, by focusing on socioecological resilience, the conceptual framework assumes limited use of technology for upstream production activities. This restricts the study to primarily agricultural value chains that hinge on dispersed production activities with unsophisticated technology.

Despite these limitations, the conceptual framework developed in this paper provides a solid grounding for future studies on supply chain resilience in agricultural value chains. Future studies that analyse resilience in agricultural value chains at the level of individual economic units should be upstream-focused, extending to raw material producers.

References


**Corresponding author**
Joshua Aboah can be contacted at: joshua.aboah@lincolnuni.ac.nz
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<tr>
<th>Authors</th>
<th>Link strength in Web of Science (Lw)</th>
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<td>Ponomarov and Holcomb (2009)</td>
<td>64</td>
<td>1</td>
<td>58</td>
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<td>122</td>
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<td>The study provides a conceptual framework for logistics capabilities towards supply chain resilience</td>
<td>Efficiency, cost minimisation, timeliness, flexibility, agility, information sharing, integration, adaptability, maintenance and recovery</td>
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<td>40</td>
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<td>The study focuses on factors that contribute to the severity of supply chain disruption</td>
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<td>Wieland and Marcus Wallenburg (2013)</td>
<td>27</td>
<td>1</td>
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<td>1</td>
<td>52</td>
<td>1</td>
<td>Using the context of European manufacturing companies, the study looks at relational competencies that enhance supply chain resilience</td>
<td>Agility, robustness and customer’s value</td>
<td>Agility: speed Robustness and customer’s value: not provided</td>
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<td>Carvalho et al. (2012)</td>
<td>24</td>
<td>1</td>
<td>26</td>
<td>1</td>
<td>50</td>
<td>2</td>
<td>The study assesses resilience of a three-echelon Portuguese automotive supply chain using a simulation of different scenarios of disruptions</td>
<td>Flexibility and redundancy</td>
<td>Flexibility: lead time ratio Redundancy: total cost (performance measures)</td>
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<td>Pettit et al. (2013)</td>
<td>25</td>
<td>1</td>
<td>22</td>
<td>1</td>
<td>47</td>
<td>8</td>
<td>The study develops a tool for measuring resilience from the context of manufacturing and service firms</td>
<td>Collaboration, flexibility in order fulfilment and sourcing, adaptability</td>
<td>Capability score and vulnerability score (using the Likert scale)</td>
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<td>43</td>
<td>1</td>
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<td>The study conceptualises supply chain resilience in relation to vulnerabilities and risk management</td>
<td>Flexibility, velocity, visibility and collaboration</td>
<td>Velocity; speed (lead time) Flexibility; effect of disruptions on cost and revenue targets</td>
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<td>43</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>43</td>
<td>The study develops a conceptual framework that explores factors that trigger supply chain disruption and the different methods that have been used to build supply chain resilience</td>
<td>Flexibility in sourcing and order fulfilment, efficiency, visibility, anticipation, collaboration, organisation, dispersion and adaptability</td>
<td>Not provided</td>
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<td>Pournader et al. (2016)</td>
<td>23</td>
<td>1</td>
<td>17</td>
<td>1</td>
<td>40</td>
<td>Develops a complex adaptive system to assess supply chain resilience for a three-tier supply chain in nine industries (automobile, construction, food processing, IT, machinery, oil and petroleum, pharmaceutical and medical, steel and textile)</td>
<td>Not provided</td>
<td>Resilience to risk ratio (efficiency score)</td>
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### Table A1

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<td>Brandon-Jones et al. (2014)</td>
<td>23</td>
<td>1</td>
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<td>1</td>
<td>39</td>
<td>5</td>
<td>In the context of manufacturing plants in the UK, provides a theoretical perspective of how visibility enhances supply chain resilience and robustness</td>
<td>Visibility</td>
<td>Likert scale</td>
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<td>39</td>
<td>5</td>
<td>A conceptual study that develops a framework for investigating supply chain resilience, incorporated with disaster management</td>
<td>Supply chain re-engineering (efficiency), collaboration (visibility), agility and risk awareness</td>
<td>Efficiency: output per inputs (resources); visibility: time; agility (velocity): speed</td>
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<td>Scholten and Schilder (2015)</td>
<td>18</td>
<td>1</td>
<td>20</td>
<td>1</td>
<td>38</td>
<td>5</td>
<td>A conceptual study (for food processing companies in The Netherlands) that narrows down on one element of resilience (i.e. collaboration) and explores how it influences supply chain resilience and establish its relationship with other elements</td>
<td>Flexibility, velocity, visibility and collaboration (information sharing, goal congruence, decision synchronization, incentive alignment, resource sharing, joint knowledge creation, communication)</td>
<td>Flexibility: no. of options to change in response to disruption and degree of difference in the options Velocity: speed Velocity: frequency of information sharing Collaboration: not provided</td>
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| Authors                  | Link strength in Web of Science (Lw) | Availability in Web of Science (x) | Link strength in Scopus (Ls) | Availability in Scopus (y) | Total link strength \( (L_r) = L_wX_w + L_sX_s \) | Context of analysis                                                                 | Elements for operationalisation                                             | Indicators for measurement                                                                 |
|-------------------------|--------------------------------------|-------------------------------------|-----------------------------|---------------------------|-------------------------------------------------|-------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| Tukamuhabwa et al. (2015) | 37                                   | 1                                   | 0                           | 1                         | 37                                              | Delivers a review of the different definitions of supply chain resilience, different conceptual models and theories adopted for resilience assessment | Flexibility, redundancy, collaboration and agility                                 | Overarching indicator: cost. Flexibility: priced using the extreme value theory. Redundancy and collaboration: not provided. Agility: recovery speed |
| Johnson et al. (2013)    | 20                                   | 1                                   | 16                          | 1                         | 36                                              | A qualitative study that examines how the facilitatory role of three dimensions of social capital to the four elements of supply chain resilience | Flexibility, velocity, visibility and collaboration                                 | Not applicable                                                                     |
| Ambulkar et al. (2015)   | 19                                   | 1                                   | 14                          | 1                         | 33                                              | A conceptual study explores factors that enhance resilience of firms and operationalise resilience for further empirical studies | Adaptability, responsiveness, awareness, redundancy, visibility and coordination | A seven-point Likert scale to measure a firm’s ability to cope with changes arising from supply chain disruptions, ability to adapt, ability to quickly respond to the changes and situational awareness |
| Colicchia et al. (2010)  | 16                                   | 1                                   | 17                          | 1                         | 33                                              | An analysis of supply chain resilience in the context of an European retailer or manufacturer engaged in a global sourcing | Flexibility                                                                        | Supply lead time is used as a proxy for resilience                                   |

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Table AI

| Authors          | Link strength in Web of Science (Lw) | Availability in Web of Science (x) | Link strength in Scopus (Ls) | Availability in Scopus (y) | Total link strength \((L_s) = L_w \times x + L_s \times y\) | Context of analysis                                                                 | Elements for operationalisation                                                                 | Indicators for measurement |
|------------------|--------------------------------------|-----------------------------------|-----------------------------|---------------------------|----------------------------------------------------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Pereira et al. (2014) | 21                                   | 1                                 | 10                          | 1                         | 31                                                        | with a focus on inbound activities                                                    | Flexibility, redundancy, visibility, agility, collaboration, integration, information sharing | Not applicable |
| Hohenstein et al. (2015) | 0                                    | 0                                 | 30                          | 1                         | 30                                                        | Investigates the generic elements of supply chain resilience and proposes measures for their assessment using a systematic literature review | Ex ante disruption phase (proactive): collaboration, HR management, inventory management, redundancy, visibility, post-disruption phase (reactive): agility, flexibility, collaboration, HR management, redundancy | Performance metrics: customer service, market share and financial performance |
| Liu et al. (2017)    | 10                                   | 1                                 | 20                          | 1                         | 30                                                        | The study explores the relationship between performance and supply chain resilience in the context of the shipping industry using the resource base view as a theoretical basis | Agility, risk management culture, supply chain re-engineering, integration | Operational performance: customer loyalty, customer satisfaction, service level, financial performance: market share and net profit before tax |
| Klibi et al. (2010)  | 10                                   | 1                                 | 19                          | 1                         | 29                                                        | The study reviews supply chain network designs under uncertainty and how it             | Flexibility, redundancy                                                           | Not applicable |

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<tr>
<th>Authors</th>
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<td>Chowdhury and Quaddus (2016)</td>
<td>15</td>
<td>1</td>
<td>28</td>
<td>1</td>
<td>Readiness: disaster preparation, flexibility, redundancy, visibility and collaboration</td>
<td>Recovery time, cost, disruption absorption, less disruption</td>
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<td>Chowdhury and Quaddus (2017)</td>
<td>15</td>
<td>1</td>
<td>28</td>
<td>1</td>
<td>Reflective constructs: flexibility, integration, financial strength, response and recovery, Formative constructs: reserve capacity, efficiency, market strength, density, complexity, criticality</td>
<td>Supply chain performance measures: recovery time, cost, disruption absorption, supply chain resilience, ability to reduce the impact of the loss</td>
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<td>16</td>
<td>1</td>
<td>26</td>
<td>4</td>
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**Table A1**

Chowdhury and Quaddus (2016) explored previous literature on the measurement of supply chain resilience and identified the elements that explain resilience in Bangladesh’s apparel industry. They developed a conceptual framework that uses the dynamic capability theory as a basis to develop a supply chain resilience measurement instrument in the context of Bangladesh’s apparel industry. They examined previous literature on disaster preparedness, flexibility, redundancy, visibility and collaboration, and recovery and identified the elements that explain resilience. They then developed a supply chain resilience measurement instrument in the context of Bangladesh’s apparel industry. They found that supply chain resilience is influenced by factors such as disaster preparedness, flexibility, redundancy, visibility and collaboration, and recovery.

Chowdhury and Quaddus (2017) developed a supply chain resilience measurement instrument in the context of Bangladesh’s apparel industry. They developed a conceptual framework that uses the dynamic capability theory as a basis to develop a supply chain resilience measurement instrument in the context of Bangladesh’s apparel industry. They examined previous literature on disaster preparedness, flexibility, redundancy, visibility and collaboration, and recovery and identified the elements that explain resilience. They then developed a supply chain resilience measurement instrument in the context of Bangladesh’s apparel industry. They found that supply chain resilience is influenced by factors such as disaster preparedness, flexibility, redundancy, visibility and collaboration, and recovery.

Dolgui et al. (2018) explored previous literature on the analysis of ripple effects in supply chains arising from disruptions and identified the elements that explain resilience. They then developed a supply chain resilience measurement instrument in the context of Bangladesh’s apparel industry. They found that supply chain resilience is influenced by factors such as disaster preparedness, flexibility, redundancy, visibility and collaboration, and recovery.

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**Context of analysis**

Elements for operationalisation

Indicators for measurement

---

**Operationalising resilience**

Joshua Aboah, Mark M.J. Wilson, Karl M. Rich and Michael C. Lyne

Supply Chain Management: An International Journal

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<td>A study that develops a conceptual model to explore the relationships amongst different enablers of resilience identified in the literature</td>
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<td>A study that reviews supply chain design and planning with disruptions and recovery</td>
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<td>A conceptual framework that develops a single index for measuring supply chain resilience</td>
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<td>Supply chain resilience index</td>
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<td>15</td>
<td>1</td>
<td>9</td>
<td>1</td>
<td>24</td>
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<td>Examines how the collaboration existing in a buyer-supplier relationship enhances resilience in the context of upstream actors in the petrochemical industry using the Kraljic matrix as a theoretical base</td>
<td>Collaboration</td>
<td>Not applicable</td>
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<td>Pourhejazy et al. (2017)</td>
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<td>1</td>
<td>11</td>
<td>1</td>
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<td>Assessing resilience in the context of petrochemical plants using the data envelope analysis method</td>
<td>Efficiency</td>
<td>Resilience score based on input usage</td>
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<td>Chopra and Sodhi (2014)</td>
<td>10</td>
<td>1</td>
<td>13</td>
<td>1</td>
<td>23</td>
<td>This study explores the different strategies that can be used to reduce disruptions in a supply chain and analyses the relationship's network connectivity and fragility.</td>
<td>Not applicable</td>
<td>Not applicable</td>
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| Cardoso et al. (2015)       | 12                                   | 1                                  | 10                          | 1                         | 22                                            | Investigates the characteristics of resilient supply chains for a five echelon supply chain comprising of raw materials suppliers, plants, warehouses, final products suppliers and markets. Proposes 11 indicators for measuring supply chain resilience | Not provided                                                                       | Network design: node complexity, flow complexity, density and node criticality. Network Centralisation: out-degree and in-degree centrality, coutflow and cinflow. Operational measures: expected net present value, expected customer service level and investment level | (continued)
<table>
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<th>Elements for operationalisation</th>
<th>Indicators for measurement</th>
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<tr>
<td>Purvis et al. (2016)</td>
<td>13</td>
<td>1</td>
<td>9</td>
<td>1</td>
<td>22</td>
<td>An exploratory study that focuses on a single case of a premium drink producer in the UK, but has outbound warehouses in seven European countries and sourcing across South America. Using a qualitative analytical approach, the RALF framework is proposed for the supply chain resilience assessment</td>
<td>Robustness, agility, leanness and flexibility</td>
<td>Not provided</td>
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<td>Bakshi and Kleindorfer</td>
<td>13</td>
<td>1</td>
<td>8</td>
<td>1</td>
<td>21</td>
<td>This exploratory study focuses on a bargaining framework that two chain actors can adopt to mitigate disruptions and enhance supply chain resilience</td>
<td>Not provided</td>
<td>Not provided</td>
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<tr>
<td>(2009)</td>
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<td>Leat and Revoredo-Giha</td>
<td>11</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>21</td>
<td>The study explores the challenges and risk associated with building resilience in the pork supply</td>
<td>Collaboration</td>
<td>Not provided</td>
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<td>(2013)</td>
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<td>Torabi et al. (2015)</td>
<td>9</td>
<td>1</td>
<td>12</td>
<td>1</td>
<td>21</td>
<td>2</td>
<td>Continuity</td>
<td>A resilience equation composed of - loss of resilience (calculated based on amount of inventory and the delivery time) - total amount of items (inventory) needed – allowable time for recovery</td>
<td>Flexibility, responsiveness, quality, productivity and accessibility</td>
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<td>Rajesh (2016)</td>
<td>10</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>20</td>
<td>5</td>
<td>A conceptual study that explores indicators that can be used to readily assess supply chain resilience using a case study of an Indian electronics manufacturing firm</td>
<td>Resilience performance indicators – flexibility: stock-out rate, inventory accuracy rate, per cent increase in sales based on the flexibility design Responsiveness: on-time delivery ratio, contract issue time, contract approval time, put-away time ratio Quality measures: quality of forecast, testing quality, shipping accuracy, fill rate, storage space utilization Accessibility: dealer accessibility, retailer accessibility, customer accessibility</td>
<td>(continued)</td>
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<th>Availability in Scopus (y)</th>
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<td>Schmitt and Singh (2012)</td>
<td>10</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>20</td>
<td>Looks at how a multi-echelon supply chain can build resilience in the face of both demand and supply disruptions in the context of a consumer-packaged goods firm that is composed of multiple products, distribution, centres and two manufacturing plants</td>
<td>Redundancy (in terms of buffers for inventory, capacity and time)</td>
<td>Customer fill rate, percentage of customers who are satisfied immediately from stock</td>
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<tr>
<td>Ali et al. (2017)</td>
<td>10</td>
<td>1</td>
<td>9</td>
<td>1</td>
<td>19</td>
<td>A qualitative study that looks at the elements (enablers) needed for building resilience in SMEs in Australia that deal in perishable products</td>
<td>Proactive elements: business certifications, globalisation, vertical integration, quality management Reactive elements: responsiveness to customer needs, responsiveness to competitor’s strategies, multi-sourcing, collaboration</td>
<td>Not provided</td>
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<td>Spiegler, Naim &amp; Wikner (2012)</td>
<td>19</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>19</td>
<td>Developed a framework for assessing supply chain resilience quantitatively in a single echelon supply chain with a focus on inventory and ordering system. The study also</td>
<td>Integral of time multiplied by the absolute error</td>
<td></td>
</tr>
<tr>
<td>Authors</td>
<td>Link strength in Web of Science (Lw)</td>
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<td>Total link strength (Ls) = LwXw + LsXs</td>
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<td>Azadeh et al. (2013)</td>
<td>9</td>
<td>1</td>
<td>8</td>
<td>1</td>
<td>17</td>
<td>Visibility, velocity, redundancy and flexibility</td>
<td>A study that focuses on a fictitious three-tiered supply chain involving a production factory, an assembling plant and a final plant. Supply chain resilience is analysed for different transportation-related disruptions, with an assumed infinite supply of raw materials to the production factory.</td>
<td>Average time in the system, utility of resources, number of breakdowns and the system's average cost</td>
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<tr>
<td>Azevedo et al. (2013)</td>
<td>8</td>
<td>1</td>
<td>9</td>
<td>1</td>
<td>17</td>
<td>Supply chain resilience behaviour. Supply chain green behaviour</td>
<td>Developed a framework that integrates greenness and resilience (ecosilient) in supply chain within the context.</td>
<td>Ecosilient index ranging from 1 to 5</td>
</tr>
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(continued)
| Authors                | Link strength in Web of Science (Lw) | Availability in Web of Science (x) | Link strength in Scopus (Ls) | Availability in Scopus (y) | Total link strength \( (L_s) = L_w X_w + L_s X_s \) | Context of analysis                                                                 | Elements for operationalisation                              | Indicators for measurement                  |
|------------------------|--------------------------------------|-----------------------------------|-----------------------------|---------------------------|---------------------------------------------|--------------------------------------------------------------------------------------|---------------------------------------------|
| Mandal et al. (2016)   | 10                                   | 1                                 | 7                           | 1                         | 17                                          | Explored the relationship between the dominant elements of supply chain resilience and how they influence supply chain resilience in a logistic capability context | Flexibility, collaboration, visibility, velocity                                    | Survey Likert scale                          |
| Ivanov and Sokolov (2013) | 8                                   | 1                                 | 9                           | 1                         | 17                                          | A conceptual study which explores the impact of disruptions on supply chain performance and highlights elements that can be systemized to enhance performance | Flexibility, adaptability                                                               | Cost, output performance measures          |
| Sahu et al. (2017)     | 10                                   | 1                                 | 7                           | 1                         | 17                                          | The study develops an index for appraising resilience performance using expert opinions followed by a mathematical representation in the context of manufacturing | Supply chain re-engineering, supply chain collaboration, SCRM culture, agility        | Fuzzy performance importance index          |

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<tr>
<td>Papadopoulos et al. (2017)</td>
<td>8</td>
<td>1</td>
<td>8</td>
<td>1</td>
<td>16</td>
<td>Factory for automobile parts / A qualitative study that develops a theoretical framework to explore the role of big data on social media platforms can lead to supply chain resilience and sustainability</td>
<td>Not provided</td>
<td>Not provided</td>
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<td>Vugrin et al. (2011)</td>
<td>8</td>
<td>1</td>
<td>8</td>
<td>1</td>
<td>16</td>
<td>The study develops both the quantitative and qualitative frameworks for assessing supply chain resilience in the context of disruptions caused by hurricanes in a petrochemical supply chain</td>
<td>System productivity, system efficiency</td>
<td>Systemic impact (the difference between targeted system performance level and actual performance), Total recovery effort (the number of resources used for system recovery), Resilience cost</td>
</tr>
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<td>Kim et al. (2015)</td>
<td>15</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>15</td>
<td>A study that conceptualises supply chain disruptions and resilience for supply chain nodes and networks using a graph theory. The context focuses on supply networks</td>
<td>Network density, the average degree of arcs, average walk length, minimum and maximum walk length, connectivity, betweenness centrality</td>
<td>Supply network resilience ratio</td>
</tr>
<tr>
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<td>Mandal and Sarathy (2018)</td>
<td>10</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>15</td>
<td>5</td>
<td>This study explores how communication, commitment, cooperation and trust influence supply chain resilience and performance in the context of manufacturing firms</td>
<td>Not provided</td>
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<td>Munoz and Dunbar (2015)</td>
<td>8</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td>14</td>
<td>2</td>
<td>A conceptual study that quantifies supply chain resilience as a multi-dimensional concept in the context of a fictitious three-tiered supply chain comprising the manufacturer, retailer and customer</td>
<td>Not provided</td>
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<tr>
<td>Ponis and Koronis (2012)</td>
<td>14</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>3</td>
<td>A conceptual study that explores the formative elements for the conceptualisation of supply chain resilience via literature review</td>
<td>Agility (flexibility and velocity), redundancy, collaboration (visibility) and supply chain structure</td>
</tr>
<tr>
<td>Authors</td>
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<td>Ratick et al. (2008)</td>
<td>6</td>
<td>1</td>
<td>7</td>
<td>1</td>
<td>13</td>
<td>6</td>
<td>A study that assesses how backup capacities can be used to enhance the supply chain resilience in the context of logistics facility management</td>
<td>Flexibility</td>
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<tr>
<td>Ishfaq (2012)</td>
<td>7</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td>13</td>
<td>3</td>
<td>The study explores the logistics strategies that can enhance supply chain resilience in the context of a logistics system faced with transportation disruptions</td>
<td>Efficiency and flexibility</td>
</tr>
<tr>
<td>Agigi et al. (2016)</td>
<td>12</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>3</td>
<td>A qualitative study that explores the different approaches that can be used to build supply chain resilience in the context of grocery manufacturing companies</td>
<td>Redundancy and flexibility</td>
</tr>
<tr>
<td>Falkowski (2015)</td>
<td>6</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>11</td>
<td>6</td>
<td>Explores the factors that influence resilience of upstream and downstream</td>
<td>Flexibility, velocity, visibility and collaboration</td>
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<td>Elleuch et al., 2016</td>
<td>7</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>7 2</td>
<td>Developed a conceptual framework (i.e. quality function deployment approach) to improve resilience in the context of food chains</td>
<td>Redundancy and capacity for rescue, collaboration and visibility, efficiency, security, integration, recovery (REC), organisation and customer satisfaction and quality control</td>
<td>Absolute importance of resilience capacities</td>
</tr>
<tr>
<td>Umar et al. (2017)</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>6 6</td>
<td>A conceptual study that explores the capabilities that can be used to enhance resilience in food chains</td>
<td>Agility, adaptability and alignment (logistics, collaboration, sourcing and knowledge management)</td>
<td>Not provided</td>
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Context of analysis: actors in an agro-food supply chain using the relationship between farmer and processor in a diary chain as a case study.