AN EVALUATION OF THE APPLICABILITY OF COMPLEX ADAPTIVE SYSTEM THEORY IN THE PHARMACEUTICAL SUPPLY CHAIN

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Abstract

Purpose: The aim of this research is to evaluate if the Complex Adaptive Systems theory can be used to explain resilience strategies within the pharmaceutical supply chain

Research Approach: An in depth review of literature surrounding resilience in the pharmaceutical supply chain. In order to pursue this study agenda, data was collected from Scopus, the largest peer review journal as well as EBSCOhost. The PRISMA guideline was adopted in the systematic review process where 34 peer reviewed papers in the field of CAS, supply chain and supply chain resilience were identified with respect to methodologies employed, location of the study and approaches.

Findings and Originality: The systematic review of literature shows that there are inherent similarities between the concept of resilience and the CAS theory. The CAS theory explains that PSC's are dynamic, have emergent behaviours complex, adaptive, interconnected as well as possess schemas that regulate their operations. Hence if resilience strategies are to be employed to mitigate disruptive events they need to be harnessed in a manner to fit this particular supply chain. This work is innovative as it provides a new insight into the contemporary discourse on resilience strategy creation and deployment, examining the use of this theory in the PSC, and thus provides original contribution.

Research Impact: This study contributes to the existing literature base, by providing theoretical underpinnings in the area of resilience and the pharmaceutical supply chain. This furthers the CAS agenda, SCR agenda and also presents an innovative output which warrants more detailed analysis and feasibility testing.

Practical Impact: Complexity principles are multi-scaled and multi-domain and as such the suggestions put forward in this theoretical framework can be adopted in various supply chain networks as well as disruptive events. It provides new insights with regards to structures for managers seeking to design and improve resilience supply chains, a key element of which is the adoption of a holistic analysis by SC managers when developing resilience strategies. This is critical if disruptions are to be identified and mitigated before their impact is felt.

1. Introduction

Recent trends in managerial practices, volatility in demand and globalization have resulted in businesses having longer and more complex supply chains (Blackhurst et al., 2011, Wagner and Neshat., 2012). These resultant features, have made supply chains more vulnerable to the impacts of disruptive activities, which have severe consequences on the operational and financial performance of the firm (Wagner and Bode, 2009; Schmidt and Raman, 2012). Resilience within the supply chain which entails that a firm has the ability to prepare, respond and recover from a disruptive event has been posited as a remedy for vulnerability (Ponomarov, 2012). This underlying notion stems from the proposition that disruptive events cannot be curbed and as such resilience is essential to mitigate the impact of these disruptions (Petitt et al., 2010; Juttner and Maklan, 2011).

Several theories have been employed to elucidate resilience as a phenomenon within the supply chain literature: Resource Based View (RBV) (Howleg and Pil, 2008; Blackhurst et al., 2011; Bellamy et al., 2015); Dynamic Capability Theory (Ponomarov, 2012); Systems theory (Erol et al., 2010; Speigeler et al., 2012). Some of these theories however remain inconclusive as some essential elements required in explaining what resilience entails are absent. For instance, the RBV/Dynamic Capabilities theory only focus on the internal workings of the firm and therefore masks the complexities involved in supply chains as well as resilience strategies (Tukamuhabwa, et al, 2015).

In view of the foregoing, this study proposes the Complex Adaptive System (CAS) view of the complexity theory by Holland, (1995) as suitable in explaining supply chain resilience. The purpose of this paper, therefore, is to critically assess the contributions of the Complex Adaptive System (CAS) theory in explaining the concept of resilience within the pharmaceutical supply chain. The next section presents the methodology used in reviewing the literature, while section three presents the findings which includes definition, historical background as well as the dimensions of the theory. The paper concludes in section four where the relevance of CAS is assessed as well as its shortcomings with respect to resilience strategies in the supply chain.

2. Methods

The main aim of this systematic review of literature is to identify previous studies that have explored CAS as a theory in explaining supply chain resilience. As such, this study adopts the five step guidelines for literature review processes highlighted by Denyer and Tranfield (2009), as well as the PRISMA guidelines (2009) which will aid in identifying, analysing, synthesizing, interpreting and reporting evidence from existing literature. This is geared at producing a systematic review that is explicit and can be reproduced (Hohenstein et al., 2015). The first step of the research was formulating the questions which were aimed at developing a focus for the review to avoid ambiguity (Denyer and Tranfield, 2009). The overall aim of this study is to explore the applicability of Complex Adaptive System (CAS) as a theoretical lens in explaining pharmaceutical supply chains resilience. As such the review seeks to understand two vital questions:

RQ1: What are the dimensions of CAS?

RQ2: Can CAS be used as a theoretical lens in explaining pharmaceutical supply chain resilience?

In seeking to reduce the bias that may occur in this study as well as cover a range of information sources, Scopus, EBSCOhost and Google Scholar were the major databases employed. In consonance with existing systematic management studies (Colicchia and Strozzi, 2012; Hohenstein et al., 2015), this review employed defined keywords in its search criteria. Here Complex Adaptive Systems/CAS combined with the phrase 'Supply Chain' and or' 'Resilience' in the article's abstract was used in the search process; this is based on the idea that, - the journal articles had to depict a clear link between CAS and supply chains or supply chain resilience. The analysis resulted in 45 preliminary articles. To certify that only high quality articles were adopted into the study, articles were limited to peer-reviewed journals as the peer review process is a quality indicator that assesses a study's conceptual and methodological rigor. As such, conference papers were excluded from the study. The review starts at 2001 because the first mention of CAS theory within a supply chain framework appeared then in Choi et al's paper in . After reading the abstracts, articles which seemed non-relevant to our study were excluded. The PRISMA checklist was used in arriving at the final papers employed in the review. Hence, 34 peer reviewed articles over a period of 16 years were identified as relevant to the study.

3. Findings

The study finds that the 34 papers employed in this study were published by 25 academic journals with *Journal of Operation Management* and *International Journal of Production Research* having the highest number of publications in 2013. The papers where then classified as either empirical articles or analytical research. Analytical papers are conceptual papers, mathematical papers or statistical papers. Empirical papers employ the uses of statistical techniques, case studies framework and or mixed methods. The study finds four empirical studies that had applied CAS theory in supply chains with their focus on the Automobile, Maritime and the Food industry. This calls for the need to examine resilience strategies, pharmaceutical supply chain and CAS theory.

Definition of CAS

CAS theory bears its roots in the complexity theory and has gained popularity in the social sciences such as; organizations studies. At the heart of Complexity theory are three basic concepts; self-organisation, emergence and interrelatedness that are developed on the works of previous system theories (Snyder, 2013). The Complex Adaptive Systems theory therefore proposes a higher level of interaction between components of a complex system with its distinguishing feature of adaptability.

A CAS is therefore defined as the ability of a system to reorganize its parts while adapting to the problems posed by interacting with its environment and evolving through a feedback mechanism (Choi et al., 2001; Holland, 1995). As such, a CAS must be able to distinguish itself from other systems as well as the ability to differentiate legitimate parts of its owners from evolving invaders without an obvious centrally controlled mechanism (Holland, 1995).

Dimensions of CAS

The study also finds 10 inherent characteristics of complex adaptive systems. Table 1 below presents the identified features, definitions and authors.

Table 1 Dimension of CAS and Corresponding Authors

Dimensions	Definitions	Authors
Adaptability	This implies that the agents of a system respond react and are sometimes proactive in its interactions with other agents or its environment.	Choi et al, 2001; Surana et al., 2005; Nilson and Darley, 2006; Pathak et al., Wycisk et al,2008; Ivanov, 2010; Hearnshaw and Wilson ,2011; Day, 2014;Aelker et al., 2013;Justice et al., 2016 Moncada et al.,2017.
Agents	This refers to the different components that make up a CAS. Agents may be individual or group of individuals within a system that operate at different levels.	Choi et al., 2001; Howleg and Pil, 2008; Wycisk et al., 2008; Ivanov et al.,2010; Kim et al., 2011; Carter et al., 2015; Nair et al., 2015; Tukamuhabwa et al., 2015.
Coevolution	Here a system learns new things that make it change and respond to the environment. These changes also affect the environment it operates in as such, affects other systems that exist within that environment.	Surana et al., 2005; Nilson and Darley, 2006; Pathalk et al., 2007; Wycisk et al, 2008; Mena et al., 2013 Day,2014; Tukamuhabwa et al., 2015.
Complexity	A CAS is made up of different agents that are interconnected and have feedback loop mechanism.	Choi et al,2001; Surana et al.., 2005; Nilson and Gammelgaad, 2012 ; Mu and Jia 2013; Carter et al., 2015; Justice et al., 2016
Dynamism	The ability of the system to continuously exchange information with its surroundings. It is dynamic as it changes and adapts to the situations that it encounters within its environment in order to achieve fitness. This may also cause a dynamic change in the whole system.	Surana et al.,2005; Nilson and Darley, 2006; Ivanov, 2010; Aelker et al., 2013; Bellamy et al., 2013; Hearnshaw and Wilson, 2013; Mu and Jia, 2013; Carter et al., 2015. Justice et al., 2016.
Dimensionality	This feature is defined as the level of freedom that each part has within a system. The presence of control restricts dimensionality.	Choi et al,2001; Nair et al., 2015; Tukamuhabwa, et al., 2015.

Non Linearity	Here, there is no consistent response between the cause of an event and the effect of that same event. It plays a role in the coevolution process. This implies that an extreme event may yield an inexplicable effect and does not depend on the nature and degree of connections of the agents within that system. It is in the process of responding to the effect of non-linearity that coevolution takes place.	Surana et al., 2005; MCarthy,et al., 2006; Nilson and Darley, 2006; Wycisk et al., 2008; Nilson and Gammelgaad, 2012; Bellamy et al.,2013; Nair et al., 2015; Tukamuhabwa et al., 2015; Sun et al., 2016; Rodewald et al., 2016.
Non Random Future	Common pattern of behaviours are exhibited /future cannot be predicted but some patterns can be identified.	Nilson and Darley, 2006; Aelker et al., 2013.
Self-Organization and Emergent Behaviour	Self-organization and emergence refer to the collective effects and behaviours of the decisions and actions of individual agents in a CAS that can cause changes. These changes may include creating of new structures and patterns and are viewed as a whole.	Choi et al,2001; Surana et al,2005; Nilson and Darley,2006; Pathak et al, 2007; Howleg and Pil, 2008; Hearnshaw and Wilson, 2011; Nilson and Gammelgaad, 2012; Bellamy et al., 2013; Mena et al., 2013; Carter et al., 2015; Sun et al., 2017
Schema	These are *order-generating rules* which determine how the agents and the system as a whole respond throughout an adaptation process. This implies that to provide for adaption, the system ought to make provision for changing rules as it interacts with each other and with its environment.	Pathak et al., 2007; Howleg and Pil, 2008; Nair et al., 2015.

The elements of CAS theory have been defined in Table 1 above these are: Adaptation, Agents, Complexity, Dynamism, Dimensionality, Non-Linearity, Non-random future, Self-Organization and Schema. The applicability of CAS to resilience strategies in the Pharmaceutical supply chain will be highlighted in the next section.

4. Contribution of CAS Theory to Supply Chain and Supply Chain Resilience

Characteristics of CAS	CAS and Pharmaceutical Supply Chains	CAS and Resilience Strategies
Adaptability	For CAS theory, adaptation implies the ability of a system to be flexible, reactive as well as proactive (Choi et al., 2001; Nilson and Darley, 206). In responding to changes in an environment, such as;- new regulations, change in consumer lifestyle, disruptive activities the pharmaceutical supply chain will have to adapt to meet up with consumers demand as well as remain competitive.	As a phenomenon in supply chain literature, resilience entails that supply chains have the ability to adapt to given changes such as threats and innovation (Ponomarov and Holcomb,2009; Ponomarov, 2012; Hearnshaw and Wilson; 2013).
Coevolution	Supply chains demonstrate coevolution features as government policies, disruptions and economic environment changes, the firms within the supply chain respond to these changes, which may in turn affect the environment they operate. For instance, if consumers demand for a product changes, the	Resilience strategies within the supply chain emanates for the combined interfaces with different firms as they apply schema to increase the chances of survival (Day,2014).

	supply chain will have to respond to this demand by changing its strategies, the process of responding is what is referred to as coevolution (Nislon and Gammelgaad, 2012; Mena et al., 2013).	
Complexity	CAS highlights the complexities within a system that arise as a result of the agents trying to adapt to changes in the environment. Drawing on this, the CAS provides explanations as to multi-party behaviours in a pharmaceutical supply network (Mena et al., 2013).	Resilience strategies are developed to mitigate the vulnerabilities within a supply chain, of which complexity is one of it (Petitt et al., 2010Juttner and Maklan, 2011). As such; By providing in-depth analysis of the fact that pharmaceutical supply chains are complex , provides understanding of the nature of the supply chain and how to situate resilience strategies like agility (Surana, et al, 2005; Pathak et al., 2007).
Dynamism	A supply chain is dynamic as it changes itself to adapt to the changes within its environment. For instance it may change its suppliers if the demand from consumers becomes volatile.	CAS theory provides explanation that disruptions and threats within the supply chain occur as a result of the dynamic environment in which they operate. Resilience strategies are dynamic in nature and involve adaptation to both internal and external threats (Tukamuhabwa et al., 2015).
Dimensionality	Modern supply networks, exhibit certain levels of freedom as a result of globalization and outsourcing. This has given room to dimensionality within the supply chain.	Resilience strategies provide the basis for firms within the supply chain to respond to events. The CAS theory has provided insights to dimensionality within the supply chain. Individual firms within the supply chain have freedom to make certain decisions that may affect its performance and the performance of other agents within the system.
Non Linearity	The supply chain and its resilience strategies are non-linear, as small strategic changes or disruptive impact in the upstream sector of the supply chain may have massive effects on the rest of the supply chain (Surana et al., 2005; Mu and Jai, 2013). Nonlinearity in the supply chain can be seen in the case of the bullwhip effect where small disruptive impact on of the agents in the upstream sector can lead to oscillating impact for the whole supply chain.	Resilience strategies have to be non –linear to respond to environmental changes. The non-linear feature of a CAS provides explanations to issues like bullwhip effects. It therefore entails agility and flexibility (Aelker et al., 2013).

Self-Organization and Emergent Behaviour	Since there is no centralized control, each agent controls its activities. The interaction of these activities produces emergent behaviours. In the context of supply chain network, there is no single large firm that controls or organizes the entire supply chain. However, each firm in trying to achieve its goals, control and organizes its activities. The interaction and interconnectedness of these firms produces a collective behaviour – meeting the demand of the consumer.	Resilience strategies are a feature of a supply chain as it entails self-organized processes of different that facilitate adaptation. No single supply chain controls resilience strategies as resilience may differ from firm to firm. However the collective interactions of these firms produce are termed emergent behaviours. Choi et al,2001;Surana et al,2005; Howleg and Pil, 2008; Bellamy et al 2013; Mena et al., 2013; Carter et al., 2015; Sun et al., 2017
Schema	Suppliers, wholesalers, distributors are agents within the supply chain and they operate at different levels. They have different sets of rules guiding them and they all strive to take actions that are most beneficial to them (Choi et al., 2001; Pathak et al., 2007; Kim et al., 2010).	Resilience strategies may be Schemas which will enable firms within the supply chain modify their operations to achieve their goals.

Table 2 above provides tabular representation of the link between CAS features, the pharmaceutical supply chain and resilience strategies. Thus Adaptability, Coevolution, Complexity, Dynamism Dimensionality, emergent behaviours and Schema have been highlighted as traits that can be explored within resilience strategies.

5. Discussions

The systematic review of literature shows that there are inherent similarities between the concept of resilience strategies and the CAS theory. For instance the theory elucidates adaptability and dynamism as inherent features which provide explanations for the dynamic and adaptable nature of resilience strategies**.** The CAS theory also explains that PSC's are dynamic, have emergent behaviours complex, adaptive, interconnected as well as possess schemas that regulate their operations. Hence if resilience strategies are to be employed to mitigate disruptive events they need to be harnessed in a manner to fit this particular supply chain. Some implications for adopting the CAS theory include the fact that some of its features such as non-linearity may provide possible predictions of risk, disruptions or policies within a supply chain. Also by employing CAS theory, the unit of analysis should be the supply chain as a system and not individual firms (Tukamuhabwa et al., 2015). This work is innovative as it provides a new insight into the contemporary discourse on resilience strategy creation and deployment, examining the use of this theory in the PSC, and thus provides original contribution.

5. Conclusion

This study employed a systematic review of literature to examine the dimensions of CAS theory and its applicability to resilience strategies within pharmaceutical supply chain. The underlying idea here is that resilience strategies deal with high level of abstractions concerning business environments. As such, businesses can gain competitive advantage from their complex interactions with their environment. The study finds ten elements of the CAS theory where each of them can be employed in understanding various facets of how supply chains operate as well as its applicability to resilience strategies within the pharmaceutical supply chain. The study also finds that there is a dearth in empirical application of this theory and calls for further research into employing it as a theory in resilience strategy studies.

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