Advancing the Understanding of Pharmaceutical Supply Chain Resilience using Complex Adaptive System (CAS) Theory

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Abstract

Purpose

The objective of this study was to advance our knowledge of pharmaceutical supply chain resilience using Complex Adaptive System theory (CAS).

Design/methodology/approach

An exploratory research design which adopted a qualitative approach was used to achieve the study's research objective. Qualitative data were gathered through 23 semi-structured interviews with key supply chain actors across the PSC in the United Kingdom (UK).

Findings

The findings demonstrate that CAS, as a theory, provides a systemic approach to understanding PSC resilience by taking into consideration the various elements (environment, PSC characteristics, vulnerabilities and resilience strategies) that make up the entire system. It also provides explanations for key findings, like the impact of power, conflict and complexity in the PSC, which are influenced by the interactions between supply chain actors and as such increase its susceptibility to the negative impact of disruption. Furthermore, the antecedents for building resilience strategies were the outcome of the decision-making process referred to as co-evolution from a CAS perspective.

Originality/value

Based on the data collected, the study was able to reflect on the relationships, interactions and interfaces between actors in the PSC using the CAS theory, which supports the proposition that resilience strategies can be adopted by supply chain actors to enhance this service supply

chain. This is a novel empirical study of resilience across multiple levels of the PSC and as such adds valuable new knowledge about the phenomenon and the use of CAS theory as a vehicle for exploration and knowledge construction in other supply chains.

Keywords: Pharmaceutical Supply Chain; Disruptions; Resilience Strategies; Vulnerabilities; Complex Adaptive System Theory.

1. Introduction

The COVID-19 pandemic, which has already led to deaths globally (World Health Organisation, 2020), is the latest example of a disruptive event that highlights the need to understand pharmaceutical supply chain resilience. There have been many other events which have impacted on the pharmaceutical supply chain (PSC). For instance, the Food and Drug Administration (FDA) announced shortage of twenty (20) medicines which had their sole source of Active Pharmaceutical Ingredients (API) or finished medicines from China (Rees, 2020). Apart from shortages of medicinal products affecting the financial and operational performance of firms within the supply chain (SC), they also significantly increased the cost of healthcare for patients and potentially led to the death of patients (Mereish et al., 2018; Phuong et al., 2019). Disruptions in supplying pharmaceutical products, thus depict an adverse impact on the whole health care system (Pauwels et al., 2015). For example, patients requiring extra therapeutic care (McLaughlin, 2013), increased stress on the staff (De Weerdt et al., 2017) and increased costs for the stakeholders (Fox et al., 2014). The increased discussions about disruptions to the PSC calls for closer scrutiny of this service supply chain as well as the need to seek ways in preventing and/or mitigating the impact of disruptive events.

Existing studies suggest that underlying weaknesses (vulnerabilities) expose supply chains to the impact of disruptions (Wagner and Bode, 2006; Craighead et al., 2007). Nonetheless, by building resilience strategies into supply chains, vulnerabilities may be reduced, and the capacity of supply chains to mitigate the impact of disruptive events increased (Christopher and Peck, 2004; Juttner and Maklan, 2011; Li et al., 2020). SC resilience thus involves the ability of the supply chain to prepare, respond and recover from a disruptive event in a timely and cost-effective manner (Tukamuhabwa et al., 2015; Hendry et al., 2019).

Although there have been extensive discussions in the literature around SC resilience (Chopra and Sodhi, 2014; Hendry et al., 2019), specific focus on resilience strategies in the PSC remains limited. The need for studies in PSC resilience is because the impact of disruptions transcends beyond losses in revenue and market shares to involve decisions regarding patients' safety. Thus, strategies adopted may differ from other supply networks (Jaberidoost et al., 2013; Lucker and Seifert, 2017).

Also, it is suspected that; the PSC differs from other supply chains. Some of the characteristics include longer lead times, stringent regulatory frameworks, difficult demand forecasting and complex applications which may influence the applicability of resilience strategies (Rossetti et al., 2011; Klueber and O'Keefer, 2013; Mehralian et al., 2015). However, these conclusions may stem from limited scope in the current understanding of PSC resilience as the studies have not approached it from a systemic perspective. Thus, once PSC resilience is viewed as a Complex Adaptive System (CAS) that is non-linear and exhibits various internal and external elements, it would become apparent that it should be approached from a systemic perspective.

CAS theory is defined as the dynamic ability of systems to adapt and evolve to changes in an environment (Choi, 2001; Day, 2014; Nair and Reed-Tsochas, 2019). We apply the components of CAS theory (internal, external and co-evolution) in this study, to examine as well as enhance our understanding of the complex dynamics of resilience in PSC as a service supply chain. We posit that PSC resilience is a CAS and provide empirical evidence to affirm our propositions. In adopting this position, we argue that advancing the knowledge of PSC resilience through a CAS lens permits us to gain maximum insight into practical approaches for building resilience into the PSC.

This study, therefore, seeks to advance our knowledge of PSC resilience using Complex Adaptive System theory**.** We begin by reviewing supply chain literature to report underlying assumptions about PSC, disruptions, vulnerabilities, resilience strategies and CAS. Through this, gaps in the literature are highlighted and inform the research objective as well as the methodological approach used. We then present the findings from interviews conducted with a purposive sample of selected supply chain actors before establishing connections between PSC resilience and CAS theory. The study concludes by underlining the novel contribution of this work, proposals for further study and recommendations for practice. At this point, we also offer considerations for the generalisability of the approach and outputs of this study to other complex supply chains.

2. Literature Review

A review of the extant literature is presented here. In Section 2.1 below, CAS theory is briefly described. Section 2.2 presents the importance of the PSC and supply chain

disruptions. Sections 2.3 and 2.4 reviews the concepts of supply chain vulnerabilities and resilience strategies respectively as well as the gaps in the literature that need to be addressed.

2.1 Complex Adaptive System (CAS) Theory

Several theories have been employed to elucidate resilience as a phenomenon within the supply chain literature: Resource-Based View (RBV) (Holweg and Pil, 2008; Blackhurst et al., 2011); Dynamic Capability Theory (Ponomarov, 2012; Hendry et al., 2019) and Systems Theory (Erol et al., 2010; Spiegler et al., 2012). Table 1 below presents a summary of the theories and discusses their limitations for gaining an understanding of PSC resilience (PSCR).

Table 1 Summary of theories used in supply chain resilience literature

Theories	**Use in SC resilience studies**	**Limitations for PSCR discussions**
Resource Based View (RBV) Holweg and Pil (2008); Ponomarov and Holcomb, (2009); Park (2011); Bradon-Jones et al., (2014); Brusset and Teller, 2017; Cheng et al., (2017) Dubey et al., (2017); Parast (2020).	SC resilience is the firm's redundant, capital or flexible resources which is used to gain competitive advantages.	Resilience strategies are limited to a firm's internal environment and within a complex supply chain.
Dynamic Capability Theory: Chowdhury and Quaddus, (2017); Gu and Huo (2017); Hendry et al., (2019); Sabahi and Parast, (2019).	SC resilience is the ability of the firm to sense and adapt to changes in the external environment that will foster sustainability and competitiveness.	The theory does not explain the systemic nature of SC resilience.
System Theory: Erol et al., (2010); Blackhurst et al.,(2011); Spiegler et al., (2012); Kaviani et al., (2016)	The SC is viewed as an open system that constantly interacts with its environment and resilience strategies are elements within the supply chain.	The theory does not explain the dynamism and adaptability in SC resilience.

In line with the studies by Day (2014) and Tukamuhabwa et al., (2015), we, therefore, assert that PSC resilience strategies cannot be viewed as just a system or resources as they are more complex in nature. The argument stems from the dynamism of the external environment, the multidimensionality of resilience strategies and the uncertainties associated with the inherent complexity of the PSC. This study proposes the Complex Adaptive System (CAS) theory to advance our knowledge on PSC resilience as it deals with high levels of abstractions

concerning business environments. (Choi et al., 2001; Holland, 2006). Some authors (Sarkis et al., 2011; and Kim et al., 2015), suggest the need to understand how firms in such complex networks coevolve with one another to determine appropriate responses to external stimuli. This will help businesses to gain competitive advantages from their complex interactions with their environment.

A CAS comprises of a range of elements, referred to as agents who follow sets of internal rules or schemas that guide their actions (Choi et al., 2001). These schemas provide the agents with reference points for their behaviour. They can be applied to new situations rather than assessing new rules for every possible situation (Nair and Reed-Tsochas, 2019).

The theory emerged to provide explanations as to how order exists within systems that are complex and non-linear, such as the human system and the galaxy (Holland, 2006). A CAS focuses on the interactions between the agents and their changing environment. In its ability to learn from its experience, a CAS evolves based not only on the dynamic interactions amongst its agents but also on the interactions between the environment and the agents (Schiffling et al. 2020). New behaviours emerge based on the interactions between each agent and the overall system. Agents can be eliminated, or new agents emerge because of interactions. Since most of the interactions between agents and their environment are non-linear, the outcome and/or the behaviour of the system is usually unpredictable (Choi et al., 2001). A CAS is deemed complex and adaptive because it is diverse, can alter itself based on learning from experience (Holland, 2006); and possesses the ability to anticipate the consequences of new actions or activities. CAS theory has gained popularity in the social sciences, for example in stock markets (Mauboussin, 2002); healthcare management (Pype et al., 2019; Fylan et al., 2019) and supply chain networks (Choi et al. 2001; Surana et al., 2005; Day, 2014; Nair et al., 2016; Schiffling et al. 2020).

Choi et al., (2001) and recently updated by Nair and Reed-Tsochas (2019), provide a CAS framework as presented in Table 2. This framework categorises elements of CAS into three significant dimensions which are the internal mechanisms, the external mechanisms and co-evolution. It is against this categorisation that the contribution of CAS theory to pharmaceutical supply chain resilience will be drawn.

Table 2 CAS Framework

Elements of CAS	Features	Inference
Internal	Agents, schemas, network, connectivity, dimensionality, non-linearity. Agents are organisations supply chain actors	Concerned with how agents interact with each other within a system.
External	Environment, disruptions such as natural disasters, pandemic, financial crises, geographic location, cultural inherences.	Concerned with the external environment in which the system operates and how agents respond to changes in the environment
Coevolution	Adaptability, anticipation, self-organisation, emergent behaviour.	Characterises the ability of the system to be flexible, respond and react to changes because of the interactions.

The complex interactions within the PSC, its non-linearity, unpredictable outcomes and the dynamism associated with resilience strategies advocate CAS theory in for advancing our understanding of PSC resilience. Thus, if the understanding of PSC resilience is oversimplified, it may create issues that inhibit the success of the application of the underlying strategies. The next section presents an overview of PSC disruptions and features

2.2 Disruptions within the Pharmaceutical Supply Chain (PSC)

The PSC consists of multifaceted procedures and operations that facilitate medicine discovery, development, manufacture and distribution under highly regulated conditions (Narayana et al., 2014). The aim is to ensure that the supply of medicines is safe, reliable and meets the set quality criteria through a supply chain which responds to actual demand and recognises the needs of the consumer (Sousa et al., 2015). See Figure 1 for an overview of the PSC.

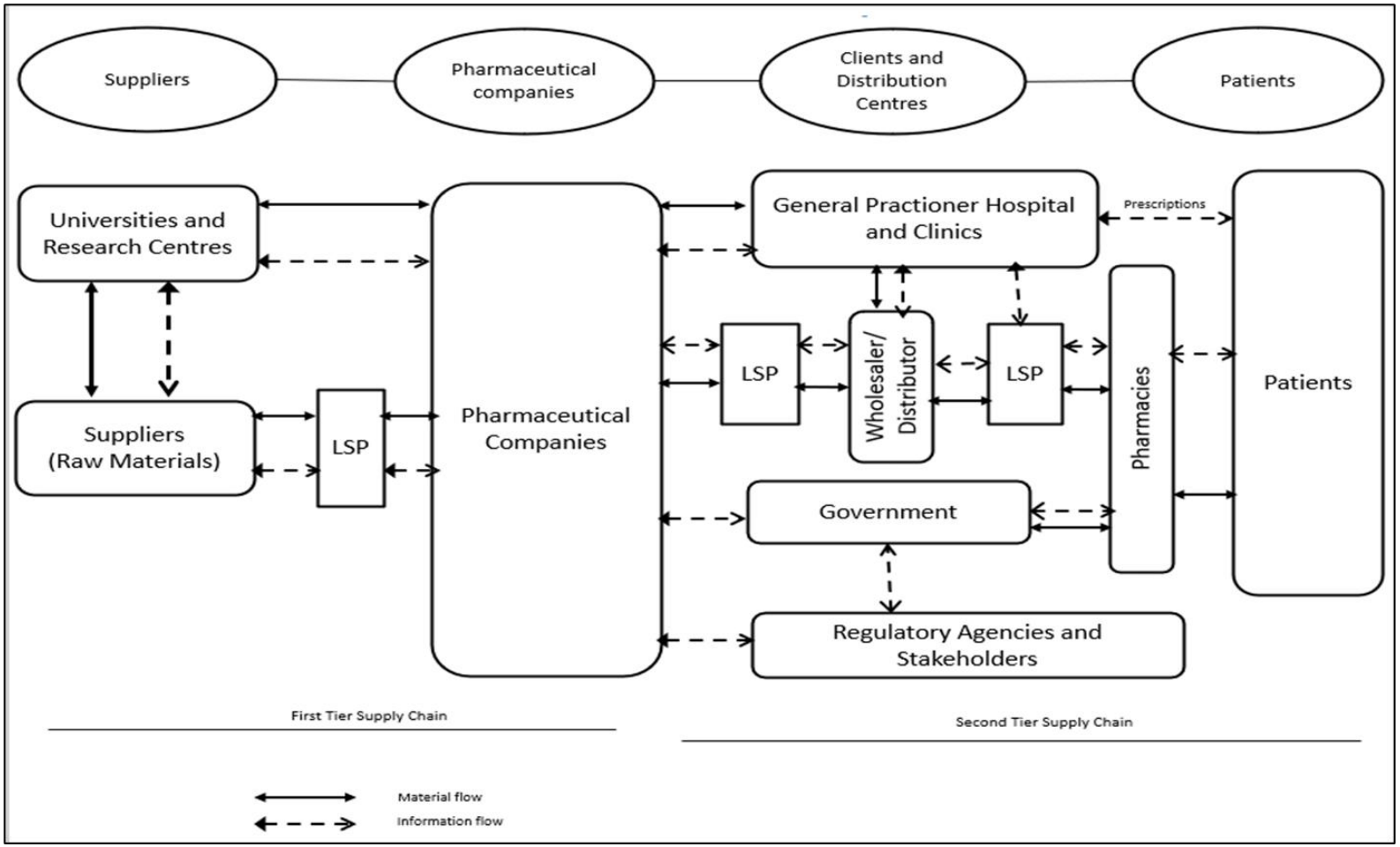


Figure 1. The Pharmaceutical Supply Chain
Source: Adapted from Evans and Gruber (2014)
*LSP: - Logistic Service Provider

Existing reports indicate an upsurge in global sales as a result of increased access to healthcare in various countries and increased prices for breakthrough medicines (Singh et al., 2016; Sabouhi et al., 2018). However, the increased incidences of disruptions-medicine shortages- in the PSC (Beck et al., 2019), call for closer scrutiny of how resilience strategies can be built to ensure the continuous flow of medicines and as such advance our understanding of this service supply chain.

Disruptions are events that disrupt the flow of goods and services within an SC and have been reported to have adverse effects on the financial and operational performance of the firm (Hendricks et al., 2019). SC disruption does not differ significantly from supply chain risk; instead, it is a realised risk (Habermann et al., 2015). *Dynamic disruptions* extend the concept of supply chain disruptions to include disruptions where the mode of occurrence and impact is largely unknown as with medicine shortages. It is therefore crucial to understand the concept and classification of disruption within the SC as it relates to risks, vulnerability and resilience to pre-empt a response and inform actual response (Juttner and Maklan, 2011).

Medicine shortages have been identified as a supply issue, yet there are limited studies that address this issue from a SC perspective. For instance, Saedi et al. (2016) advocated the use of optimisation techniques in curbing medicine shortages. In addition, Tucker et al. (2019) used optimisation techniques to study the resilience of the PSC to medicine shortages in the US. Their study concluded that deliberate managerial decisions were a primary vulnerability driver within PSCs, but this was targeted at low-cost medicines. Jia and Zhao (2017) presented the use of inventory management through Pareto improving contracts, while Scioli (2017) suggested the use of leadership strategies in curbing medicine shortages. The findings from these studies show the importance of exploring medicine shortages, vulnerabilities, PSC resilience. Thus advancing our understanding is pertinent.

For this study, medicine shortages will be explored as the dynamic, disruptive activity that affects the PSC, the underlying vulnerabilities and resilience strategies. The next section discusses the relationship between SC vulnerability and PSC resilience.

2.3 Supply Chain Vulnerability (SCV)

Supply chain vulnerability is the susceptibility of the SC to the impact of disruption (Peck, 2005; Wagner and Bode, 2006; Chowdhury and Quaddus, 2017). Proponents of supply chain

resilience suggest that resilience and vulnerabilities are interwoven, and not all disruptive activities can be avoided, controlled, or eliminated (Juttner and Maklan, 2011). Pettit et al., (2010) validated this through an empirical study that found that supply chain resilience increases as capabilities increases and vulnerabilities decrease. Similarly, Christopher and Holweg (2017), provided quantitative evidence that SCV resulted in higher costs and therefore resilience was advocated. Therefore, understanding SCV is pertinent to effectively manage SCV (Wagner and Bode, 2006; Wagner and Neshat, 2012).

Although drivers of SCV have been highlighted in existing literature, empirical evidence is limited. For instance, supply chain density and structure has been identified as a primary propellant of SC vulnerability as tightly coupled suppliers inhibits flexibility of operations (Wagner and Bode, 2006; Craighead et al., 2007; Falasca et al., 2008). Complexity as an SCV driver occurs as a result of managerial decisions, globalisation and outsourcing has been suggested to heighten the severity of a disruption as well as increase risks (Bode et al., 2016; Blackhurst et al., 2017). These activities lead to more prolonged and multiple layered SCs which reduce visibility and increase vulnerability, plant performance, production costs, and supplier innovation (Wagner and Neshat 2010).

SC power denotes the ability of a SC actor to influence the outcomes of other actors at different levels of the supply chain (Benton and Maloni, 2005; Golgeci et al., 2018). Power dynamics have been identified as central to SC relationships (Reimann and Ketchen, 2017). However, the possibility that power may increase vulnerabilities in the SC has not received much attention in SC resilience literature. The argument is that power asymmetry; where one firm needs another firm's resources (Huo et al. 2017) and therefore holds less power, may expose the SC to the impact of disruptions. Thus, the more powerful firms have been suggested to have higher market share and may use power to gain a competitive advantage. Resilience strategies should be incorporated into the SC to reduce power dynamics and mitigate the impact of disruptions.

2.4 Supply Chain Resilience

An approach to dealing with the impact of disruptive events in an SC is by adopting resilience strategies (Juttner and Maklan, 2011; Melnyk, et al., 2014). This study adopts the definition of SC resilience proposed by Tukamuhabwa et al., (2015:5599) as "*The adaptive*

capability of a supply chain to prepare for and/or respond to disruptions, to make a timely and cost-effective recovery, and therefore progress to a post-disruption state of operations – ideally, a better state than prior to the disruption". This is because it encompasses the essential ingredients of what a resilient SC entail.

SC resilience relates to balancing both recovery and resistance strategies (Melnyk et al*.,* 2014; Sáenz and Revilla, 2014; Christopher and Holweg, 2017; Chowdhury and Quaddus, 2017). Recovery as an arm of resilience strategies implies that the SC adjusts *ex-post* to changes, and SCs adopting this strategy are referred to as agile supply chains (Braunscheidel and Suresh, 2009). Resistance strategies, however, imply that the supply chain implements *ex-ante* measures to cope with turbulence, with no adaptation needed during times of change. SC adopting this strategy are robust supply chains (Klibi et al*.,* 2010; Vlajic et al., 2012). Relevant studies in this area have focused on critical aspects of SC resilience. For instance, flexibility and collaboration (Juttner and Maklan, 2011); relational capabilities (Toyli et al., 2013); resilience scale development (Ambulkar et al., 2015); collaboration with the government (Yang and Xu, 2015); interface of resilience and sustainability (Ivanov, 2018); building routine for non-routine events (Scholten et al., 2017); resilience strategy model development (Jain et al., 2017); the interrelatedness of threats, resilience strategies and outcomes arguing for a systemic approach to supply chain resilience (Tukamuhabwa et al., 2017) and seizing and sensing capabilities required in building SC resilience (Hendry et al., 2019). Although these studies have examined resilience strategies in parts, most have identified the need for more empirical research since resilience strategies are dynamic and cannot be restricted to specific parts of the SC. In order to advance our knowledge of resilience strategies a holistic or systemic approach is needed .

2.5 The Relationship between CAS and Resilience in the PSC

In seeking to advance the discussions around PSC resilience, a clear rationale needs to be identified. Issues reported which impact on SC resilience in the PSC include visibility, vulnerability, product life cycle and system maturity as indicated by the studies presented in Table 3.

Table 3 shows that previous studies failed to explain why vulnerabilities occurred in the supply chain and how resilience strategies could be used in mitigating the vulnerabilities.

Also, there was no practical use of theory in any of the studies, and these studies failed to adopt a systemic approach to understanding how the various elements of PSC resilience (vulnerabilities and antecedents of resilience strategies) are interrelated. This litersture review provides conclusive evidence to support the need for a holistic approach. This study, therefore, posits that if PSC resilience is explored from a CAS perspective, which adopts a holistic approach, our understanding of PSC resilience will be enhanced.

Table 3 Empirical Evidence of PSCR

Author	**Focus**	**PSC insight**
Klueber and Keefe (2013),	Visibility and regulations	Supply chain visibility cannot be achieved in a highly regulated environment
Mehralian et al., (2015)	Visibility	Emerging demand and PSC complexities inhibits transparency.
Aigbosun et al., (2015)	Vulnerabilities and resilience	Vulnerabilities include turbulence, sensitivity and external pressures. Resilience strategies include adaptability, collaboration and reserve capacity.
Lucker and Seifert (2017)	Agility capacity	Resilience strategies are predominantly applied at mature stages of the PSC.
Sabouhi et al., (2018)	Supply chain design	Resilience strategy is redesigning of the PSC.
Ward and Hargaden (2019)	Risk and resilience using SCRAM tool by Pettit et al., (2010)	Resilience strategies include visibility, collaboration, and flexibility.
Tucker et al., (2019)	Vulnerabilities and Resilience	Vulnerability drivers include deliberate managerial decisions

Table 4 presents a summary of how CAS can be used to extend our understanding of PSC resilience. The summary suggests that CAS theory can be used as a lens in explaining the dynamic, adaptive and emergent features of PSC resilience. CAS theory also highlights that the interactions between agents are non-linear. So the outcomes of the decision-making process may be uncertain. The above discussion clearly makes the case for the importance of advancing our understanding of PSC resilience in the face of dynamic disruptions through the adoption of CAS theory .

Table 4 A summary of pharmaceutical supply chain resilience as a CAS

Features CAS	CAS and PSC Resilience
Internal Mechanisms	Concerned with interactions of SC actors with each other when disruptions occur. Their decision-making process in response to the changes within their environment. These decisions could include, information sharing, outsourcing, power dynamics, strategic alliance.
External Mechanisms	Refers to disruptions which can be dynamic or static such as medicine shortages, pandemics, natural disasters
Coevolution	The outcome of the decision-making process by supply chain actors in response to environmental changes may either increase resilience or vulnerability.

3. Research Methods

The goal of this paper was to advance our understanding of PSC resilience using the CAS Theory. This is in response to the demand for more empirical studies into SC resilience and specifically to understand resilience in the context of the PSC due to its unique characteristics. In this paper, we sought to understand why the PSC was susceptible to the impact of disruptions and how resilience strategies were adopted to reduce the impact of disruption. To achieve the research objectives, gaining insights into the experiences of actors at various levels of the PSC was required and justifies the need for a qualitative exploratory study (Creswell and Poth 2016).

3.1 Data Collection

Respondents in charge of making decisions at various levels of the UK's PSC were selected, to provide rich, diverse and holistic views of disruptions, vulnerabilities and resilience strategies. A purposive sampling technique was used to ensure that the research participants met the criteria specifications set out in the study (Saunders, 2012). Thus the study included participants representing each level in the PSC: manufacturers, wholesalers, logistic service providers, secondary and primary care pharmacists. In each case, their job roles involved: responsibility for decision making with regards to the strategies related to disruption management in the PSC. Participants were therefore able to provide rich, diverse and holistic insight into the phenomenon of disruptions, vulnerabilities and resilience strategies.

It was envisaged that 16-24 interviews would be required to achieve data saturation (Hennink et al. 2017). Participants were recruited until no new information was generated from the

respondents (Morse, 1995). Ultimately this was achieved with data collected from 23 key pharmaceutical supply chain actors using semi-structured interviews between June 2018 and August 2018. Telephone interviews and conversations were recorded using a digital voice recorder, based on the study's research objective.

Table 5 presents the characteristics of the research participants and how they were coded before the data analyses.

Table 5 Characteristic of Interview Participants

Participant Type	Number of Interviews	Participant Type Identifier	Participants Roles	Years of Experience
Manufacturers	5	MFC	Director Packaging and Sales	4
		MFC	Global business Product Development	5
		MFC	Head of Supply Chain operations	15
		MFC	Head of Supply Chain Operations	9
		MFC	Head of Supply Chain and Procurement	20
Pre- Wholesalers	1	PWS	Operations Manager for Procurement	20
Wholesalers and Logistic Service Providers	2	LSP LSP	Operations Manager Operations Manager	20 3
Community Pharmacists	6	COMM	Superintendent Pharmacists	18
		COMM	Superintendent Pharmacists	44
		COMM	Superintendent Pharmacists	15
		COMM	Head of Buying /Group Pharm	17
		COMM	Superintendent Pharmacists	16
		COMM	Superintendent Pharmacists	5
Hospital Pharmacists	5	HOSP	Procurement Specialists	25
		HOSP	Regional Procurement Specialists Officer/	31.5
		HOSP	Regional Procurement Specialists Officer	17
		HOSP	Regional Procurement Specialists Officer	20
		HOSP	Regional Procurement Specialists Officer	37
Other Pharmacists	1	GP	GP Practice	12
Regulatory Bodies	3	REG	Director for Supply chain	15
		REG	Economic Director Primary and Secondary care	7
		REG	Principal Pharmacists	1.5

3.2 Interview Protocol

An interview protocol was developed to ensure that the process of generating the data was structurally sound. The interview protocol asked respondents why the PSC in the UK is prone

to the impact of disruptions and how resilience strategies can be employed to mitigate the impact of these disruptions. The structure of the interview protocol was developed using critical themes from the SC resilience literature. These themes included: vulnerabilities, disruption and resilience strategies. Questions around this thematic structure facilitated a positive interaction with participants and encouraged them to speak more openly about their perceptions and experiences (Kvale, 1999). The interviews focused on two main categories of questions; the description of how firms within the PSC handled disruptions when they occurred. Secondly, the questions explored reasons why these firms felt the impact of SC disruptions if at all and possible solutions to resolve the impact. The interview protocol consisted of 20 questions (see Appendix A for interview protocol) with an average duration of 30 minutes. This protocol enabled the interview process to be replicated across the various supply chain partners, thus ensuring reliability (Yin, 2013).

In accordance with recommendations by Pettigrew (1997), the interview protocol was piloted on the first four participants: a manufacturer, a hospital pharmacist, a regulatory body representative and a community pharmacist. The responses from the pilot study generated amendments which facilitated the development of the final interview protocol used in the study. The amendments were minor and related to terminology such as '*disruptions*' instead of '*dynamic disruptions*'. These amendments minimised any risk of misunderstanding.

3.3 Data Analysis

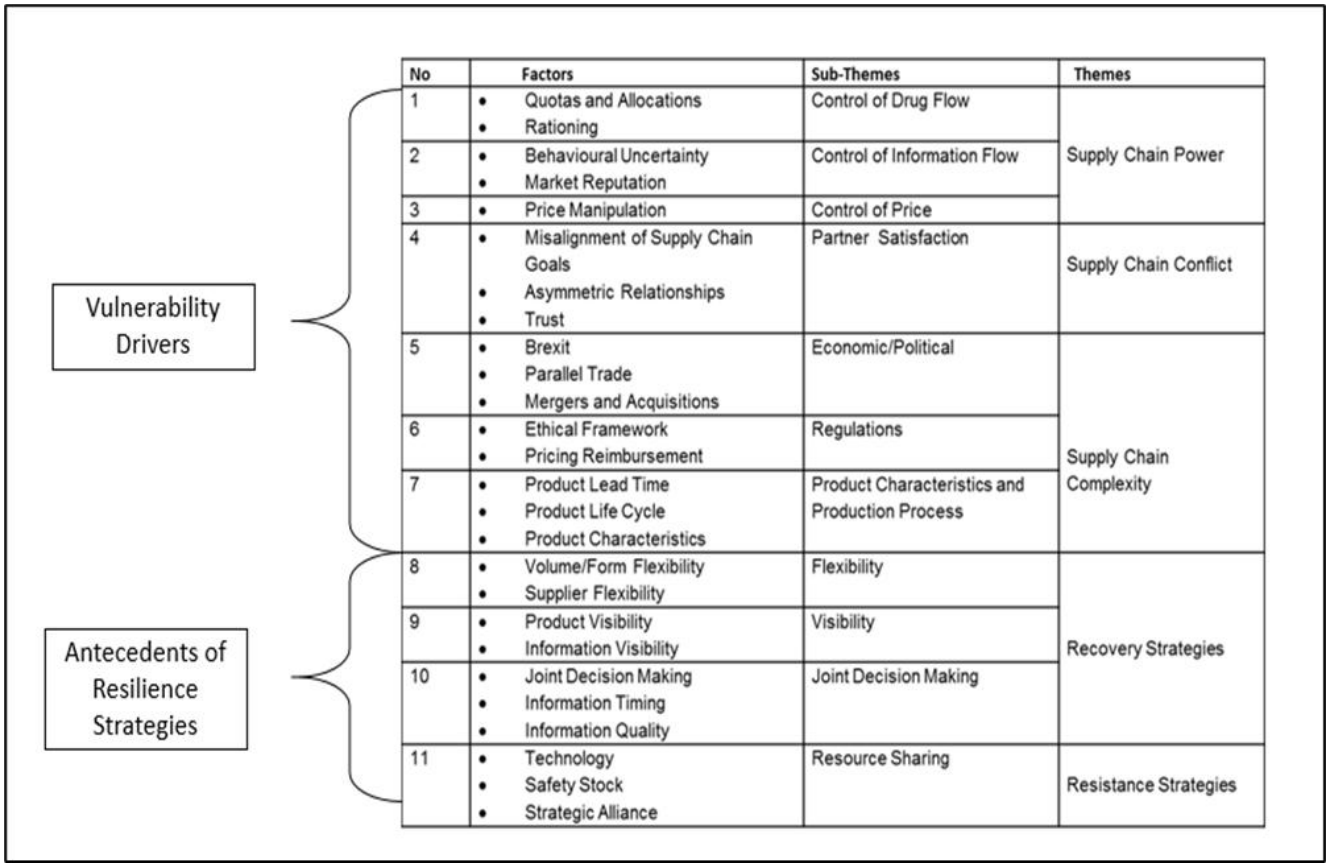
All interviews and conversations were audio-recorded with the permission of the respondents. The interviews were transcribed verbatim and the transcripts anonymised. Interviews were analysed using thematic analysis which aimed to present a comprehensive account of themes related to the objectives of the study, rather than a representation of the entire dataset (Braun and Clarke, 2014). For this study, a 'theme' constituted a pattern of meaning which was either directly observable in the data (explicit content) or was seen to underlie the data (manifest content; Joffe, 2012). The use of thematic analysis was chosen because of its flexibility which is not rooted in any theoretical perspective (Brannen, 2017). As prior research across this participant group is limited, this approach allowed for analysis to be primarily inductive, reflecting the experiences of participants.

This study thus followed Braun and Clarke's six-step method for theme development (Braun and Clarke, 2014). The first step was familiarisation of the data which was achieved through

repeated readings of the transcripts to understand the data and identify fragments of the data that referred to various parts of the research questions. The next step was coding where the interviews were initially coded, and the themes developed by the lead researcher. These themes were subsequently reviewed by three other experienced researchers in Supply Chain Management and Pharmacy and any areas of disagreement resolved through discussions. For further confirmation, an interdisciplinary research group (Operations Management and Pharmacy) reviewed the output and validated the constructed themes. The use of multiple researchers in the development of themes, thus reduced any issues of bias that may arise from a single (Strauss and Corbin, 1990). Although there are software packages developed for thematic analysis, they did not fit the purpose of this study as it had been developed under various epistemologies (Petty et al., 2012). Therefore, to maintain control of the data, the thematic analysis of the data was carried out manually. These themes are presented and analysed in the following section of this paper.

4. Findings

The interview protocol focused on understanding PSC resilience by exploring vulnerability drivers and antecedents of resilience strategies as informed by pertinent literature. The data analysis identified power, conflicts and complexity as a vulnerability driver. At the same time, recovery and resistance strategies were dimensions of resilience in the PSC. The characteristics of the supply chain were identified as pertinent in the decision-making process. A summary of the strength of participants' agreement with statements linked to the identified themes is presented below. As indicated in Figure 2, no 1–7 in the diagram denotes drivers of SCV and 8-11 are the antecedents of SC resilience. The brackets in the diagram highlight the differences in the categories.



No	Factors	Sub-Themes	Themes
1	• Quotas and Allocations • Rationing	Control of Drug Flow	Supply Chain Power
2	• Behavioural Uncertainty • Market Reputation	Control of Information Flow	
3	• Price Manipulation	Control of Price	
4	• Misalignment of Supply Chain Goals • Asymmetric Relationships • Trust	Partner Satisfaction	Supply Chain Conflict
5	• Brexit • Parallel Trade • Mergers and Acquisitions	Economic/Political	Supply Chain Complexity
6	• Ethical Framework • Pricing Reimbursement	Regulations	
7	• Product Lead Time • Product Life Cycle • Product Characteristics	Product Characteristics and Production Process	
8	• Volume/Form Flexibility • Supplier Flexibility	Flexibility	Recovery Strategies
9	• Product Visibility • Information Visibility	Visibility	
10	• Joint Decision Making • Information Timing • Information Quality	Joint Decision Making	
11	• Technology • Safety Stock • Strategic Alliance	Resource Sharing	Resistance Strategies

Figure 2. A summary of the themes and subthemes

The findings will be presented based on the themes that were evident in the data.

Table 6 Key Summary of Empirical Evidence

Themes	Sub-Themes	Activities	Sample Quotes from the Evidence
Power	**Control of Drug Flow**	To Protect Revenue Stream	*"If the pharmacists are selling a product to a competitor in Germany, the pharmacists take the profit and not the manufacturer..... All I will suggest the pharmaceutical society and the General Pharmaceutical Council should take stronger measures against pharmacists that are exporting products".*
		To Ensure Patient Treatment Continuity	*"If we have low stock, the first strategy is to investigate if we don't think we can react in time to bring in additional stock, we would need to put in allocation for the stock to ensure that all of our stock doesn't go to one consumer or a few consumers and sure that we adopt everybody".*
	Control of Information Flow	Protect Reputation	*"Some manufacturers don't necessarily want the market to know that they are going to go short in supply ...it's a reputational thing as well".*
		Behavioural Uncertainty	*"As a manager of someone in a managerial capacity, you can create drug shortages by panic buying. If you hear that there is a shortage is likely to occur, the first instance some people will do is the need to get plenty of that product when it is still available, then demand goes up ...One of the dilemmas you are trying to manage. Is how much information can you give people".*
	Control of Price Flow	Price Manipulation	*"A drug used to be on the market selling for maybe £3 to £4, I can't remember exactly. Amacol bought the license for this drug, removed it from the market for about six months and sort of created havoc rereleased it back onto the market with an inflated price of about £20. And that's the other aspect, so we have got that manipulation".*
Conflict	**Partners' Satisfaction**	Misalignment of goals	*"There is a debate as to understanding the role of pharmacy, additional service to patients or make profit... certainly the more money you take from the pharmacy.... community pharmacy is not about making money whereas for the multiples it's about profit not about service".*

			"Because all these are individual businesses, and all reacting to their own individual strings and pressures and needs at that time."
		Trust	*"For instance, the direct to the patient model where the manufacturer supplies directly to the patient is not actually practical as it tends to cause more issues, if something goes wrong, there is no resilience."*
		Asymmetric relationships	*"Drug shortages occur because somebody else in the chain is making a profit by locking these items, or increasing prices, or stopping them from coming into the country*".
Supply Chain Complexity	**Product Characteristics and Production Process**	Production lead time	*"The drugs we predominantly sell are not the type of drugs like other products. It must be like diabetes, heart failure …… We manufacture based on patient prescription numbers which are not quite straight forward. I would say the manufacturing of pharmaceuticals is quite a long process. It is a complex release process. There are certain things that need to take place. It's not a quick process".*
	Political and Economic Uncertainties	Brexit	*''Let say BREXIT… because the wholesalers play a major part in the supply chain. If at the moment they are importing products from other countries and we are not aware of that, if we are not able to do that pre-Brexit then we will find that demand for products in the UK will increase and we might not have forecasted the market".*
		Parallel trade	*Other problems will be related to parallel trade, using an example where there is a product which is an eye care product and 10% of the sales of the product are the UK taxed which we distribute, 90% are products that are imported into the UK. The parallel importers for whatever reason had problems with getting hold of the products and so suddenly we were faced with an increase in demand of 10 times what the normal demand was. On an average, we would have 1.5 to 2 months of stock so very quickly we ran out of stock for that product and there was a gap between 6 to 8 weeks before we were in a position to supply".*
		Mergers and Acquisition	*"In the last few years, a lot of big manufactures have merged together so there is less variance, less competition, so if there is manufacturing problem that hits the supply chain a little harder".*
	Regulations	Ethical framework	*"For instance, a lot of drug shortages around Europe have been caused by the constant change in regulatory bodies. The FDA going to manufacturers saying the standards have changed. For manufacturers to meet up with these requirements, they must disrupt their manufacturing process"*
		Price	*"The trouble is, for instance, if this is June; they don't normally accrue till the end of June. So,*

		reimbursement	*you have dispensed all though June those prescriptions let's say Lamotrine. Sometimes you must go all through your prescriptions, take them out and send them in July so you get the higher price otherwise they will charge you at the old price. So, it's very difficult for us, more work for us".*
Recovery strategies	**Flexibility**	Alternative volume	*"So what happened with that was that you may have decided 100mg may have gone out of stock originally so you double up with 50mg and everyone was doing that it took a good three or four weeks for things to settle down because people were trying to make do with whatever ".*
		Alternative form	*"A coping strategy might be to use syrup instead of a tablet, or strength of tablet rather than the strength that is out of stock or a non-sustained release rather than a sustain release. For example, we had a long-standing problem with diamorphine injection we had to get people to switch to morphine".*
		Alternative supplier	*"I occasionally have to buy from the main short-line if I get something; I pay over tariffs to make sure I have supplies for my patients".*
	Visibility	Information visibility	*Obviously, we had to communicate to the customer to tell them what the situation was especially if the disruption was going to last longer".*
	Joint Decision Making	Joint planning	*"We would have a local meeting to discuss the situation, a local meeting within the stakeholders across our business, so our regulatory colleagues, our quality colleagues supply chain and also our communication with colleagues as well".*
Resistance Strategies	**Resource sharing**	Technology	*"It's not effective for each trust to be doing the same thing. NHS trust is spending time. It should be done centrally. Some sort of central resource like they have in the US is a good example. Foster information sharing. It's about developing a centralized resource to help manage the shortage which people can find. You could share the information that will be a low cost of it".*
		Strategic alliance	*"Because of our alliance with bigger firms, our buying is better. The company we buy from tend to build bulk order in advance; a lot of smaller independents really struggle for stock we recover more quickly because we tend to hold on to stock longer than other people would have."*
		Buffer stock	*"We also have a safety stock based on historical demand. We build at least three months of safety stock."*

4.1 Vulnerability Drivers

4.1.1 Supply Chain Power

According to our findings, power dynamics increased vulnerability in the PSC. Three instances that depicted the presence of power were: control of drug flow; control of information, and price control. A summary of power as an SCV is presented in Figure 3.

The findings indicated that SC actors, controlled drug flow using the quota system, to protect their revenue stream and to ensure patients' treatment continuity. The quota system involved rationing of drug allocation or withholding products from SC actors until scanned copies of patients' prescriptions were received. Since some SC actors were perceived to be selling their excess drugs abroad for profit, manufacturers of the product faced revenue losses and imposed the quotas. Also, to ensure there were sufficient supplies for patients to remain on medications throughout the disruptions, restrictions on product distribution was imposed.

Information control within the PSC was to protect the reputation of SC actors and avoid behavioural uncertainty such as panic buying. Thus, some SC actors were hesitant to divulge information about disruption because they feared news about their situation might affect reputation and market share. Besides, supply chain actors indicated that they were uncertain about the reaction of their supply chain partners when they received information about a disruption.

The data also revealed that some SC actors were perceived to control prices in the PSC. The control of prices began by creating artificial demand for some products and then reintroducing these products into the market for profit. These scenarios were prevalent in instances when the SC partner had not reached their sales target. As such, product prices could be manipulated by SC partners who had the power over the prices and products within the SC.

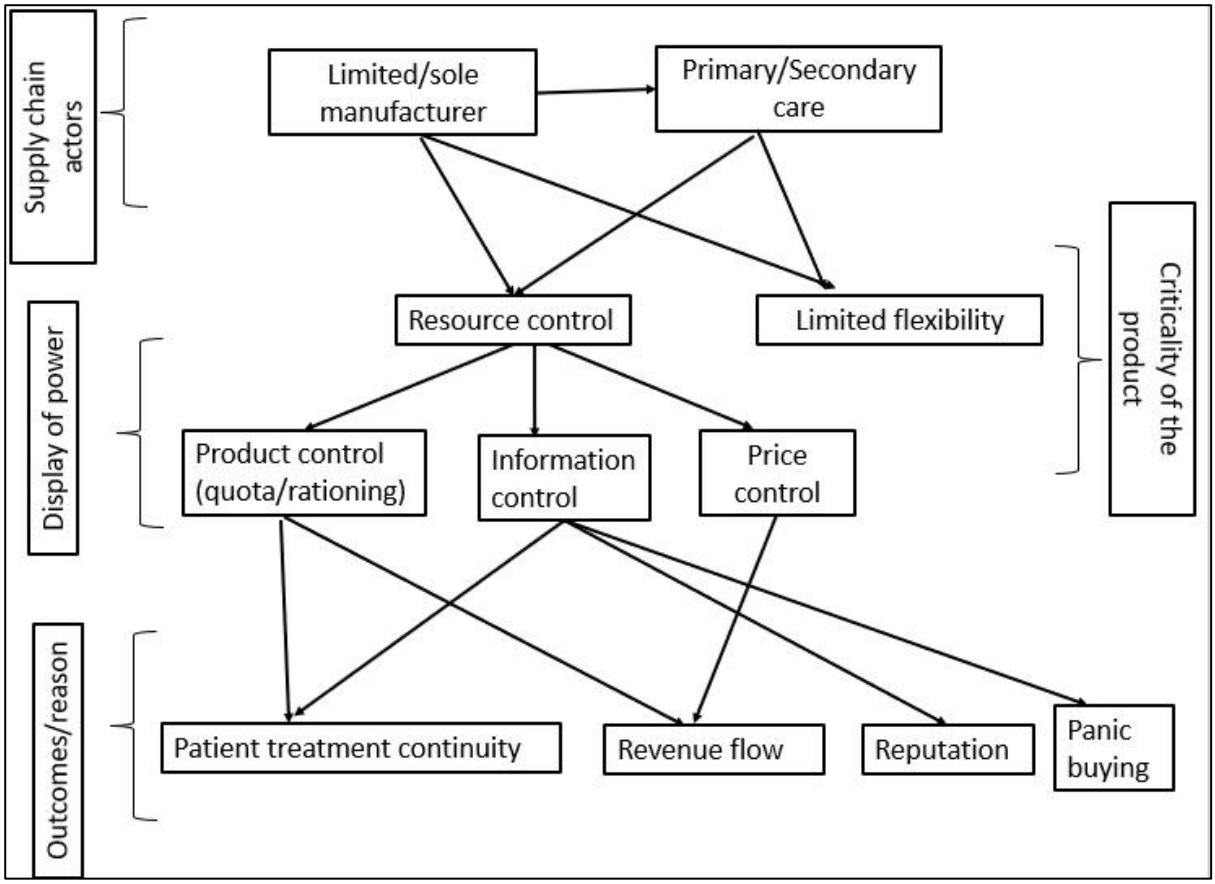


Figure 3. Power as a vulnerability in the PSC

4.1.2 Supply chain conflict

Our findings indicated that the absence of trust, misalignment of organisational goals and the asymmetric relationship within a SC created conflict. The inability of SC actors to audit the behaviours of their partners and/or in some instances, evaluate the quality of resources brought to the SC affects the level of trust. The absence of trust thus reduces SC partners' satisfaction and creates conflict within the PSC.

Misalignment of the goals of SC partners also increased the incidences of conflict. For instance, using tenders, the NHS's objective was to supply drugs to patients at the minimum possible price. Manufacturers producing branded products who could not compete favourably for lower prices with the tender system sought alternative markets or in extreme cases ceased production. Thus the tender system can drive suppliers out of the market, and this increases SCV.

Another indicator of SC conflict was the presence of asymmetric relationships amongst SC partners, and this affected the level of partners' satisfaction among SC actors. Asymmetric

relationships emanated from the amount of control the manufacturer and the regulatory bodies had over material and information in the SC. These dominant activities bred asymmetric relationships that led to conflict and partner dissatisfaction and increased SCV.

4.1.3 Supply Chain Complexity

Complexity within PSC were also deemed pertinent as a vulnerability driver in this study. Antecedents of PSC complexity included product/process characteristics, regulations, economic and political issues.

Our findings showed that the product and production process characteristics were SCV drivers. These SCV drivers included production lead times, product composition, scarcity of alternatives, storage and distribution process as well as the product life cycle. The responses from the interviews identified that for pharmaceutical products to be effective, they had to be the right product, taken in the right dosage, strength and at the right time. For production lead times, the findings indicated that pharmaceutical products differed significantly from other products as manufacturing usually took about eight to twelve weeks. Product and production processes of pharmaceutical products were usually subject to the specificity of the product, manufacturing complexity and stringent regulations. These complexity made it difficult for SC actors to respond timely during a disruption and a such exposed the SC to the impact.

Economic and political issues were also identified as elements of complexity within the PSC. Uncertainties related to these led to issues such as stockpiling. Mergers and acquisitions were also an economic issue that added complexity to PSC. The respondents indicated that the processes of big pharmaceutical companies who had products coming off patent merging with smaller pharmaceutical firms usually created monopolistic behaviours which were detrimental to the PSC. Another example of economic uncertainty was the issue of parallel trade. The findings showed that although trading of pharmaceutical products within the European Union was legal, SC actors took advantage of the weakening British pound against the Euro to make profits. The whole movement of pharmaceutical products across borders confused demand signals and caused chaos when inadequately managed.

4.2 Resilience Strategies

Two forms of resilience strategies emerged from the data and were classified as either 1) recovery or 2) resistance strategies. For recovery strategies, the data revealed that several measures that PSC actors employed in mitigating the impact of disruptions were strategies that facilitated the 'return to normal operations' of the SC; hence the term 'recovery'. These recovery strategies included flexibility, visibility and joint decision making. Regarding flexibility, the data indicated that two forms of flexibility were used in recovering from a dynamic disruption. These were flexibility relating to the form and or/volume of medicines flexibility and supplier /logistic flexibility. For form/volume flexibility, the respondents explained that to recover from a disruptive activity, using products that had similar strengths, or a suitable clinical alternative at the right dosage or available combinations of products were the viable options for patients' treatment continuity. Flexibility was particularly relevant depending on the product the disruption had affected. Supplier logistics entailed seeking a new supplier.

Visibility through information sharing within the SC was identified as an effective strategy used in recovering from a disruption in this study. Information sharing here was concerned with the flow of stock and demand levels. For example, primary care respondents said they were able to closely monitor product flow from their suppliers through an online database, and when the stock level was on red, it was an indication that there was a problem with products which required further inventory planning.

The findings from the interviews also suggests that in the event of disruptive activity, joint decision making had a positive impact. Jointly planning strategies with SC partners helped all SC actors to restrict the negative impact on patients' treatment continuity as well as maintaining operations. On the matter of maintaining operations, one of the manufacturers proved that joint planning was valuable as all stakeholders jointly developed strategies on how to tackle the impending disruption. It involved meetings to inform SC actors about the disruption and its duration. They jointly decided the best possible course of action, and this was carried out to prevent operational as well as financial losses and potentially the death of patients. The decision-making involved the stakeholders attending to various aspects of the SC.

The regulatory bodies acted as intermediaries between competitors to see if production could be ramped up to meet demand, as it was against competition laws for manufacturers to

discuss this directly with other manufacturers. The Commercial Medicines Unit (CMU) and the Department of Health and Social Care (DHSC) had conversations with secondary care pharmacists to determine how to recover from the disruption. These recovery strategies were either through sourcing alternatives products, rationing, importing from abroad or manufacturing within the NHS production plant.

For resistance strategies, the data analysis showed that through the sharing of resources with SC partners, the PSC was able to plan and prepare for disruptions. This sharing of resources was only feasible when strategic alliances had been formed which enabled actors share timely information, infrastructure and technology. As such, SC actors were able to pre-plan for disruption and curtail its impact. A community pharmacist that engaged in strategic alliance practices explained that their suppliers usually provided up to date information about pending disruptions as well as provision of the infrastructure to stockpile. This strategy is in contrast with the 'just in time' practices that are in existence with independent SC actors.

Our findings highlight that it was challenging to explain SCV and resilience strategies separately as some of the decisions that depicted vulnerabilities were actually strategies used to achieve market share by some of the SC actors. For instance, the manufacturers reported that they controlled the flow of medicines in the SC to ensure the flow of their revenue stream. This action was perceived as a vulnerability by other SC actors as it hampered adequate planning and further compounded the impact of disruptions. The findings also revealed that some SC actors adopted decisions based on the characteristics of the entire PSC. For instance, some pharmacists chose not to stock some product because of the pricing regulation involved in reimbursement. Pricing reimbursement is standard practice in this PSC.

The underlying argument here is that, although the findings attempted to categorise vulnerabilities and resilience strategies separately, there was evidence to confirm the relationship between vulnerabilities and antecedents of SC resilience. These relationships may sometimes lead to outcomes such as flexibility and/or power asymmetry as a result of misalignment of goals. These relationships depict non-linearity as a fundamental element of a CAS. The next section, therefore, discusses the findings using CAS as a framework for explaining PSC resilience.

5. Discussions on Building Pharmaceutical Supply Chain Resilience

Our findings have provided evidence to suggest that advancing our understanding of PSC resilience can be explained effectively by adopting the CAS lens and its key components: internal, external and co-evolution. This implies that vulnerabilities and resilience strategies are all interconnected in the building of resilience in the PSC.

5.1 Supply Chain Vulnerabilities

The findings established that the presence of power, conflicts and complexity increased the PSC susceptibility to the impact of medicine shortages as a dynamic disruption. With regards to power, the ability of SC actors to control the basic tenets of the SC product, information and price depicts the presence of power asymmetry (Benton and Maloni, 2005, Bandara et al., 2017). The findings revealed that SC actors, controlled the flow of drugs using a quota system, controlled information and prices. The control of drug flow through the PSC, however, hampered SC actors' ability to plan for disruption, thus increasing the susceptibility of the PSC (Tukamuhabwa et al., 2015; Hendry et al., 2019). Although the presence of power asymmetry was to ensure the efficiency of operations and financial performance of their firms, it ultimately increased SCV.

From the findings we see that the divergent organisational goals of SC actors increased the incidences of conflicts, and this increased the vulnerability of this service SC. A careful examination of the data revealed that not all actors in the PSC engaged in business activities to make a profit, and these differences created conflict. Factors signalling misalignment of goals in the study included: NHS strategy through the tender system, service orientation of the pharmacists and profit margin goals for manufacturers. These activities may lead to decreased efficiency and diminished services in the SC. Also, the differences in organisational goals created conflict and made it difficult for SC actors to collaborate in order to strengthen the PSC as asserted by Lundin and Norman (2010).

The absence of trust reduced SC partners' satisfaction and as such increased the potential for conflict within the PSC according to the findings. The presence of trust is pivotal for sharing information between SC partners (Barratt and Oke, 2007). However, as a result of the absence of trust, which was evidently absent among actors in the PSC, information sharing was limited; this increased SCV SC actors were unable plan and or respond promptly.

Complexity was also identified as a driver of vulnerability in the PSC and aligns with other researchers that have highlighted complexity as an impediment to the operational and financial performance of SCs (Craighead et al., 2007). There were also interrelationships between the vulnerability drivers. For instance, although the display of power emerged as a result of revenue flow, behavioural uncertainty and reputation. Another underlying issue was as a result of the absence of trust, which inadvertently increased SC conflict. Also, the display of power may further increase uncertainties like those related to economic and/or political issues.

5.2 Supply Chain Resilience

Recovery and resistance strategies were the primary mechanisms that enhanced resilience in the PSC according to the findings in this study which aligns with existing literature (e.g. Blackhurst et al., 2011; Scholten et al., 2019). Flexibility, visibility and joint decision-making were the antecedents for recovery strategy while strategic alliance was employed as a resistance strategy.

According to our findings, in the PSC, flexible operations consisted of the ability of SC actors to employ alternative forms of treatment in the right dosage, volume or form to ensure the continuity of patient treatment. However, this strategy was used after a disruption had occurred by patient-facing SC actors to enable them to respond quickly to patients' demands. Thus, flexibility in the PSC may be a temporary departure from practice as a short-term solution and may not be sustainable as argued by Fayezi et al., (2017).

SC visibility is referred to as the ability to access viable (timely, accurate and purposeful) information, which provides a reliable description of supply and demand (Wei and Wang, 2010). Our findings indicated that the timing and quality of information shared were pertinent for building recovery mechanisms in the PSC. Information quality was measured by the ability of SC actors to state the cause and length of the disruption as well as other useful information, such as the availability of alternatives (Brandon-Jones et al., 2014) and (Scholten and Schilder, 2015). The reaction of stakeholders to information shared on impending SC disruptions, however, restricted the type of information SC actors shared, which reduced visibility and increased SCV (Juttner and Maklan, 2011). For instance, the findings showed that sharing information about a disruption triggered panic buying which led

to further disruptions. This argument thus provides possible explanations for the reluctance of SC partners to share information regarding disruptive activities.

Our findings indicated that joint decision making as a recovery mechanism contributed to building resilience in the PSC. The success of the joint decision-making process in this study, stemmed from relationships that had been built among SC partners over the years, as asserted by Li et al., (2015). Thus, to successfully agree on mutually defined goals, reduce operating costs and encourage better use of external resources, relationships had to be developed. The joint decision-making strategy adopted by actors in the PSC is, however, a recovery mechanism which differs from existing literature where coordination of decisions is a proactive, collaborative process (Scholten et al., 2019).

The findings showed that resistance strategies provided SC actors with the capacity to prepare for disruption. Resistance strategies were developed by forming strategic alliances and this involved sharing of infrastructure and stockpiling (holding buffer stock with SC partners). Strategic alliance in the PSC was successful among SC partners who had closely linked goals, and it involved independent tasks from each SC actor. In this arrangement, manufacturers formed strategic alliances with wholesalers as well as community pharmacists in the SC, where the wholesalers engaged in the warehousing and transportation of the manufacturer's products and the pharmacists aided in the distribution of manufacturers' products at the community level. Strategic alliance here increased visibility, information sharing and facilitated decision-making. SC actors were, therefore, able to mitigate the impact of disruption by forming strategic alliances, as explained by (Minerbo et al., 2018). Thus, strategic alliances were critical in building resilience strategies in service SCs such as PSC.

5.3 Understanding PSCR as a CAS

Using CAS theory, we describe how the interactions between SC actors, build SC resilience at a systemic level.

First, our findings indicated that the PSC is an open system that interacts with its environment and these interactions influence the ability of the PSC to develop resilience strategies (Nair and Reed- Tsochas, 2019). For instance, in the event of a disruption, the manufacturer

responds to this disruption by sharing timely information with other SC actors. The sharing of information provides SC actors with the ability to plan and prepare for the disruption and as such, makes the PSC more resilient to the impact of disruption (Tukamuhabwa et al. 2015). However, controlling of information about disruption increases the susceptibility of the PSC vulnerable. Also, in responding to parallel trade in the environment, some wholesalers and pharmacists decide to sell abroad for profit, especially when the exchange rate is favourable. Manufacturers impose quota systems to reduce parallel trading and to control their revenue flow. Thus, the decision-making process by SC actors in responding to the environment builds resilience strategies or drives SCV.

Our results also reflected that SC actors act independently and are primarily guided by internalised goals (Nair and Reed-Tsochas, 2019). Participants in our study indicated that they had diverse goals. The goal of the NHS was to provide quality medicines at the lowest possible cost. The community pharmacists indicated that their goal was service-oriented; seeking patient safety, and the manufacturers identified making a profit as their internalised goal. These internalised goals provided SC actors with reference points for their behaviour. For instance, since the goal of the manufacturer was to make a profit, their inability to compete favourably for tenders by the NHS forced them to seek profits in other markets and thus increased vulnerabilities in the PSC. When their goals were strategically aligned, as seen in the case of a strategic alliance among SC actors, they developed resilience to disruptions.

Since internal goals guide SC actors, their interactions produce non-linear dynamics as in a CAS system (Choi et al., 2001; Holland, 2006). In this study, an example of non-linear interactions is conflict. For instance, pharmacists explained that they wanted to ensure patients continued their treatment and as such stockpiled products. Manufacturers also introduced quotas to control their revenue stream. The outcome of these interactions produced elements of conflicts such as the absence of trust and asymmetric relationships and made the PSC vulnerable to the impact of disruptions.

Interactions between SC actors also produced new behaviours. These learned behaviours emanated from past interactions between SC actors. Our findings showed that as a result of manufacturers sharing information about a disruption, this led to stockpiling, thus creating false demand and manufacturers decided to display their power. Also, SC actors' decision to jointly share resources to increase visibility and flexibility depicts strategic alliances are

formed as a new behaviour. SC actors, thus, learned from these past actions to make new decisions when disruptions occured, which caused the SC to evolve.

Figure 4 portrays PSC resilience as a CAS, which includes the internal environment and the external environment. The underlying processes involved in developing resilience in the PSC stem from SC actors' interactions with each other given underlying PSC characteristics in responding to their external environment. The outcome of these interactions either build resilience into the PSC or increase SCV.

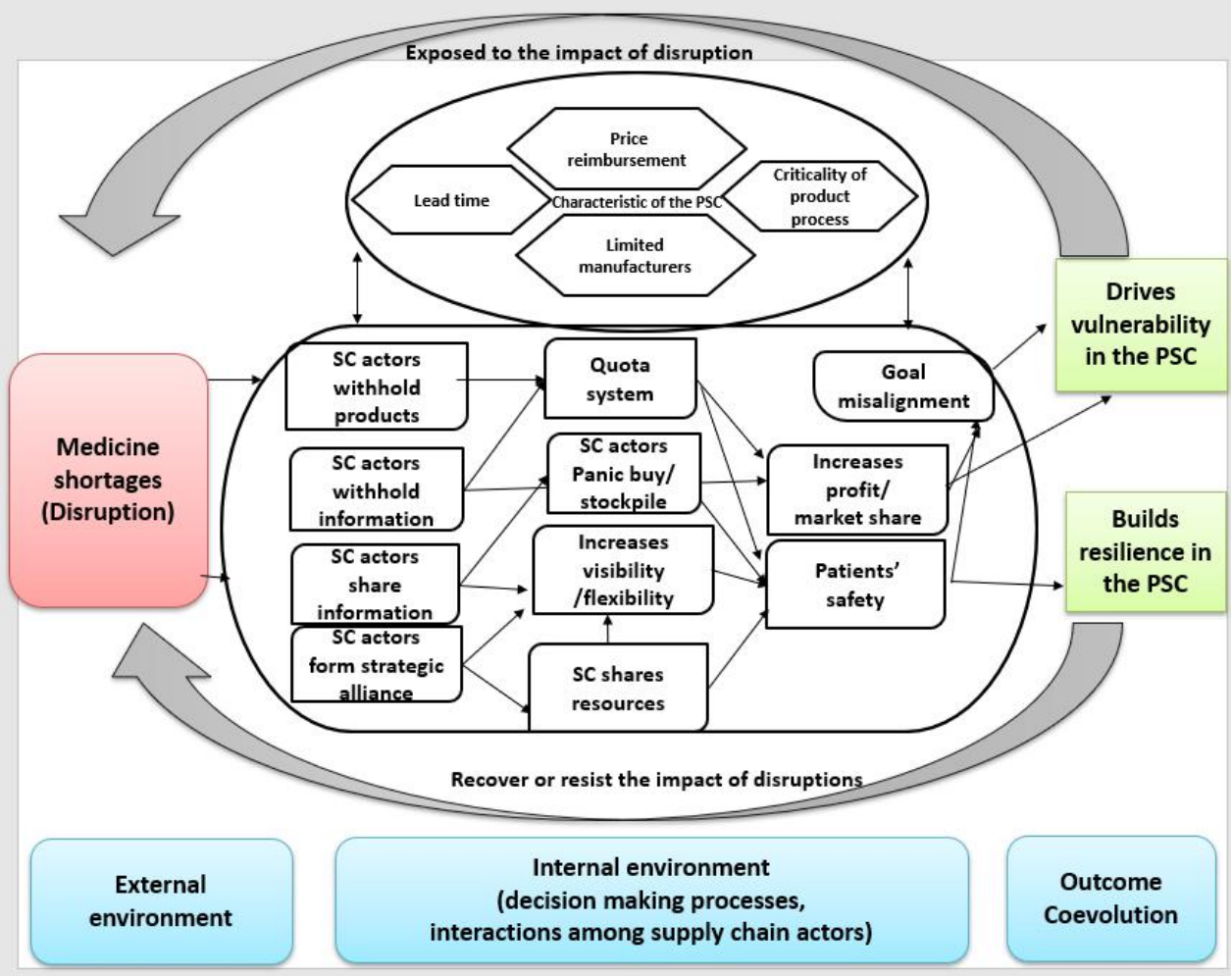


Figure 4. Supply chain actors' decision-making process.

6. Conclusions

This study aimed to advance our knowledge of PSC resilience using CAS theory. In order to achieve the research objective, the study explored why the PSC was susceptible to the impact

of disruptions and considered how resilience strategies had been employed to reduce the impact of disruptions in the PSC using CAS theory as a medium for further exploration.

Our study found that the presence of power, conflict and complexity within the PSC increased SCV. Resilience strategies were developed by increasing flexibility, visibility, joint decision making and strategic alliances in the SC. The findings also demonstrated that understanding and developing resilience in this service SC involved adopting a systemic approach that included disruptions, vulnerabilities and resilience strategies. This is in line with CAS theory which advocates a holistic approach to understanding a system rather than parts of the whole (Day, 2014; Nair and Reed-Tsochas, 2019). Through the CAS lens, therefore, it can be seen that the outcomes of these resilience strategies stem from the vertical interactions of SC actors in response to their environment. Thus, resilience in the PSC as a complex system is based on its existing internal mechanisms and its reaction to external mechanisms.

6.1 Research Contributions

In this study, we argue that recognising PSCR as a complex system is an essential step in designing the PSC that can advance the services of this SC. Proponents of CAS theory (Choi, 2001; Day, 2014; Tukamuhabwa et al., 2015) hitherto have not emphasised the importance of vertical collaboration and the decision-making processes of SC actors whilst simultaneously adapting to changes in the external environment. This study, therefore, extends the CAS theory by providing explanations as to how SC actors interact to develop resilience to the impact of disruptions. The findings also extend existing SCV literature by identifying the presence of power as a vulnerability driver which has not been previously recognised.

6.2 Areas for Further Research

The limitations identified in this study could be targeted as avenues for further research.

First, the exploratory nature of the study inhibited examining underlying vulnerabilities and resilience strategies from various vantage points. Examining PSCR for specific medicines within the PSC like orphan drugs to see if their SC differs woul be advantageous. Secondly, prioritisation tools such as the Multiple Criteria Decision Making (MSDM) could be used to develop vulnerability tools in assessing suppliers' tendering capacity and the selection of partners for strategic alliances. Thirdly, whilst this study did advance the understanding of the

PSC as a service SC utilising CAS theory, it did not measure the starting and endpoints for PSCR strategies. As such, future studies in this area should examine at what point SC actors develop resistance strategies in time to combat disruptions within the SC. Finally this study focused on the UK PSC, which comprised of manufacturers, wholesalers, primary care, secondary care, and regulatory bodies. Future studies should include other SC actors like; packaging, labelling, and parallel trading firms to provide a broader insight into PSC resilience and similar studies in other parts of the world would provide a useful comparison

6.2 Recommendations

The findings from this study can aid SC actors in the planning and preparation for SC disruptions. It validates the pursuit of understanding the interactions and decision-making processes of key SC actors as a critical driver of resilience in the PSC. The finding can also provide managers with insights into investment decisions regarding the best resilience tools to use. For instance, manufacturers can invest in visibility tools to facilitate the sharing of information and increase traceability of products which will significantly reduce the impact of disruptions and further advance the services of the PSC

This study has focused on medicines unavailability, which is a fundamental issue in the PSC. The current COVID 19 has again raised awareness of the importance of this SC and its products. The history of medicines shortages highlights its fragility. It is for all these reasons that exploring complexity in this service SC is critical. Learnings from this study (approach, methodology and outcomes) apply to professionals in other complex service SCs such as humanitarian logistics, blood SCs, perishable food SCs and patients in healthcare SCs.

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Appendix

Section One

Date and time of interview
Name of Interviewee and Company
Type of Company
Area of responsibility
Years of experience on Job profile
Kindly provide a brief description of your supply chain position in terms of information and material flow.

Section Two

Supply Chain Disruptions

•Could you describe a time when your firm faced a delay in the supply of its goods to consumers. How long did the delay last? Why do you think it lasted as long as it did?
•How quickly did your firm discover this disruption or the event that may have triggered the disruption? Are there metrics available to detect early warning signals of a disruptive event?
•How quickly does your firm assess the impact of the disruption when a disruption is discovered? How does your firm efficiently assess what areas of the supply chain may be affected?
•What kind of barriers to an effective disruption recovery does your firm face?

Section Three

Supply Chain Vulnerabilities

• Could you explain the major features of the products you supply to your consumers and do you think any of these features amplify the effect of a disruptive activity?
•How would you describe your supply chain? Do you think any of these features amplify the impact of disruptive activities?
•Could you describe the role of your suppliers in the event of a disruptive activity? Do they have a role and if so what do they do at this point in time?
•How would you describe the effect of your managerial decisions on the supply chain in the face of a disruption?
•How would you describe the role of regulatory bodies in the supply of your goods to consumers?

Section Four

Supply Chain Resilience

•Could you explain the type of strategies your firm employs when preparing and responding to a disruption?
•What type of resources and process enablers are available to the firm to withstand the impact of a disruptive event?
•How would you describe the effect these strategies have in reducing the impact of a disruption? How would you describe your firm's competitive position with respect to the adoption of these strategies?
•How would you describe the process involved in getting information from the various stakeholders in the supply chain?
•What type of activities are in place that foster sharing of information between other firms of the supply chain?
•How would you describe your ability to source for goods on demand when faced with a disruptive activity? Are there readily available suppliers? What kind of hindrances do you encounter?
•How can the pharmaceutical supply chain be better prepared for a disruptive activity?