CREATING SUPPLY CHAIN RESILIENCE WITH INFORMATION COMMUNICATION TECHNOLOGY

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Supply chain resilience refers to the capability of a supply chain to both withstand and adapt to unexpected disturbances. In today's turbulent business environment, firms are continually seeking to create more resilience within their supply chain through increased information communication technology use and enhanced business-to-business relationships. The focus of this dissertation is the investigation of how information communication technology creates resilience at the differing process levels of supply chain operations. Past research into information communication technology use within supply chains has often been conducted at the macro-level of supply chain phenomena. As such, there is still much to understand about how decision-makers interact with information communication technology at the micro-level of supply chain decision-making. A more in-depth, broad coverage of this interaction will provide both practitioners and academics a better understanding of how to leverage information communication technology in achieving supply chain resilience. To meet this aim, this dissertation contains three essays that re-orient conceptual thinking about supply chain phenomenon, explore how advances in information communication technology influence business-to-business relationships, and identify how information communication technology effects the decision-making of supply chain managers.

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The views expressed in this dissertation are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense or the U.S. Government.

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INTRODUCTION

The ability of a supply chain to maintain continuity of operations under variant conditions is increasingly being posited as competitive advantage (Hohenstein, Feisel, Hartmann, & Giunipero, 2015; Pettit, Croxton, & Fiksel, 2013; Ponomarov & Holcomb, 2009). In today's competitive markets, firms are continually turning to information communication technology as a panacea against disruptions within their operations and supporting supply chains. According to industry forecasts, expenditures on supply chain management software will increase 11 percent to $13 billion through firms seeking to leverage emerging information technology solutions that offer more flexible and affordable strategies in managing supply chain operations (van der Meulen & Forni, 2017). As more firms seek out the latest, innovative information technology solution they are realizing that to achieve success, however defined, the behaviors and skills of people within their organization must be compatible with the chosen technology. As recent as this past year, practitioner journals report 33 percent of firms cancelling an information technology project sought out as a competitive strategy and 28 percent of firms describing their implementation as a failure due to a disequilibrium between the chosen technology solution and the skills of their organization (Tait, 2017). Hence, there exists a need for supply chain scholars and practitioners to better understand how the interaction of information communication technology and human behavior drive the macro-level behavior of a supply chain. Under a unifying theme of supply chain resilience, the purpose of this three-essay dissertation is to extend extant scholarship on the sociotechnical aspects of a supply chain and investigate the influence that information communication technology has on the micro-level decisions of managers and the macro-level behaviors of a supply chain.

Essay 1, titled "Theory of Paradox within Service-Dominant Logic", posits that the provision of service emerges from the micro-level actions of firms. Against the backdrop of systems theory, we focus on advancing the concept of service provision using the theoretical framework of Service-dominant logic (Vargo & Lusch, 2004) and a soft systems methodology (Sauser & Boardman, 2015). Additionally, this essay promotes the conceptualization of supply chain phenomenon by presenting and exploring the inherent paradoxes within recursive structures of service exchange. Moreover, this essay contributes to the literature by promoting an understanding of the concept of emergence in supply-chain phenomena (Schorsch, Wallenburg, & Wieland, 2017). Conceptualizing supply chain phenomenon in the context of service provision and understanding how supply chain behavior emerges is warranted due to the novelty of supply chain research and the need for practitioners to better understand how a supply chain should be designed given the strengths and weaknesses of its inclusive firms (Sweeney, 2013, p. 81).

Essay 2, titled "The Governing Influence of Information Technology on Supply Chain Resilience", extends the discussion of supply chain resilience as presented in Essay 1, by concentrating on how different information communication technology strategies best govern supply chain resilience. Within the practitioner community, the emerging technology strategy of cloud-based systems is being publicized to offer a single supply chain management solution that delivers scalability, efficiency, agility, and visibility at lower costs of capital when compared to traditional information technology strategies such as on premise, enterprise installations (Kewill, 2015). The dynamism of today's business environment and the speed of technological change underpins the need for firms to be successful with their information technology strategies. Extant literature has focused primarily on how supply chain resilience is achieved through relational competencies such as collaboration, communication, and integration (Gligor & Holcomb, 2012;

Wieland & Wallenburg, 2012, 2013). Little theoretical research exists on explaining the impact information communication technologies can have on the interfirm relationship competencies that foster supply chain resilience (Y. Wu, Cegielski, Hazen, & Hall, 2013). This research addresses this gap in literature through the application of resource-based view and relational view theories of the firm (Barney, 1991; Dyer & Singh, 1998; Wernerfelt, 1984) in order to determine how a firm's information communication technology acts as a governance structure on its relational competencies. We contribute to research by not only investigating the influence information communication technology has on supply chain resilience strategies, but also the impact that technology solutions have on firms' relational competencies.

Essay 3, titled "Understanding the Influence of Information and Analytics on Supply Chain Resilience", centers on the concept of emergence and the paradox of identity from Essay 1 by exploring how supply chain resilience emerges from the use of information technology in aiding human decision-making. Uncertainty as a result of individual firm behavior is a complicating factor for those networks of firms who strive to fortify their supply chains against unexpected events (Manuj & Mentzer, 2008; Milliken, 1987). Little extant supply chain resilience literature has given substantial consideration to the common and controllable risk event of a decision made by an individual firm. Using a multi-echelon supply chain simulation, human subjects are profiled on two cognitive dimensions – analytical ability and consideration of future consequences - and their decision-making is studied under various levels of information and analytics. Better insight into the understanding of drivers in variance of human decisions can allow supply chain managers to better leverage their information technology solutions in eliminating self-inflicted risk while focusing on those threats which can have greater impact to the prosperity and survival of individual firms and the overall supply chain.

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THEORY OF PARADOX WITHIN SERVICE-DOMINANT LOGIC[1]

Introduction

Over time, the evolution of a theory should be paradoxical because phenomena that science attempts to explain and predict are complex, diverse, and ambiguous (Boardman & Sauser, 2008, p. 171). In developing theory, scholars are faced with two opposing goals – increasing the explanatory and predictive power of a theory while maintaining simplicity in its framework. Simplicity usually wins out, but the opportunity to use the tension between these two goals – a paradox in itself - could stimulate the development of more inclusive theories and understanding of real world phenomenon (Poole & van de Ven, 1989). Service-dominant logic's (S-D logic) framework of service exchange may have reached this tipping point as its foundational premises describe a recursive, self-referential system of service that when viewed holistically challenges our intuitive understanding of the nature of exchange. Scholars of service systems and those looking to advance S-D logic as a supporting theory may benefit from using the concept of paradox in their research.

S-D logic's maturity as a theoretical framework has evolved research focus from a linear exchange of tangible resources and embedded value to a more systemic exchange of intangible resources and the cocreation of value (Vargo & Lusch, 2004). This systematic view of exchange advanced by S-D logic is currently described through eleven foundational premises that posit behaviors, governance, and outcomes of exchange based on service. The present framework of S-D logic reveals that the structural features of service exchange are more accurately reflected by a dynamic, multi-dimensional systems orientation (Vargo & Lusch, 2015). This latest view of

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exchange reveals a complex system of exchange that is much more than the collective sum of individual elements. The process of transforming knowledge and skills into value is now being conceptualized as an ever-evolving system of actors who are engaging in the exchange of resources and the creation of value (Vargo & Lusch, 2015). S-D logic's finite description of exchange explains a complex view of reality that is circular and self-referential in nature with diverse actors defining and co-creating value for themselves through direct and indirect relationships with other actors. This recursive structure of exchange inherently creates paradoxes - apparent inconsistencies and oppositions occurring in phenomena or logic - among S-D logic's foundational premises. The insights gained from exploring, understanding, and appreciating paradoxes within S-D logic's theoretical framework provide the opportunity for further theory development and advancement of service exchange.

Since 500 B.C, paradoxes have been known as phenomena that have challenged numerous scholars in their quest for knowledge. Paradoxes are often defined as a set of statements that, while seemingly plausible on their own, collectively derive a contradictory conclusion (Rescher, 2001, p. 8). A common example of a paradox is the Sorites paradox whose qualifying supposition concerning heaps of sand leads to the contradictory conclusion that even single grains of sand can be considered heaps (Sainsbury, 2009, p. 41). Paradoxes of perspectives, such as the Sorites paradox, can commonly arise in societal interactions as a result of diversity and multiplicity of circumstances. While social paradoxes may be initially perplexing, their use can lead to deeper understanding of complex phenomena that collectively emerge from smaller, individual events. Thinking in terms of paradoxes have been promoted as a way to better manage the complexity associated in business research (Baldwin, Sauser, Boardman, & John, 2010). Learning to be comfortable with the conflicting tension of a paradox and thinking in terms of "*both*" versus "*and/or*" when seeking understanding of phenomena can lead to new ideas and richer thinking (Boardman & Sauser, 2008, p. 171). It's this type of thinking – paradoxical thinking – that has contributed to advancements within organization and management theory (Poole & van de Ven, 1989), and from which marketing and service systems researchers could benefit from taking advantage of developing S-D logic into a more parsimonious, testable theory on service exchange.

Using paradoxical thinking to understand and develop an appreciation for this plurality of service exchange may create a more robust and concise understanding of markets and marketing (Vargo & Lusch, 2015). The purpose of this paper is to examine the system orientation of S-D logic and to identify the paradoxes inherit within its framework and description of service exchange. This paper amplifies the work of various academics that have contributed to the development of S-D logic's conceptualization of service exchange. Organized in four sections, this paper addresses the following questions: *What system paradoxes exist within S-D logic's systems orientation to service exchange? What can be gained from their understanding?* In the first section, a system orientation is presented that conceptualizes service exchange as a system of systems. Second, we describe the applicability and use of paradoxes in social science research as well as the use of systems theory and the soft systems methodology in this paper. Third, through the use of soft systems methodology (SSM) we identify four potential system paradoxes inherit within the framework of S-D logic. Specifically, this paper utilizes work conducted by Dickens, Glassburner, Sauser, and Randall (2016) in representing S-D logic as a system using diagrams of prose, known as Systemigrams, built with the Boardman SSM (BSSM) SystemiTool application. Finally, a discussion is provided on the implications and future value of using systems theory, SSM, and system paradoxes in S-D logic's future development.

Systems Orientation of S-D logic

To appreciate how S-D logic's foundational premises communicate the exchange of service as a system, one must conceptualize how actors are connected within service systems (Chandler & Lusch, 2015). In the realm of systems thinking, a system is defined as "a set of elements interacting for a purpose to achieve some common goal" (Baldwin et al., 2010). This paper defines the system described by S-D logic as *Society* (Vargo & Lusch, 2015) – a pure set consisting of elements that are a set in themselves called *service ecosystems*. Like all systems, *Society* has a structure and process that progresses towards a common function or goal (Boardman & Sauser, 2013, p. 78). The structure of *Society* is created by the temporal process of value cocreation by way of institutionalization (Vargo, Wieland, & Akaka, 2015). Value cocreation is the evolutionary process by which structures emerge, evolve, interact, and perish through the joint activities of actors (Vargo & Lusch, 2015). Institutionalization is the maintenance, disruption, and change (Vargo et al., 2015) of institution logic - shared rules, norms, beliefs and behavior amongst the subsystems of *Society* - *service ecosystems* (Robert F Lusch & Vargo, 2014, p. 18). Institutionalization is an enabler of value cocreation and gives *Society* and *service ecosystems* their structural boundaries, exteriors, and interiors. The systems definition of *Society* is a set of diverse individual *service ecosystems* connected by institutionalization and mutually conducting reciprocal activities of value creation (Vargo & Lusch, 2015) in order for the system of *Society* to evolve and survive. As *service ecosystems* emerge, evolve, interact, and perish in creating value through institutional changes so does the system of *Society*.

Service ecosystems are the immediate lower-level subsystems of *Society.* They exist as pure sets. In other words, *service ecosystems* can consist of sets of other subordinate ecosystems or actors who are also sets of resources and institutions. In general, a *service ecosystem* is a set of "resource-integrating actors connected by shared institutional arrangements and mutual value cocreation through service exchange" (Vargo & Lusch, 2015). *Service ecosystems* can take the form of markets (*institutionalized economic solutions*) or groupings of actors formed by shared institutional logic (*institutional arrangements*) (Vargo & Lusch, 2015). For instance, healthcare is a service ecosystem. Healthcare consumers, service providers, and insurance payers are all resource-integrating actors connected by shared institutional logic who cocreate value through reciprocal service exchanges. The value realized through the actors' actions serve as a feedback mechanism that influences and determines the survival of the healthcare ecosystem.

The hierarchies within *service ecosystems* consist of networks, triads, and dyads of actors (Chandler & Vargo, 2011). These arrays of actors are connected to one another by institutions, but defined by the directness and complexity of value creation through service exchange (Chandler & Vargo, 2011). At the most elementary level is a direct activity of value cocreation between two individual actors. As the perspective of activity is broadened, increasingly indirect exchanges of value form because of activities between intersecting pairs of individual actors. These indirect exchanges of value form a network of both explicit and implicit actor connections. Within the aforementioned example of healthcare, the elementary level of activity is between the consumer and provider. These two actors work together to cocreate value through shared decisions (McColl-Kennedy, Vargo, Dagger, Sweeney, & van Kasteren, 2012). Most often, both the consumer and provider are indirect recipients of value created by other actors such as pharmaceutical companies, healthcare specialists, insurance companies, and other network actors. These indirect exchanges of service create a complex network of value cocreation.

Service ecosystems emerge when networks of value creating entities replicate and institutionalize with respect to other networks (Chandler & Vargo, 2011).

No actor within the system of *Societ*y or *service ecosystems* operates independently in the value creation process (McColl-Kennedy et al., 2012). The process of mutual value creation through service exchange occurs within and through all hierarchical levels of the system of *Society*. The complexity of interacting *service ecosystems* and actors is the nature of value cocreation. Direct exchange of service between two actors can suffice when the value desired is simple in nature and definition. At the most complex level, value cocreation occurs in nested and overlapped *service ecosystems* (Vargo & Lusch, 2015). In the healthcare example, *service ecosystems*, such as public government, may interact to coordinate the creation of value amongst consumers, providers, and insurance payers. Through the intersection of institutions, the public government will interact to cocreate value with all exchange parties. The value created in these intersections reorients and influences each actor; thereby reshaping institutions amongst *service ecosystems* and redefining the structure of *Society*.

The common goal or function of elements is the essence of what describes them as a system. The goal of the system of *Society* is survival by way of *service ecosystem* evolution and survival. *Society* must provide the opportunity and framework for value cocreation to take place within *service ecosystems*. To remain a system, *Society* must continually pursue its goal of survival through facilitating value cocreation in an environment of perpetual change. Change is inflicted onto a system by exterior environments and internal elements (Boardman & Sauser, 2008, p. 30). Systems that fail to respond to these changes fail to exist. In S-D logic, *Society* and its inclusive elements create value and pursue survival by creating opportunities for the occurrence of mutually benefitting activities. The process of value cocreation enables the creation of system structures that support the goal of survival (Vargo & Lusch, 2015).

Leveraging Paradox in S-D logic's Framework

Introducing Paradoxes

Paradoxes are thought provoking contradictions in the otherwise seemingly obvious of our real world. They are a common occurrence in the pursuit of ontological certainty of societal systems. They force us to question our comprehension and understanding of the phenomena occurring around us daily. When faced with a paradox, critics often dismiss them as errors in logic or whimsical comprehension. To the scholar skilled in the use of paradox, they serve as a tool to balance both what is and what is not (Boardman & Sauser, 2008; Lawrence John, Boardman, & Sauser, 2009). Thinking in terms of paradoxes and using their existence as something to be managed and not solved can lead to a more reasoned, intuitive understanding of phenomena (Cuonzo, 2014).

The functioning of the economic ecosystems of *Society* are a paradox of control. Economic ecosystems function as a result of actors, such as manufacturers and producers, exhibiting self-control and self-discipline to successfully operate within frameworks set by controlling authorities (Boardman & Sauser, 2008, p. 176). The paradox of control states that one has to have command and control in order to ensure order and conformity to a strategic direction, but one must also not have command and control in order to allow for the fostering of innovation, tactical opportunism, and preservation of self-awareness (Boardman & Sauser, 2008, p. 176). For the economic ecosystems to be efficient and effective, they have to ensure the production of goods or services and the expenditure of money in the purchase of those goods or services. At face value, our economic ecosystems seem to be managed and controlled by central authorities that establish hard and soft governing mechanisms (i.e. money, tax laws, etc.) which enable a smooth distribution of goods and services. In reality, though, no one and everyone dictate the performance of our economic ecosystems. For it takes the central authority and the self-controlled autonomy of everyone producing and purchasing goods or services to make these ecosystems efficient and effective. To understand this apparent contradiction in how our economic ecosystems perform, researchers have to learn to accept this paradox of control and leverage it to further their understanding.

Paradoxes have been defined and categorized in a variety of typologies. Classic logicians have often defined paradoxes in terms of rhetoric and cognitive reasoning. Classifying paradoxes as either veridical, truth telling; falsidical, fallacy in argument; or as an antinomy, crises in thought, Quine (1976, p. 1) defines a paradox as “any conclusion that at first sounds absurd but that has an argument to sustain it.” . In his extensive exploration of paradox management, the philosopher Rescher (2001, p. 3) traces the linguistic origins back to the Greek words of para (beyond) and doxa (belief) and identifies paradoxes as belonging to either a logical or rhetorical class. According to Rescher (2001, p. 4), logical paradoxes involve a predicament amongst propositions asserted, accepted, or believed to be plausible while rhetorical paradoxes are instances of comparing conflicting statements for the sake of insight. Sainsbury (2009, p. 1) advocates paradoxes as arising from unacceptable conclusions or indistinct flaws in reasoning and classifies them based on degrees of truth and belief. Cuonzo (2014) describes the essence of a paradox as an “inconsistency among seemingly innocuous elements” and uses subjective probability to rate the truth and validity of paradoxes. Classic logicians know, though, that arguments based upon sustained paradoxes have led to major shifts in foundational thought by exposing inconsistencies in premises and preconceptions considered central to a theory (Quine, 1976, p. 1).

In a more pragmatic sense, social science researchers have defined the concept of paradox on the grounds of tension and opposite positions occurring in the interactions of individuals of social systems. L. John, Boardman, and Sauser (2008) characterizes paradoxes of social systems as the "continuing competition between opposing, apparently inimical tension that somehow must coexist for the ecosystem to survive and thrive." In using her work on organizational theory-building, Lewis (2000) illuminates paradoxes as being derived from "cognitively or socially constructed polarities that masks the simultaneity of conflicting truths". In the context of organizational systems, Baldwin et al. (2010) accepts that paradoxes "involve some form of perception of absurdity or some form of contradiction." Boardman and Sauser (2008, pp. 172-178) classify paradoxes relating to soft systems (i.e. human activity) on the terms of boundary, the demarcation between that of a system boundary and element inclusion; control, the tension created by the obedience, loyalty, and liberty of elements to that of a system's overall command and control; and diversity, the conflict between individuality of elements and system togetherness. Poole and van de Ven (1989) describes paradoxes occurring within the social science context as "tensions and oppositions between incompatible positions…about a real world, subject to its temporal and spatial constraints." We capitalize on this definition of paradox as we attempt to identify the paradoxes inherit in S-D logic and its description of service exchange.

While the concept of paradox has taken on different meanings, their use has led to major shifts in foundational thought across various academic disciplines. Classic logicians have used paradoxes to re-educate their intuitions which, in turn, has led to developments in scientific hypothesis testing and modern mathematics (Cuonzo, 2014). Researchers in the hard sciences have used the notion of paradox to develop aircraft stability systems and quantum computing (Lawrence John et al., 2009). Soft science disciplines have successfully used paradoxes to gain a more comprehensive understanding of social science phenomena. Westenholz (1993) used the concept of paradoxical thinking to explain how employees construct different frames of reference over time to identify problems, solutions, and deeper understanding of their environment. Lewis (2000) advocates paradoxes by creating a framework from which to study, foster insight, and further develop theory on the interaction of individuals, groups, and organizations. She posits that thinking in terms of paradoxes can help manage complexity and ambiguity in organizational research. Prahalad and Ramaswamy (2004) exploit the concept of paradox in describing how the concepts of growth and value creation, while seemingly at odds with each other, can be liberating in understanding how the process of value creation and extraction takes place in the interactions between firms and consumers. In their work on market dynamics, Mattsson and Tidström (2015) present the argument that the co-existence of competition and cooperation within markets form a paradox from which further insight is gained on how market formation and equilibrium is achieved. Further use of paradoxes in social science research include works on consumer identity and market growth (Caruana, Crane, & Fitchett, 2008; Newholm & Hopkinson, 2009); brand experience management (Fisher & Smith, 2011); market experientialism (Woodward & Holbrook, 2013) and institutional work (Battilana & D'aunno, 2009, p. 31).

Using Systemic Thinking to Identify Paradoxes

In order to leverage paradoxes, researchers have to conceptualize a phenomenon at both the holistic and elementary levels. They have to think systemically about how the phenomenon becomes more than the sum of its parts. Systemic thinking provides an avenue from which to study and model systems from a holistic viewpoint that allows us to understand not only the wholeness of the problem, but the relationships between the individual parts and their influence on the whole. When a phenomenon is represented as a system, it allows a research to model and exploit possible tensions and conflict among the individual parts of a phenomenon to gain new perspectives and worldviews. In the context of systemic thinking, paradoxes of systems (i.e. system paradoxes) are not situations to be avoided or problems to be solved. Scholars versed in systemic thinking and systems theory view paradoxes as a liberating phenomenon that leads to acumen based on the acceptance of a "*both/and*" possibility (Lawrence John et al., 2009).

A challenge of systemic thinking is to accurately represent a phenomenon as a system of inclusive elements. This challenge is amplified when the phenomenon is of the social nature and includes not only physical elements, but also a diverse array of autonomous individuals and subjective perspectives. To support systemic thinking, systems thinking, as a developed methodological practice, allows a researcher to unify multiple relationships, perspectives, and contexts, at all levels of organization, into a simpler representation that can be better understood by all stakeholders (Sauser & Boardman, 2015, p. 273). One such methodology with foundations in general systems theory (Baldwin et al., 2010; Bertalanffy, 1972) is soft systems methodology (SSM). SSM provides an iterative approach to understanding human activity systems and developing a model of a real-world phenomenon as a system of interest (Sauser & Boardman, 2015; Sauser, Li, & Ramirez-Marquez, 2011). SSM uses the following seven general steps.

1. Express the system of interest unstructured.
2. Formulate the system of interest expressed.

3. Define the system of interest in structured text.

4. Conceptually model the system of interest.

5. Compare the derived model with the expressed system of interest

6. Identify feasible and desirable changes to the system of interest.

7. Take action to improve the system of interest.

The seven steps of SSM have been applied for over forty years across different research domains as a methodology from which to apply systems thinking (Checkland, 2000; Mingers & White, 2010). For example, Lehaney and Paul (1996) use SSM within the healthcare field to develop a simulation of out-patient services. Ramsay, Boardman, and Cole (1996) demonstrates how SSM can be used to reinforce learning within organizations. Using SSM, Lasfer, Pyster, and Sauser (2011) model and identify the strengths and weaknesses of an educational enterprise responsible for learning outcomes of pre-Kindergarten children. Sauser et al. (2011) articulate how SSM was applied to refine strategic policy for the Department of Homeland Security's (DHS) Small Vessel Security program. Moreover, the use of SSM by Sauser et al. (2011) led to fundamental policy changes, within the DHS security program, through the identification of a paradox. Finally, Rose (1997) proposes how SSM can be used to build 'middle range' theory and as a method of theory testing.

Building upon SSM's conceptual modeling techniques, Sauser and Boardman (2015, p. 275) have derived the Boardman Soft Systems Methodology (BSSM) and a diagramming tool called SystemiTool, which graphically depicts systems thinking through structured text. The BSSM encompasses the seven steps from SSM, but differs in representing the expressed system of interest in a diagram of prose called a Systemigram (Systemic Diagram) (Sauser & Boardman, 2015, p. 276). Like SSM, each step of the BSSM is repeated until all pertinent stakeholders agree on a single, concise visual representation of the system of interest. The final Systemigram model supports systems thinking by synthesizing diverse perspectives of an unstructured situation into a comprehensive and unified system of interest. A finalized systemigram is a semantic network model that uses natural language to conceptually represent qualitative dimensions of human interaction (Ramsay et al., 1996; Sauser & Boardman, 2015, p. 281). This paper uses the BSSM to build a systems model of S-D logic, and use systemic thinking to identify and explain inherent paradoxes.

Systems theory defines and classifies paradoxes based on the elements and relations belonging to a system. A paradox in the context of systems theory can be described as “a contradiction or some form of absurd perception related to a set of elements interacting for a purpose. (Baldwin et al., 2010)” To systemic thinkers, paradoxical thinking is systems thinking at its finest (Boardman & Sauser, 2008, p. 170). Diagramming a system through BSSM and Systemigrams shows what is and what is not part of the system of interest (Lawrence John et al., 2009). It also allows for the identification of paradoxes amongst the individual parts of a system and their relations that may not be realized when each part is evaluated individually. Identifying paradoxes in S-D logic provides an opportunity for scholars to enhance their understanding of how service ecosystems interact across time and space; resources are created, integrated, and applied amongst economic actors; and value co-creation occurs in a service-dominant view of exchange.

Applying Systemic Thinking and BSSM to S-D logic and Service Exchange

The use of BSSM and Systemigrams is novel in the discipline of service science, but their applicability is justifiably increasing as a system-oriented view of service exchange becomes more widely adopted amongst academics. The application of systemic thinking in the context of S-D logic's foundational premises is a nascent orientation (Vargo & Lusch, 2015). S-D logic's foundational premises infer dynamic, multi-level connections between service ecosystems or actors who connect through shared institutions and mutual service exchanges (Maglio, Vargo, Caswell, & Spohrer, 2009; Vargo, 2009). The lack of direct application of systemic thinking to S-D logic's theoretical framework provides an opportunity to further extend our understanding of service exchange and value cocreation. Application of the holistic perspective of systems theory allows us to explore the dynamic relations of S-D logic's foundational premises in dimensions of form, function, and utility (Boardman & Sauser, 2013, p. 78). In other words, use of systems theory provides an opportunity to better understand how S-D logic's foundational premises create a structure of service exchange that explicates the process of value co-creation. Systemic thinking offers an approach to discovering the connectivity between actors, the environments in which value co-creation takes place, and the emergent characteristics of service ecosystems (Sauser & Boardman, 2015, p. 274). Applying BSSM and systemic thinking to S-D logic's framework allows us to manifest S-D logic and service exchange into communicable diagrams of constructs and relationships (Boardman & Sauser, 2013, p. 105). Depicting S-D logic in the form of a system allows for the investigation of paradoxes or apparent inconsistencies (Baldwin et al., 2010). A depiction of a systems orientation to S-D logic, in the form of a Systemigram, is presented in Figure 1.

Through the use of set theory and based on the work of Lawrence John et al. (2009), Baldwin et al. (2010) defines a typology of six paradoxes occurring within systems. It is through his definition and typology of systems paradoxes that the next section evaluates the structured nature and paradoxes of S-D logic. To enhance clarity and conciseness, this paper employs set theory to mathematically represent a systems orientation to S-D logic’s theoretical framework and the paradoxes offered for consideration. Set theory allows for the logical inclusion of individual elements into classes of elements provided certain criteria are met. Table 1 provides the set theory notation required to aid the reader’s understanding of mathematical representations in the next section. By using set theory in conjunction with S-D logic’s narrative of service exchange, we believe it strengthens the descriptive narrative of S-D logic’s theoretical framework.

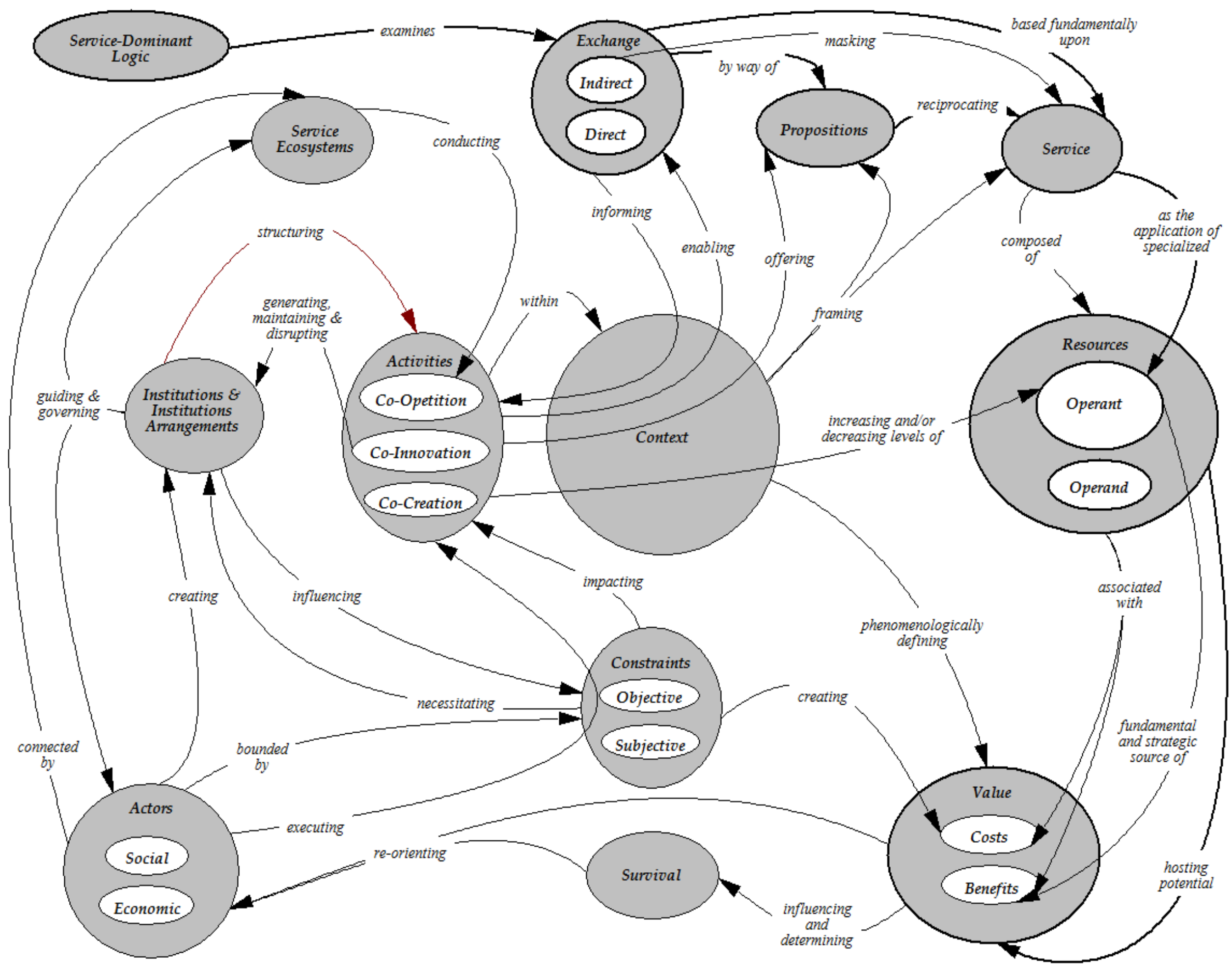

Figure 1. Systemigram Model of S-D Logic

Table 1

Set Theory Notation

Symbol	**Meaning**
$=$	“Equal”
$\neq$	“Not Equal To”
$\in$	“Element of”
$\notin$	“Not Element of”
$\vert$	“Given” or “Such
$\sim$	“Approximately”
$\wedge$	Logical “and”
$\vee$	Logical “or”
$\rightarrow$	“If…then”
$>$	“Greater Than”
$<$	“Less Than”

Systems Paradoxes of S-D logic

Paradoxes of social systems are often characterized by perceptual tensions intensified through reinforcing cycles amongst involved elements and witnessed in forms such as self-referring loops and system contradictions (Lewis, 2000). S-D logic views recursive social relationships as tantamount to the mutual exchange of service through resources (Vargo & Lusch, 2004). Evolution of social and market systems is the result of the release of tension between different layers of service exchange (Chandler & Vargo, 2011). It is through the recursive nature of service exchange and the emergence of tension amongst the elements of service systems that we posit paradoxes are inherent within S-D logic’s theoretical description of service exchange. S-D logic’s narrative of institutions and mutual value cocreation through service exchange naturally promotes the occurrence of conflict within social and economic structures evolving into larger systems. Thinking in the form of systems paradoxes allows for greater insight on the collective forces influencing and emerging from the service systems described by S-D logic. Thinking paradoxically about S-D logic allows us to not only appreciate the variety, parsimony, and harmony amongst the elements involved in service exchange, but also the openness, hierarchy, and emergence of a service exchange structure (Boardman & Sauser, 2013, p. 75).

S-D logic implies that value cocreation is contextual in nature (Vargo & Lusch, 2015). Collectively, the number and types of actors; availability of resources and constraints; and the presence of institutions and institutional arrangements create and influence the context through which an actor phenomenologically determines the value of a service. It is plausible that context does matter in gaining an understanding of S-D logic's narrative of exchange (Vargo & Lusch, 2015), but context can also isolate a system from connections that contribute to or exasperate a phenomenon (Lawrence John et al., 2009). The basis for identifying paradoxes in S-D logic is to clarify a more holistic picture of service exchange.

Conjunctional Paradox of S-D logic

The meaning of the word "value" is an elusive concept (Badinelli, 2015; Vargo, Maglio, & Akaka, 2008). Aristotle was regulated to using the word "value" as the name of the unknown substance that solves the problem of commensurability through a single common material or property (Fleetwood, 1997). Through time, the word "value" has taken on a variety of definitions. Examples of definitions include "a perception of difference between what is received and what is given" (Zeithaml, 1988); "a customer's perception of the performance of product attributes towards their goals and purposes" (Woodruff, 1998); or "an emotional bond between a customer and supplier" (Butz & Goodstein, 1996). In other words, the definition of the word "value" has and can take on a variety of statements. A conjunction is a single concept represented by several statements and whose truth is determined by the affirmation of individual statements (Quine, 1982, p. 9). A conjunctional paradox occurs when two statements, representing the same concept, individually contradict each other. The system paradox of conjunction, as defined by Baldwin et al. (2010), is a paradox where system elements and their negation co-exist within the same system.

The sixth foundational premise of S-D logic – *Value is cocreated by multiple actors, always including the beneficiary* – presents the situation from which a system element can co-exist with its negation in a service ecosystem. In a service-dominant environment, value takes on two contrasting forms – "in-use" and "in-exchange" (Vargo et al., 2008) – that co-exist within a service ecosystem. "Value-in-use" is the determination of experiential capacity of a resource by an actor. In this case, value is determined through an actor's use of the resource. "Value-in-exchange" has been described to be experiential capacity embedded in a resource, void of actor determination. Value in this instance is a measurement of trade. Different actors within a service ecosystem can hold different valuations of service – "in-exchange" or "in-use". Based on these two meanings of value, this composition posits that "value-in-exchange" is the negation of "value-in-use". S-D logic contends that value-in-exchange cannot exist in the absence of value-in-use (Robert F Lusch & Vargo, 2006), thus we have a conjunctional system paradox, as described by Baldwin et al. (2010), of "value-in use" (v_{in-use}) and "value-in exchange" ($v_{in-exchange}$) within the set of elements defining a service system (S).

$$S = \{v_{in-use}, v_{in-exchange} \in S \big| \left(v_{in-use} = \sim v_{in-exchange}\right) \wedge \left(v_{in-use} \neq v_{in-exchange}\right)\} \quad (1)$$

From a systems perspective, it is necessary to understand this paradox and ask is there an optimal mix or governance structure of value-in-use and value-in-exchange in a social or economic system. It is plausible that the optimal mix or governance structure is one that drives resources to levels that perpetuate a system's evolution and survival. This optimal mix largely depends on the interests of participating actors being aligned with the goals of the overall system. Interests of actors that are unbalanced can create a destructive environment where survival means defeating others – even those whom an actor depends on for their own survival (Handy, 1995, p. 89). This potential of self-defeating interests creates a need for a suitable governance structure that aligns value-in-use with value-in-exchange.

Only when the system goals are superordinate and a proper mix of value-in-use and value-in-exchange exists will the probability of survival increase for the system. For instance, business firms are now realizing mutual, strategic benefits can be created by prioritizing performance-based, relational goals (value-in-use) over economic, transactional goals (value-in-exchange) (Randall, Pohlen, & Hanna, 2010). Both types of value, though, must exist in harmony for firms and their inclusive service ecosystem to survive. "Value-in-exchange" is the economic feedback mechanism for firms provisioning service. "Value-in-use" serves as the coordinating mechanism of "value-in-exchange" and reorients firms towards activities of business survival. This work posits that the application of the conjunctional system paradox to S-D logic allows for deeper understanding of value types, their optimal mix and conducive governance structures. It also provides insight into the influence of value cocreation activities on the survival of actors and service systems.

Biconditional Paradox of S-D logic

Boundaries of systems are somewhat paradoxical – they are created over time by a system's structure, yet they define a system's structure. System boundaries tell us what elements belong to the system’s interior and what elements exist in the system’s exterior environment (Boardman & Sauser, 2013, p. 39). Boundaries to systems must exist and deny entry for the system to exist. Time is an imperative factor in the creation of a boundary, but its importance is usually implied. A system is defined by its current structure, which may have evolved from a system in the past, and a common goal to be achieved at a future time. Within a system, the concept of time can entail a process of evolution, a distinction of existence, or a precedence of events. As systems evolve over time, there exists a possibility of two contradictory elements being included within its boundaries. The biconditional system paradox, as defined by Baldwin et al. (2010), is a paradox of temporal conditions that have led to the existence of an element’s opposite within a system.

The eleventh foundational premise – *Value cocreation is coordinated through actor-generated institutions and institutional arrangements* – presents the possibility of a biconditional system paradox occurring within a service ecosystem. Service ecosystems are collections of actors connected by shared institutional logics and value co-creating activities (Robert F Lusch & Vargo, 2014). Institutional arrangements form over time through connections of actors who share institutional logic. As institutional arrangements increase in institutional density they create the boundaries of the service system and its inclusive subsystems. A service ecosystem boundary is formed when the activities of mutual value cocreation are replicated over time by and amongst actors (Chandler & Vargo, 2011). Homogenous institutions can result in greater value cocreation by overcoming the limited cognitive abilities and bounded rationale of actors, but institutions come in many forms (Vargo & Lusch, 2015). While service ecosystems develop over time, they do not replace all of the institutions over which they govern. Institutions that may conflict with the governing institutional arrangement can still exist within the boundaries of a service ecosystem. These conflicting institutions are constantly competing to ensure society evolves and survives (Thornton, Ocasio, & Lounsbury, p. 119). In these situations, the biconditional system paradox can also be considered as paradox of embedded agency where tensions exist between actor agency and institutional arrangements (Battilana & D'aunno, 2009, p. 31). This composition posits that a biconditional system paradox, as described by Baldwin et al. (2010), exist within the theoretical framework of S-D logic as different, individual institutions (I) develop over time (t) within a single service system (S).

$$S = \{I, \sim I \in S | (I_{t0} \rightarrow \sim I_{t1}) \wedge (\sim I_{t1} \rightarrow I_{t2}), t_0 > t_1 > t_2\} \quad (2)$$

The biconditional system paradox guides comprehension into the development of different individual institutions over time. This comprehension and understanding of institutional development is key because institutionalization drives the creation of service systems and their inclusive ecosystems (Vargo & Lusch, 2015). Individual actor institutions are affected by societal institutional arrangements (Thornton et al., 2012, p. 148). Service systems must be self-adapting and self-governing as differing individual institutions evolve over time (Vargo & Lusch, 2015). These different institutions and the self-governance of a service system and its ecosystems drive increasing levels of service and new value cocreation activities.

In combination with the aforementioned conjunctional paradox of value in S-D logic, this biconditional system paradox provides insights into why some service systems survive and others cease to exist. Handy (1995, p. 26) alludes to the notion that evolution of individual institutions is a major factor in the survival and demise of various "do-it-yourself" ecosystems. He states that some economic activities such as growing vegetables start out of necessity, but are quickly turned into businesses and industries as institutions of value-in-exchange and institutional arrangements are levied against the original activity. Eventually, priced activities become too expensive and priced out of existence thereby causing the extinction of the original activity (Handy, 1995, p. 26). Handy's example provides a temporal example of how institutions develop over time and affect the survival of service ecosystems. Analysis of biconditional system paradoxes within the theoretical framework of S-D logic can help provide understanding of the relationship amongst institutions, institutional arrangements and the evolution of service systems.

Equivalence Paradox of S-D logic

When a system element possesses contradictory qualities simultaneously it is said to be dialetheic. A system's boundary can be said to be dialetheic in that its definition can be vague and ambiguous. This is especially true of soft or conceptual systems. Baldwin et al. (2010) provide an example of the conundrum of defining a boundary when questioning whether a business team's boundary is defined by the office building or by the number of team members. Move between office buildings and the team still exists. Remove a team member and the team can still exist.

In the context of systems, the equivalency paradox questions the existence and description of a boundary condition (Baldwin et al., 2010). The equivalency paradox of a system is a result of vagueness and ambiguity (Sainsbury, 2009, p. 41) and is best represented by the boundary question of the Sorites Paradox – "When does a heap become a heap?" An equivalency systems paradox occurs when an element of a system is dialethetic or possess qualities that simultaneously conflict (Baldwin et al., 2010).

S-D Logic's eighth foundational premise – *A service-centered view is inherently beneficiary oriented and relational* – creates the potential occurrence of an equivalency systems paradox about the simple concept of value. Value within a service-dominant system is inseparable from an actor. It is no longer defined by an embedded aspect of an operand good (Vargo & Lusch, 2004), but through a beneficiary's perception obtained through the experience of applying knowledge (Vargo et al., 2008). This new realization of value allows for the inclusion of context, but it also allows for the meaning of value to take on an aspect of vagueness and ambiguity because its meaning can differ for a single actor participating in different contexts or between different actors within a single context. Vagueness and ambiguity can be considered extreme definitions of variety as they indicate an absence of uniformity or sameness. Systems must possess degrees of both variety and parsimony. Variety in elements provides survival capabilities to a system and parsimony amongst a system's elements makes those capabilities impactful and efficient (Boardman & Sauser, 2008, p. 36). In defining the value (v) of service as oriented to the beneficiary, there is an equivalency systems paradox, as described by Baldwin et al. (2010), within a service systems (S).

$$S = \{v \in S | v = \sim v\} \quad (3)$$

The equivalency systems paradox can easily be stated to exist in any system of interest when one of its inclusive elements is value, because there exists an impression that the meaning of value is more sharply defined than what is known (Rescher, 2001, p. 82). The lesson to be learned from the existence of the equivalency systems paradox is that value is untenable without context. Contexts may mask a single definition of value, but context doesn't create a total loss of the meaning of value in other contexts (Rescher, 2001, p. 88). The existence of the equivalency systems paradox within S-D logic's theoretical framework supports the proposition that value is "idiosyncratic, experiential, contextual and meaning-laden" (Vargo & Lusch, 2007).

Disjunction (Identity) Paradox of S-D logic

The concept of emergence is what distinguishes a system from being more than the sum of its parts and its presence is often witnessed in complex systems (Boardman & Sauser, 2013, p. 212). Emergence can be considered an outgrowth of the system from the individuality of its elements. An example of an emerging element is the togetherness of a team created by the sameness, differentiation, and interaction of its individual elements (Boardman & Sauser, 2008, p. 178). It is a paradox when a system isn't fully defined by its parts. A systems paradox of disjunction arises when a system becomes defined through the emergence of an element that does not exist within the complete set of elements defining the system (Baldwin et al., 2010).

Threaded through this paper is the emergence of a system concept that has been discussed, but not focused on – context. The eleventh foundational premise – *Value is always uniquely and phenomenologically determined by the beneficiary* – facilitates the emergence of context as it makes each actor the center of discussion when determining service and value cocreation (Vargo & Lusch, 2015). Context defines the circumstance for understanding a system, but it is not a pre-defined element of the system. In terms of S-D logic, context provides for greater understanding of how service is exchanged and value is co-created amongst actors. Context, though, is not an element of service systems. It is created through actors' activities and unique perspectives; changed by actor interactions; and enabled and constrained by institutions and institutional arrangements. Context emerges out of the elements and activities of a service system. In defining two actors ($a1, a2$) and the emergence of context (c) from their interactions, there is a disjunction systems paradox, as described by Baldwin et al. (2010), within a service systems (S).

$$S = \{a1, a2 \in S, c \notin S \mid (a1 \vee a2) \rightarrow (a1 \vee a2 \vee c)\} \quad (4)$$

The disjunction systems paradox describes how an element of a system, which is hidden in plain sight, emerges and causes a system to be more than the sum of its individual parts. Context of exchange is implicit in the relations between the elements of service systems as the whole system is constantly formed and re-shaped by actor interactions (Vargo et al., 2015). Context of interaction amongst actors conducting mutual value cocreation constantly changes – it is the "dynamic and living fluidity" of service systems with no beginning or end (Chandler & Vargo, 2011). In other words, contexts of service systems emerge out of the individual identities of its elements. It is intangible, immeasurable, and different to each actor, but its emergence gives essence to the whole of the system. The system paradox of disjunction provides an appreciation for diversity of actors and their ability to form a service system that is greater than the sum of its parts. Thinking about value cocreation from a system paradox of disjunction supports the long-standing notion that no single substance exists to commensurate incommensurable items and S-D logic's proposition of value being contextual in nature.

Discussion

It is a matter of evolution that a systems-oriented approach is being applied to S-D logic's understanding of service exchange and value cocreation. Systems thinking can assist in maturing S-D logic as its theoretical framework has moved from consumers and producers towards actors (Vargo & Lusch, 2011); acknowledged the contextual nature of exchange (Vargo, 2009) and existence of service ecosystems (Chandler & Vargo, 2011); and recognized the effects of individual institutions and larger, institutional arrangements (Vargo & Lusch, 2015). It allows us to recognize the elements of service systems; explain their relations; and, possibly, lead to the development of theories that can predict and explain their behaviors. Viewing the nature of service exchange from both systems and contextual aspect can lead to arguments that are beyond our belief or seem absurd in description. Theory that expands our worldview, though, should be paradoxical at times because the phenomena of exchange can simultaneously be complex and simple; parsimonious and diverse; and concise and ambiguous. The acceptance of paradoxical thinking can generate transcendent, creative thought and help guide research to a greater understanding of the phenomena of interest (Lewis, 2000).

The holistic view of S-D logic's description of service exchange is a phenomenon defined by experience and created through interaction and cooperation (Vargo & Lusch, 2015). Using BSSM to materialize S-D logic's theoretical framework into a conceptual, structured text model reveals a system of exchange that is more than the sum of its parts and possesses qualities of structure, process, and function; variety, parsimony, and harmony; and openness, hierarchy, and emergence (Boardman & Sauser, 2013, p. 75). Encompassing a description of service exchange in eleven statements masks the dynamism and emergence of elements and behaviors within service systems. Thinking in terms of paradoxes protects S-D logic from cognitive over-commitment (Rescher, 2001, p. 4), while allowing for the contrast of its foundational premises in order to deepen our insight of value cocreation through service exchange. Paradoxical thinking reveals different types of value must co-exist with their negation to perpetuate the survival of service systems and its actors; institutions will evolve to create new institutional arrangements and service ecosystems; value of service is unique and phenomenological; and context is an emergent element within service systems.

To highlight the existence of paradoxes within service-exchange, consider again the complex system of healthcare. This service system is composed of a diverse set of actors applying knowledge, skills, and abilities to deliver unique outcomes. Both types of value co-exist within this service ecosystem. Value-in-exchange enables providers, specialists, and insurers to profit from the services provided and to deliver services to patients. Value-in-use allows patients to formulate continuous value assessments of provider and specialist services. It also serves as the indirect economic feedback mechanism to providers and specialist, thus re-orienting them towards greater future value cocreation opportunities. The differing institutions within health care have created tension amongst actors and caused the health care delivery system to constantly adapt to the changing needs of its interior elements and exterior environment. What started out as a strategy of public health care has transitioned, though time, to a profit-maximizing schema and then back towards a model of universally managed health care. These transitions occurred because over time institutions resulted in the existence of contradictory institutions.

Viewing the example of health care void of systems thinking creates a challenge to understanding the dynamism and emergence of the health care delivery ecosystem. Applying systems thinking allows us to transcend a transactional mindset; juxtapose the elements of the health care system; and understand how this service system is more than the aggregation of its individual parts. This example demonstrates the value of paradoxical thinking in S-D logic and service systems. Handy (1995, p. 12) compared paradoxes to weather conditions – they are phenomena that must be accepted, coped, and understood in order to survive in life.

Conclusion

The service-dominant view of exchange is a complex system that is constantly adapting and reforming to endogenous and exogenous influences. Concepts such as emergence and dynamism within service ecosystems are becoming increasingly important in the realistic portrayal of social and economic systems (Badinelli, 2015; Vargo & Lusch, 2015). This work suggests that an application of system paradoxes, in combination with systems theory and soft systems methodology, will enhance the maturity of S-D Logic's theoretical framework of value cocreation and service exchange. System paradoxes can serve as a guide in decomposing the complexity of service exchange, while providing more intuitive understanding of service-dominant systems.

Understanding complex systems requires an approach unlike those found useful to comprehending transactional relationships. It requires a different type of thinking. A type of thinking that allows for comprehension of the circularity of reality and can expose a concept of emergence amongst predefined sets of elements. This work posits that the type of thinking needed to mature S-D logic is one of thinking in terms of soft systems and system paradoxes. System paradoxes can reveal the unforeseen tensions, dynamisms, and evolution within service-dominant systems. Paradoxical thinking is powerful because it allows for the acceptance of ambivalence in human interactions while sharpening our intuitive understanding of phenomena. Paradoxical thinking allows us to see service systems for what they are – complex, yet simple based upon your perspective.

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INFLUENCE OF CLOUD-BASED TECHNOLOGY ON SUPPLY CHAIN RESILIENCE

Introduction

The supply chains that support a firm's operations are complex sociotechnical systems whose success depends on inter-firm relationships (Wieland & Wallenburg, 2013). Information and communication technology (ICT) is a key enabler to supply chain operations, since it facilitates the coordination of activities and processes between firms within a supply chain (Skipper, Craighead, Byrd, & Rainer, 2008). More important, ICT provides the foundation that allows supply chains to become connected to maintain control and cohesion over activities and processes during normal and disrupted states of operation (Ponomarov & Holcomb, 2009). Partnering firms acquire the ability to reconfigure, using information and communication technologies (ICT) that allow them to modify both the type and ways of information exchange regarding operations (Gligor & Holcomb, 2012). Firms rely on ICT, such as internet-enabled inter-organizational systems, (IIOS) to obtain visibility over resources within their supply chain (Y. Wu et al., 2013). In general, implementation of ICT assumes one of three models: on premise, hosted, or cloud-based. Of the three, cloud-based systems have become the popular ICT method for firms to ensure the coordination of activities and processes. Little is known, however, regarding the advantages of using cloud-based systems in the management of supply chains.

The National Institute of Standards and Technology defines cloud computing as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released within minimal management effort or service provider interaction" (Mell & Grance, 2011). Cloud-based systems can facilitate the provisioning of software to include programming language platforms, or hardware through private, public, or hybrid ownership models (Mell & Grance, 2011). They allow multiple firms to integrate and share a single software or infrastructure service, enabling their business processes. Researchers have regarded the use of cloud computing within supply chain operations as an enabler of enhanced coordination, collaboration, and business process integration (Xu, 2012). The inherent configurability of cloud-based systems allows firms to proactively and reactively adapt communication and collaboration in turbulent environments, thus facilitating the ability of the supply chain to maintain connectedness, control, and coherence during disruptions (Gligor & Holcomb, 2012; Ponomarov & Holcomb, 2009; Y. Wu et al., 2013).

The predominant focus of existing research on the use of cloud-based technology and its impact on support operations has largely centered on the adoption of cloud computing in supply chain operations (Buyya, Yeo, Venugopal, Broberg, & Brandic, 2009; Y. Wu et al., 2013). There is limited empirical or theoretical work on how cloud-based technology affects the resilience of supply chains from a relational perspective. In this study, we attempt to fill this gap by examining the impact of cloud-based computing technology on supply chain resilience.

This paper examines the impact that cloud-based systems have on inter-firm relational competencies. The research draws on the resource-based view (RBV) (Barney, 1991; Wernerfelt, 1984) and relational view (RV) (Dyer & Singh, 1998) theories of the firm to derive how a firm's ability to exploit inter-firm relationships can be translated into supply chain resilience. We expand the existing literature regarding supply resilience (Brandon-Jones, Squire, Autry, & Petersen, 2014; Pettit et al., 2013; Ponomarov & Holcomb, 2009; Swafford, Ghosh, & Murthy, 2008; Wieland & Wallenburg, 2012) and the impact of relational competencies on the antecedents of supply chain resilience (Wieland & Wallenburg, 2013). In approaching this research from these two streams of literature, we attempt to narrow the gap in understanding how firms can use their relational competency to influence supply chain operations for competitive advantage.

The remainder of this paper is organized into four sections. First, a concise literature review is provided, which gives the theoretical foundation for the development of hypotheses. Second, we continue with a methodology discussion. Third, model analysis and empirical findings are presented. Finally, practical implications and academic contributions are discussed as well as areas for future research.

Literature Review and Hypotheses Development

The operation of a supply chain consists of more than the flow of goods and materials. Supply chain success depends on the exchange of timely, accurate, and concise information between buyers and suppliers. Extant literature tells us that in the perfect market, the price mechanism would fulfill all information needs by exchanging parties (Ouchi, 1979). Additionally, previous economic research tells us that when the price mechanism fails to provide adequate information, firms will seek out governance structures to help lower information asymmetry between partners (Heide, 1994; Williamson, 1979). Short of consuming a business function internally, firms began to develop bilateral relationships with other firms. The relationships between firms drive the need for competencies and capabilities that aid in the reduction of information search costs. Drawing on previous work investigating the competitive advantages of a firm through possessed resources (Penrose & Pitelis, 2002; Wernerfelt, 1984), Barney (1991) offers the formative findings on the social complexity involved in firms building competitive advantages through resources. Since this seminal article appeared, relational competency and its impact on competitive advantage has been developed in the disciplines of management and marketing (Dyer & Singh, 1998; Grant, 1991; Wathne & Heide, 2004). This study draws on the RBV and RV of the firm literature to develop the latent construct of relational competency and its individual dimensions, which facilitate increasing supply chain resilience.

Resource-Based View of the Firm

Research in the area of strategic management has shown that a firm’s competitive position is not only a function of the industry environment, but also the firm’s possessed resources. The resource-based view (RBV) of the firm explains how an organization can achieve a competitive advantage within an industry by developing heterogeneous resources that enhance internal strengths, mitigate internal weaknesses, and protect against external uncertainty and weaknesses (Barney, 1991; Wernerfelt, 1984). A firm's resources refer to those assets, capabilities, and processes that a firm can implement in their competitive strategies. RBV literature apportions firm resources into categories of financial, physical, human, technological, reputational, and organizational resources (Barney, 1991; Grant, 1991; Penrose & Pitelis, 2002). While categorized separately, these areas of resources are often combined to various degrees in the formulation of a firm’s competitive strategies.

The RBV postulates that firms can achieve competitive advantages by developing and blending their resources in a way that makes them valuable, rare, imperfectly imitable, and non-substitutable (VRIN) (Barney, 1991). According to Barney, resources that are valuable allow a firm to capitalize on opportunities and protect against threats. Resources that are rare have the quality of not being possessed simultaneously by a large number of competing firms. Imperfectly imitable resources are those that cannot be obtained by competing firms because of their idiosyncratic development, ambiguous relationship to other resources, or social complexity.

VRIN resources can be single resources or obtained through the combination of two or more heterogeneous resources. One example of a combination of resources that would constitute a VRIN resource is the way firms in a supply chain leverage their knowledge over ICT to coordinate their supply chain actions. The outcome of VRIN resource combination defines a firm's capabilities (Grant, 1991).

As a resource by itself, ICT offers a competitive advantage to the extent that no two competing firms are implementing the same technology simultaneously (Barney, 1991). ICT, however, is usually not a sustained competitive advantage, since the technology can be replicated by potential or current competitors (Barney; Fawcett, Wallin, Allred, Fawcett, & Magnan, 2011). Yet ICT can facilitate capabilities (i.e., bundles of resources) that can become sustained competitive advantages when integrated with a firm's other resources (F. Wu, Yeniyurt, Kim, & Cavusgil, 2006). Specifically, cloud computing, with its dynamic and scalable pool of resources, can help firms maintain alignment of action and interest with their supply chain partners, thus offering the potential for a competitive advantage that is sustainable well into the future.

A major criticism of the RBV of the firm theory is that it ignores that an individual firm's performance is often highly dependent on resources that extend beyond its formal and informal boundaries (Dyer & Singh, 1998). Using only RBV of the firm theory to understand supply chain management has a drawback: it orients strategic focus inward on building competitive advantages through internally controlled and possessed resources. A large portion of supply chain theory and practice, however, informs us that competitive advantage in supply chain management is rooted in the management of relationships (Lambert, 2008, p. 2; Lambert, Emmelhainz, & Gardner, 1999). This supposition is supported by other inter-organizational research, which has demonstrated that individual advantages are derived as much as joint payoffs from congruent, strong, and enduring inter-firm relationships (Dyer & Singh, 1998). To strengthen our theoretical foundations, we supplement RBV of the firm theory with the relational view of dyadic firm associations to provide greater depth for understanding how supply chain resilience is derived from the combination of a firm's internal resources and its idiosyncratic inter-firm linkages (Dyer & Singh, 1998).

Relational View of Competitive Advantage

The relational view (RV) of the firm builds on RBV literature, maintaining that a firm's competitive advantage depends on its network of relationships (Dyer & Singh, 1998). RV theory hypothesizes that advantages and profits exceeding those attainable by individual firms are achieved when firms partner with other firms to combine, exchange, and invest in joint assets, knowledge, and capabilities (Dyer & Singh, 1998). Relational rents are formed when the volume of unique assets, knowledge, and capabilities exchanged between firms increases, thus strengthening not only the partnership but also creating a competitive advantage from the partnership. Sources of relational rents can be found in relation-specific assets, knowledge-sharing routines, complementary resources and capabilities, and effective governance (Dyer & Singh). In making relational rents possible, a key factor is the employment of a government mechanism between the firms, which decreases the costs of transactions between firms and enables coordination and cooperation in the combination of assets, knowledge, and capabilities (Dyer & Singh, 1998). Governance mechanisms are the rules and systems of information exchange that facilitate partner firm cooperation and congruent goal achievement (Ouchi, 1979).

Drawing on transaction cost economics (Williamson, 1979), RV theory postulates that the assets that can be exchanged and combined between firms have the characteristics of site specificity, physical asset specificity, and human asset specificity. Of these three characteristics, physical asset specificity denotes investments in technology, which enables interfirm processes. Previous supply chain research has demonstrated that ICT strengthens coordination and cooperation among firms (Vickery, Droge, Setia, & Sambamurthy, 2010), thus enhancing the relationships between firms. Dyer and Singh (1998) state that relational rents can only be achieved when firms have systems that are compatible enough to facilitate coordinated action. Compatibility in ICT systems refers to the ability to allow information and processes to be shared and used in new ways (Byrd & Turner, 2000; Y. Wu et al., 2013). ICT represents coordination costs (Gulati & Singh, 1998), suggesting that firms pursue governance mechanisms that are compatible enough to facilitate coordination action at low costs. The scalable, dynamic resources of cloud-based systems are a governance mechanism that allows firms of any size to achieve compatible systems at low costs that offer flexibility in meeting a variety of situations (Mladenow, Kryvinska, & Strauss, 2012).

In the area of supply chain resilience, increased information and knowledge sharing among partnering firms improves control, cohesion, and connectedness(Ponomarov & Holcomb, 2009). Dyer and Singh (1998) argue that governance mechanisms can preserve relation-specific competitive advantages by allowing for the combination of resources and capabilities in ways that allow them to coevolve for the duration of the relationship and by fostering an environment that inspires compatible institutions among firms. When incentives and actions are aligned between firms, there is a high degree of control and cohesion between them. Due to scalability and rapid deployment of resources, cloud computing is not only furthering coordination and cooperation among firms during normal operations but is also enhancing the ability of firms to coordinate with supply chain partners in times of disruption (F. Wu et al., 2006). Thus, the use cloud computing to enhance relational competencies in the context of supply chain resilience could be seen as a sustained competitive advantage from the RV perspective.

Developing Supply Chain Resilience through Cloud-Based Systems

Within a supply chain, the risk to one firm poses a risk to all firms (Christopher & Peck, 2004), making it imperative that firms maintain strong relationships with partnering firms in their supply chain. In a complex business environment, every supply chain is susceptible to potential disruptions (Ambulkar, Blackhurst, & Grawe, 2015; Knemeyer, Zinn, & Eroglu, 2009). Disruptions to supply chain operations have the potential to cause significant financial losses for firms and damage relationships between customers and suppliers (Bode & Wagner; Fiksel, Polyviou, Croxton, & Pettit, 2015). To cope with the negative consequences of supply chain disruptions, firms need to construct resilient supply chains (Golgeci & Ponomarov, 2013; Peck, 2005b). Firms can protect themselves against the negative consequences of supply chain disruptions by working with their partnering firms to build resilient supply chains (Ismail & Ponomarov, 2013; Peck, 2005a). Ponomarov and Holcomb (2009) define supply chain resilience as:

> The adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function.

For a capability to be adaptive, it must first exist in its original state. The definition of Ponomarov and Holcomb (2009) implies that supply chain resilience is made up of both proactive and reactive measures. In previous literature, these measures have been categorized as strategies of robustness and agility. Wieland and Wallenburg (2012) define supply chain robustness as a supply chain’s ability to withstand disruption in its current configuration. Martin and Peck (2004) advocate that resilience should be designed into the supply chain, arguing that certain proactive actions should take place before unwanted changes materialize. Supply chain robustness is a proactive management strategy that reflects how firms anticipate risk and prepare for disruption before it happens. Robustness within a supply chain can be developed through investments in buyer-supplier relationships. For example, a supply chain is better prepared for disruption when supply chain partners invest in one another by communicating critical supply and demand information, developing coordinated activities, and understanding the role of each firm’s interests in mutually benefitting outcomes.

Supply chain agility means the ability of a supply chain to rapidly respond to and recover from disruptions in operations caused by environmental uncertainty (Christopher & Peck, 2004; Gligor & Holcomb, 2012). Supply chain agility has its roots in the concept of manufacturing flexibility, where flexible systems are defined as those capable of adapting to uncertain future environmental developments while still efficiently churning out products of acceptable quality (Gligor & Holcomb, 2012; Sethi & Sethi, 1990). As a concept, supply chain agility has been conceptualized in many different forms. Li (2008) provides the most comprehensive framing of supply chain agility by adopting a work-design perspective that refers to how the dynamic capabilities of an organization (Teece, Pisano, & Shuen, 1997) are embedded into the work activities of a supply chain. Drawing on theory in knowledge management, Li (2008) highlights that supply chain agility is a behavioral trait of the buyer-supplier relationship, meaning that supply chain agility is determined by processes between supply chain partners. A growing body of literature has provided evidence that supports supply chain agility as a relationship behavior. Gligor and Holcomb (2014) found that the relationship processes of coordination and communication positively impact the ability of a supply chain to rapidly respond to disruptions.

Wieland and Wallenburg (2013) determined that communication and cooperation are influential antecedents of supply chain agility. Scholten (2015) revealed that processes of information sharing, communication, joint decision-making, resource-sharing and incentive alignment influence a supply chain's ability to respond to disruptions. Additionally, the works of Soni (2011) and Pettit (2010) have contributed to frameworks of supply chain resilience, including agility, pointing to the relationship behavior of collaboration.

Unique strategies of supply chain resilience that are formed between firms and are able to withstand disruption and uncertainty better than other supply chains can become competitive advantages. If firms seek to make supply chain resilience a "supernormal profit," then firms must better prepare their supply chains for disruption and enhance the capabilities of the supply chain above and beyond the capabilities of competing supply chains. ICT offers a mechanism for a supply chain to prepare for risk events and respond to and recover from disruptions. To jointly solve problems and mutually adjust a firm's actions during disruptions requires a high degree of connectivity between firms (Ponomarov & Holcomb, 2009; Skipper et al., 2008).

By itself, cloud computing as an ICT solution does not meet the RBV criteria of valuable, rare, imperfectly imitable, and non-substitutable (Barney, 1991). ICT solutions are available to any firm and can easily be replicated by a firm's competitors (Fawcett et al., 2011). However, when embedded into a firm's supply chain process, ICT can facilitate capabilities that are difficult for other firms to imitate (F. Wu et al., 2006). That is where cloud-based SCM and cloud-based enabled relational resources come into play. Advanced ICT systems, such as cloud computing technology, can achieve better coordination and ensure the availability and timeliness of relevant and important information by allowing access to on-demand, scalable pools of resources that can adapt to the needs of the organizations (Herrera & Janczewski, 2015; F. Wu et al., 2006). Information and knowledge sharing between supply chain partners facilitates the processes of coordination and cooperation (Gligor & Holcomb, 2012; F. Wu et al., 2006), which in turn encourage robust and agile strategies that protect firms against disruptions. Obtaining real-time data and instant updates helps supply chain partners to make rapid decisions in response to supply chain disruptions. For instance, cloud-based systems facilitate proactive coordination of financing strategies within the apparel industry. Small suppliers within the apparel industry are now able to coordinate better financing terms, thus making them more reliable suppliers for apparel retailers (GTNexus, 2014). Cloud-based systems also allow for transparency within supply chains (GTNexus, 2015), thus acting as a mechanism of alignment for both action and intention (Herrera & Janczewski, 2015). Cloud-based SCM systems allow supply chain partners to see risks and rapidly develop mitigation strategies to limit the impact of disruptions, thereby gaining a competitive advantage over supply chains that rely on more traditional SCM systems.

Coordination

The interdependent nature of supply chains makes the alignment of actions imperative for risk management and response strategies. The supply chain’s resilience depends on the abilities of individual firms to maintain constant control over their strategic and tactical actions that contribute to the benefit of other firms (Ponomarov & Holcomb, 2009). Control in interfirm relationships relates to the mutual direction and regulation of actions among supply chain partners (Ponomarov & Holcomb, 2009). Robustness in the face of disruptions requires that firms develop measures to guide their actions in ways that help avoid and resist changes (Durach, Wieland, & Machuca, 2015). Responsiveness, or agility, to disruptions depends on how firms regulate their actions to cohesively and quickly work together in turbulent times (Gligor & Holcomb, 2012). These capabilities require a high degree of coordination among interfirm relationships.

Supply chain coordination is the ability of firms to systematically and effectively work together toward the achievement of mutually desirable outcomes. Coordination among firms within in a supply chain enables the integration of resources (Richey, Roath, Whipple, & Fawcett, 2010; Stank, Keller, & Closs, 2001) and allows the reconfiguration of resources in response to disruptions (Gligor & Holcomb, 2012). As an interfirm process, coordination is enabled by the sharing of knowledge and information among firms. Interfirm knowledge sharing and information exchange enables the supply chain to improve its operational efficiency under normal operations and provide quick response strategies to materialized risks (Sahin & Robinson, 2002). Therefore, we posit that coordination among supply chain partners is positively associated with the capabilities of supply chain robustness and agility.

Hypothesis 1: Coordination is positively associated with Supply Chain Robustness.

Hypothesis 2: Coordination is positively associated with Supply Chain Agility.

Wieland and Wallenburg (2013) argue that supply chain robustness and agility are independent dimensions of supply chain resilience. They view robustness as the proactive strategy by supply chain partners to work together to develop measures to resist changes caused by disruptions with few shifts to the original configuration of the supply chain. In contrast, they view agility as a reactive strategy, where supply chain partners work together to adapt to changes caused by a disruption. Robust strategies require that firms coordinate ex-ante to determine complementary resources and dependencies. Thus, robust strategies have a direct impact on the ability of a supply chain to reconfigure itself during disruptions. Therefore, we posit that the actions taken by supply chain partners ahead of disruptions mediate the level of coordination required in the reactive strategies associated with supply chain agility.

> *Hypothesis 3: Strategies of supply chain robustness mediate the relationship between supply chain coordination and supply chain agility.*

Cooperation

The advantages of belonging to a supply chain are only realized when firms recognize their interdependence. The effectiveness of a supply chain relies not only on the coordination of activities of interdependent firms, but also on a firm's willingness to balance self-interests with those of supply chain partners. The misalignment of self-interests results in competition between firms, with each firm attempting to maximize its own outcomes with little consideration for the outcomes for partnering firms. Cooperation within a supply chain occurs when there is an alignment of interests between supply chain partners in the pursuit of mutually benefitting outcomes (Gligor & Holcomb, 2012; Lawrence & Lorsch, 1967). Cooperation is a key antecedent to supply chain resilience strategies since firms that pursue their own self-interests may act in ways that impact the overall supply chain's ability to withstand or respond to a disruption (Gligor & Holcomb, 2012).

Previous research has found a positive relationship between interfirm cooperation and supply chain resilience. For example, Wieland and Wallenburg (2013) provided evidence that interfirm cooperation positively affects the level of perceived agility within a supply chain. They operationalized cooperation as the psychological commitment among firms in pursuit of mutual outcomes. Their operationalization of cooperation is based on the dimensions of joint responsibilities, willingness to bargain fairly, attitudes toward change, and unselfish concern for supply chain partners. They did not, however, find a significant impact of interfirm cooperation on proactive strategies of supply chain robustness, and called for future research on situations where cooperation may increase supply chain robustness. Gligor and Holcomb (2012) determined that the levels of coordination and communication within a supply chain mediated the influence of cooperation on the supply chain's agility. They define cooperation as an alignment of interests between supply chain partners, and operationalize it as an attitude among supply chain partners. In contrast to the findings of Wieland and Wallenburg (2013), Hall et al. (2012) furnish evidence that cooperation between supply chain partners enhances the effectiveness of the contingency planning process. They posit and support the proposition that cooperation among supply chain partners ensures that expectations about achieving mutually benefitting outcomes are understood and pursued during supply chain disruptions. Given the results of previous research, we hypothesize that:

Hypothesis 4: Cooperation is positively associated with Supply Chain Robustness

Hypothesis 5: Cooperation is positively associated with Supply Chain Agility.

Similar to the mediating role of supply chain robustness on coordination, we propose that supply chain robustness mediates the relationship between cooperation and supply chain agility. If expectations and interests are aligned in advance of experiencing a disruption, there is little need for supply chain partners to require higher levels of interest alignment during responses to disruptions, since expectations should already be established. Therefore, we posit that strategies of supply chain robustness mediate the levels of cooperation needed during reactive responses to disruptions.

Hypothesis 6: Strategies of supply chain robustness mediates the relationship between supply chain cooperation and supply chain agility.

Operational Performance

Maintaining a desired state or achieving a more desirable state of supply chain operations is the ultimate goal of supply chain resilience (Hohenstein et al., 2015; Ponomarov & Holcomb, 2009). Measures of supply chain resilience have been explored from a variety of perspectives within the supply chain management literature. In building a framework for defining and measuring supply chain resilience, Hohenstein et al. (2015) determine that the performance metrics of customer service, market share, and financial performance can serve as measures of supply chain resilience. Gligor and Holcomb (Gligor & Holcomb) adopt measures of service performance to determine the resilience of supply chains. Wieland and Wallenburg (2013) measure the impact of supply chain robustness and agility strategies relative to a firm's performance in comparison with their competitors. Pettit et al. (2013) developed a survey-based assessment tool for supply chain managers to measure the resilience of their supply chain.

Supply chains facilitate the flow of services and products. Firms rely on supply chains to provide the right products or services in the right quantities at the right times and in the right condition. Supply chains do not make money; their operational performance affects the financial success of individual firms. Thus, any negative impact from the operations of a supply chain affects the bottom line of a firm. In our model of supply chain resilience, we posit that supply chain resilience should be measured relative to how well it serves individual firms in their pursuit of financial success. In the present study, we propose that strategies of robustness and agility mediate the operational performance of a supply chain.

> *Hypothesis 7: Supply Chain Robustness is positively associated with Operational Performance.*

> *Hypothesis 8: Supply Chain Agility is positively associated with Operational Performance.*

Research Model

As stated in the aforementioned hypotheses, this research proposes that the interfirm processes of coordination and cooperation are key antecedents to supply chain resilience strategies of robustness and agility, which in turn affect the operational performance of the supply chain. In looking at the impact of ICT, we posit that firms utilizing cloud-based technologies will see stronger relationships between the antecedents of coordination and cooperation and supply chain resilience strategies than other firms that depend on traditional ICT approaches, such as on-premise and hosted systems. Additionally, we postulate that firms using cloud-based systems will demonstrate stronger relationships between their strategies of supply chain resilience and the operational performance of their supply chains. Figure 2 depicts the research model tested in this study.

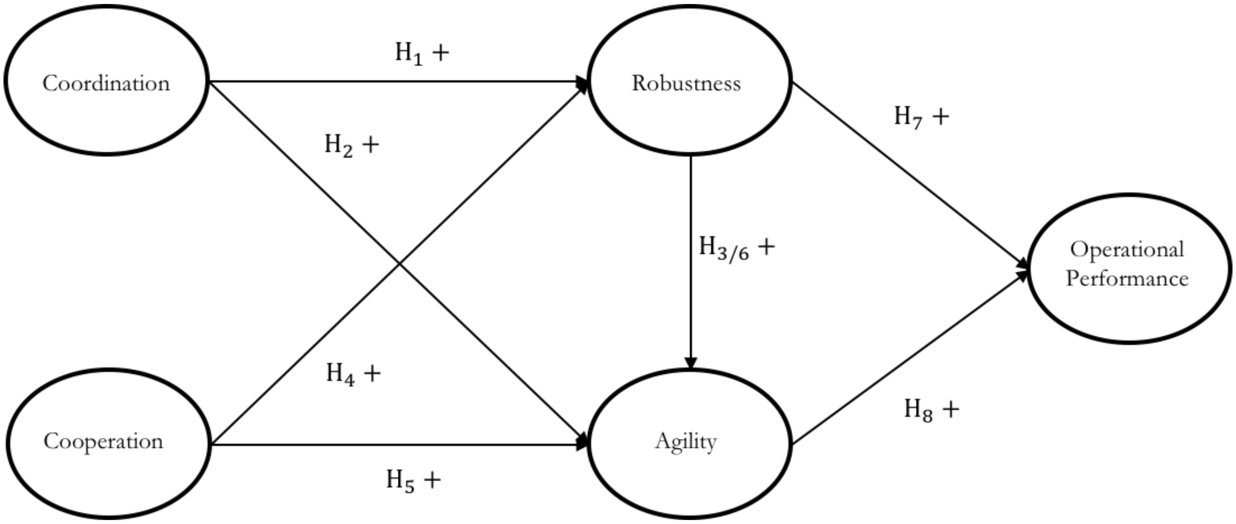

Figure 2. Research Model

Methodology

Sample Description

This study was conducted using survey methods. Survey responses consisted of single informants whose occupation related to logistics, operations, or supply chain management within their organization. Empirical data for our research model was collected through an online survey, distributed through the Internet-based Amazon Mechanical Turk (AMT) website. AMT is a human intelligence marketplace where, for a nominal fee, individuals can voluntarily elect to complete pre-defined tasks. AMT offers an opportunity to improve realized sample size, collect supply chain management survey responses on well-defined criteria (Knemeyer & Naylor, 2011), and collect enough data to employ statistical techniques affected by sample size (Schoenherr, Ellram, & Tate, 2015). Data collected from Internet sources has been previously utilized in supply management research to study supply chain analytics (Zhu, Song, Hazen, Lee, & Cegielski, 2018); collaborative technologies (Adams, Richey Jr, Autry, Morgan, & Gabler, 2014); supply chain technology adoption (Autry, Grawe, Daugherty, & Richey, 2010); and inter-organizational behaviors and operational flexibility (Grawe, Daugherty, & Roath, 2011).

The survey in AMT was limited to individuals who held managerial or executive jobs in retail, wholesale, distribution, or manufacturing firms. Criteria pertaining to employment industry, geographical location, and respondent task completion rate were defined on the AMT task. Individuals who did not meet the criteria the AMT task criteria were prevented from participating in the survey. Employing survey strategies recommended by Schoenherr et al. (2015), respondent job functions and titles were screened within the survey to protect against misrepresentation of qualifications and to improve response quality. Those who failed to meet established criteria were prevented from completing the rest of the survey. Additionally, “attention filters” were used throughout the survey to assess the attentiveness of respondents (Schoenherr et al., 2015). Finally, survey completion was limited by IP address to prevent repeat survey takers.

A total of 187 responses were received from AMT workers. These were screened for disengaged responses and "attention filter" questions. Five respondents were deemed "disengaged" and subsequently deleted from analysis. In addition to disengaged responses, we evaluated responses based on adequate responses to "attention filter" questions. Eight responses were removed from the final sample due to the respondent failing to adequately answer five "attention filters" placed into the survey instrument. After screening, a total of 174 responses were retained as the final sample for statistical analysis. Demographics of the sample used for statistical analysis are presented in Table 2.

Table 2

Respondent Demographics

Demographic	**Count**	**Percent**	**Cumulative Percent**
Job Function			
Logistics	12	7%	7%
Operations	80	46%	53%
Supply Chain	82	47%	100%
Job Title			
Supply Chain Executive	15	9%	9%
President/Vice-President	5	3%	12%
Senior Director/Director	7	4%	16%
Senior Manager	25	14%	30%
Manager	122	70%	100%
Firm Size			
1 – 500	102	59%	59%
501 – 1,000	21	12%	71%
1,001 – 1,500	11	6%	77%
1,501, - 2,000	4	2%	79%
> 2,000	36	21%	100%
Annual Sales Revenue			
$10 million and less	46	26%	26%
More than $10 million, up to $50 million	51	29%	56%
More than $50 million, up to $100 million	19	11%	67%
More than $100 million, up to $200 million	12	7%	74%
More than $200 million, up to $500 million	18	10%	84%
More than $500 million, up to $1 billion	7	4%	88%
More than $1 billion	21	12%	100%

Measures

All scales utilized were previously established by extant studies in the areas of relation-based view of the firm and supply chain resilience. Table 3 provides a summary of the dimensions of each latent construct and example questions used in the questionnaire.

Table 3

Measurement Summary: Content, Sources, and Sample Questions

Latent Construct[1]	**Content**[2]	**Sample Question**
COORDINATION (I = 3, F = 3)	Alignment of actions between two companies. S = (1, 3)	Implementation plans are formed jointly with other key supply chain members.
COOPERATION (I = 3, F = 3)	Alignment of interest between two firms. S = (1, 3)	There is a cooperative attitude between our firm/SBU and other key supply chain members.
ROBUSTNESS (I = 8, F = 5)	Supply chain's ability to withstand a disruption to its operations S = (2, 4), (3, 4)	For a long time, our supply chain retains the same stable situation as it had before changes occur.
AGILITY (I = 8, F = 8)	Supply chain's ability to quickly adjust its tactics and operations after experiencing a disruption S = (1, 8)	Detect changes in supply in a timely manner.
OPERATIONAL PERFORMANCE (I = 3, F = 3)	Perception of performance on activities that fulfill customers' needs and wants. S = (1, 3)	Delivers undamaged orders each time.

Note:
(1) I = Initial number of scale items, and F = final number of scale items after measure refinement
(2) S = (Source, Number of Items): (1) = Gligor and Holcomb (2012), (2) = Wieland and Wallenburg (2013), (3) = Durach et al. (2015)

Following an analysis of results from a pilot test involving 151 participants recruited through AMT, we decided to retain the original wording of each scale. An ordered progression of factor analysis (Anderson & Gerbing, 1988) was conducted to determine the structure of items and the proposal of the measurement model. The exogenous constructs of coordination and cooperation were adapted from the study by Gligor and Holcomb (2012). Supply chain robustness was measured using four items from the study of Wieland and Wallenburg (2013) and four additional items were created by modifying the definitions of supply chain robustness as provided in the systematic literature review of Durach et al. (2015). Supply chain agility and operational performance were measured using the scales originally developed by Gligor and Holcomb (2012). All variable scales were measured using a 7-point Likert-type response, and reversed coded scales were manipulated prior to analysis.

Analysis and Results

This study analyzes the proposed research model with partial least squares (PLS) structural equation modeling (SEM) using SmartPLS 3.0. PLS-SEM is a causal modeling technique, the objective of which is to maximize the explained variance of dependent latent constructs by estimating partial relationships in a repeated sequence of ordinary least squares regressions (Joe F. Hair, Ringle, & Sarstedt, 2011). The decision to use of PLS-SEM in this study was made on the basis of PLS-SEM’s use in theory development and its ability to handle small sample sizes.

Measurement Assessment

The item-construct relationships used in this study were reflective in that the theorized construct is considered to produce the manifest item (Chin, Peterson, & Brown, 2008). Reflective measurement models are evaluated through a review of reliability, convergent validity, and discriminant validity (Hair Jr, Hult, Ringle, & Sarstedt, 2016, p. 105). The reliability of our items is reported in two tests. First, we report the composite reliability (CR) of our constructs as a measure of internal consistency reliability. The CRs for all latent constructs in our model were above the 0.70 threshold, indicating acceptable reliability (Bagozzi & Yi, 1988; Hair Jr et al., 2016, p. 111). Since CR tends to overestimated internal reliability (Hair Jr et al., 2016, p. 111), we also report the Cronbach's alpha, which often underestimates internal reliability. All Cronbach's alphas exceeded a value of 0.70, also indicating adequate reliability (Cronbach; Joseph F Hair, Black, Babin, & Anderson, 2010, p. 125). Based on the reported CRs and Cronbach's alphas, we conclude that the reliability of our model's constructs is acceptable.

Evaluation of a convergent validity within a PLS-SEM model is assessed by examining the outer loadings of items and average variance extracted (AVE) of each construct (Hair Jr et al., 2016, p. 113). The outer loadings of each item within the proposed research model are presented in Table 4.

All item loadings exceed the recommended threshold of 0.708 (Hair Jr et al., 2016, p. 113), with each item's p-value indicating statistical significance. Additionally, the AVEs of each construct are also reported in Table 4 As shown in Table 4, each construct's AVE exceeds the proposed minimum threshold of 0.50 (Bagozzi & Yi, 1988; Fornell & Larcker, 1981). The outer loadings of the items and the construct AVEs reported in Table 4 confirm the convergent validity of the measurement model. With composite reliability and convergent validity of the constructs in our model confirmed, we provided evidence leading to the establishment of discriminant validity.

Discriminant validity within a measurement model indicates the degree of differentiation between each construct and the ability of each construct to measure a distinct nomological concept (Hair Jr et al., 2016, p. 114). Discriminant validity is evaluated by comparing the square root of each construct's AVE against its correlation with other constructs (Fornell & Larcker, 1981). Table 4 reports the square root of each construct AVE along with the inter-construct correlations. The values reported in Table 4 indicate that the square root of each construct's AVE exceeds the inter-construct correlations, implying adequate levels of discriminant validity.

Table 4

Composite Reliability and Convergent Validity Measures

Construct	**Items**	**Loadings**	**p-value**	**Cronbach's alpha**	**CR**	**AVE**
Coordination				0.908	0.942	0.845
	COORD1	0.918	0.000			
	COORD2	0.929	0.000			
	COORD3	0.910	0.000			
Cooperation				0.841	0.904	0.758
	COOP1	0.882	0.000			
	COOP2	0.897	0.000			
	COOP3	0.832	0.000			
SC Robustness				0.858	0.898	0.638
	SCR3	0.778	0.000			
	SCR4	0.781	0.000			
	SCR6	0.828	0.000			
	SCR7	0.778	0.000			
	SCR8	0.826	0.000			
SC Agility				0.931	0.944	0.677
	SCA1	0.775	0.000			
	SCA2	0.723	0.000			
	SCA3	0.828	0.000			
	SCA4	0.805	0.000			
	SCA5	0.861	0.000			
	SCA6	0.869	0.000			
	SCA7	0.858	0.000			
	SCA8	0.852	0.000			
Operational Performance				0.872	0.921	0.795
	OPPERF1	0.888	0.000			
	OPPERF2	0.882	0.000			
	OPPERF3	0.905	0.000			

Note:
(1) SCR1, SCR2, and SCR5 deleted due to outer loadings < 0.70
(2) COORD = Coordination; COOP = Cooperation; SCR = Supply Chain Robustness; SCA = Supply Chain Agility; OPPERF = Operational Performance

As an additional assessment of discriminant validity, the heterotrait-monotrait (HTMT) ratio of correlations are also reported. The HTMT ratio estimates the disattenuated correlation between two constructs by reflecting the amount of indicator correlation across constructs relative to the mean correlation of indicators measuring a single construct (Henseler, Ringle, & Sarstedt, 2015). An HTMT ratio above a value of 0.90 indicates a lack of discriminant validity. The HTMT ratios for the proposed model are reported in the top-half of Table 5. All HTMT ratios are below the specified threshold of 0.90, indicating that each of the measured constructs within our model is conceptually distinct.

Table 5

Discriminant Validity Measures

Construct	**SCA**	**COOP**	**COORD**	**OPPERF**	**SCR**
SCA	**0.823**	*0.674*	*0.683*	*0.569*	*0.843*
COOP	0.601	**0.871**	*0.763*	*0.447*	*0.633*
COORD	0.626	0.671	**0.919**	*0.409*	*0.577*
OPPERF	0.523	0.388	0.366	**0.892**	*0.631*
SCR	0.759	0.544	0.515	0.559	**0.799**

Note:
(1) Bolded diagonal elements are square roots of the construct AVE. Inter-construct correlations are presented in the bottom half of the table. HTMT ratios are italicized and presented in the top half of the table.
(2) COORD = Coordination; COOP = Cooperation; SCR = Supply Chain Robustness; SCA = Supply Chain Agility; OPPERF = Operational Performance

Structural Path Assessment

In confirming the validity and reliability of our construct measures, we now turn to assessing the results of the proposed structural model (Figure 2). Estimating the structural path provides statistical evidence of relationships between proposed constructs in a model. In first testing for collinearity in our model, we find that the variance inflation factors for each relationship between constructs was lower than the value of 5 (Hair Jr et al., 2016, p. 142), indicating low levels of linearity among our constructs and appropriate estimations of our posited relationships.

Through 1,000 iterations, the PLS algorithm revealed that the constructs of COORD and COOP explained 66.0% and 33.7% of the variance in SCA and SCR, respectively. Additionally, the results of the PLS-SEM indicated that 33.5% of the variance in OPPER was explained through SCA and SCR. Path coefficients were estimated through 5,000 bootstrap samples drawn from the original sample. As shown in Table 6, the relationship between COORD and SCR was determined to be significant ($\beta = 0.273$, $p = 0.006$), as well as the relationship between COORD and SCA ($\beta = 0.252$, $p = 0.02$).

Table 6

Structural Path Measures

	Standardized β	**t-value**	***p*-value**	**Collinearity**	
				Tolerance	**VIF**
Direct Effects					
COORD → SCR	0.273	2.773	0.006	0.550	1.818
COORD → SCA	0.252	2.336	0.020	0.518	1.930
COOP → SCR	0.361	4.410	0.000	0.550	1.818
COOP → SCA	0.127	1.590	0.112	0.497	2.014
SCR → OPPERF	0.381	3.997	0.000	0.424	2.361
SCA → OPPERF	0.234	2.541	0.011	0.424	2.361
Indirect Effects					
COORD → SCR → SCA	0.153	2.885	0.004		
COOP → SCR → SCA	0.202	3.436	0.001		

Note:
(1) COORD = Coordination; COOP = Cooperation; SCR = Supply Chain Robustness; SCA = Supply Chain Agility; OPPERF = Operational Performance

Thus, support was found for H1 and H2. The indirect effect of COORD on SCA through SCR was found to be significant ($\beta = 0.153$, $p = 0.004$), indicating complementary or partial mediation (Baron & Kenny, 1986; Xinshu Zhao et al., 2010). The construct of COOP was found to positively influence SCR ($\beta = 0.361$, $p < 0.001$), but the relationship between COOP and SCA

($\beta = 0.127$, $p = 0.112$) was determined to be fully mediated by SCR ($\beta = 0.205$, $p = 0.001$) (Baron & Kenny, 1986; Xinshu Zhao et al., 2010). Therefore, we find support for H4 and H6, but not for H5. Finally, there were significant positive relationships between SCA and OPPERF ($\beta = 0.233$, $p = 0.011$), and SCR and OPPERF ($\beta = 0.381$, $p < 0.001$). Hence, we conclude support for both H7 and H8.

Multiple Group Analysis

To assess the impact of cloud-based computing on supply chain resilience, we subject our structural path model to a partial least squares multiple group analysis (PLS-MGA). PLS-MGA is a non-parametric, one-tailed test that compares observed distributions of bootstrapped estimates of path coefficients between groups (Hair Jr, Sarstedt, Ringle, & Gudergan, 2017, p. 150; Henseler, Ringle, & Sinkovics, 2009).

Table 7

PLS-MGA Results

	Standardized *β* (*p-values*)		**PLS-MGA**	
	Cloud	**Non-Cloud**	**Difference**	***p-value***
Direct Effects				
COORD → SCR	0.510 (*0.044*)	0.247 (*0.020*)	0.263	0.168
COORD → SCA	0.296 (*0.018*)	0.232 (*0.074*)	0.065	0.349
COOP → SCR	0.038 (*0.879*)	0.432 (*0.000*)	0.394	0.931
COOP → SCA	0.227 (*0.039*)	0.108 (*0.250*)	0.119	0.201
SCR → OPPERF	0.176 (*0.289*)	0.413 (*0.000*)	0.237	0.885
SCA → OPPERF	0.474 (*0.034*)	0.189 (*0.082*)	0.285	0.127
Indirect Effects				
COORD → SCR → SCA	0.264 (0.072)	0.141 (0.019)	0.122	0.208
COOP → SCR → SCA	0.019 (*0.889*)	0.247 (*0.001*)	0.228	0.927

Note:
(1) COORD = Coordination; COOP = Cooperation; SCR = Supply Chain Robustness; SCA = Supply Chain Agility; OPPERF = Operational Performance

Prior to running the PLS-MGA, we further refined our groups into two categories: cloud-based (*n* = 38) and non-cloud based systems (*n* = 136) - to test the influence of cloud-based systems on our model. Table 7 shows that the result of 5,000 bootstrap sample PLS-MGA indicates that the posited relationships in the research model do not statistically differ between different types of information systems. Thus, we conclude that cloud-based architecture does not influence the relational antecedents to supply chain resilience as proposed in this study.

Implications for Research and Practice

This study's results suggest that supply chain resilience is largely based on the ability of firms to develop relational processes among their supply chain partners, however, we report that information system architecture does not significantly moderate these relational processes. While our research failed to uncover positive, relational implications for adopting cloud computing technology, the results of our main model shed light on the importance of strong interfirm relational processes in building supply chain resilience.

In this study, we proposed two relational processes – cooperation and coordination – as antecedents to the dimensions of robustness and agility within the concept of supply chain resilience (Gligor & Holcomb, 2012; Wieland & Wallenburg, 2013). We hypothesized that cooperation would positively influence the robustness and agility of a supply chain. We found that cooperation has a significant direct effect in building the proactive strategy of robustness, but that its influence does not directly influence the ability of a supply chain to adapt to unexpected events. This finding differs from that of Wieland and Wallenburg (2013), who found cooperation to have a statistically significant influence on the dimension of agility, but they did not propose the dimension of robustness to have a mediating influence on supply chain agility.

Yet our results align more with those of Gligor and Holcomb (2012), who concluded that in forming agility within a supply chain, cooperation is mediated by the process of communication. Their operationalization of communication rests on the definition of sharing information between firms (Anderson & Narus, 1990). This definition suggests that communication is a proactive process, much like our operationalization of supply chain robustness. Therefore, our operationalization of supply chain robustness as proactive measures serves as an enabler through which interests are aligned and maintained during periods of disruption.

Our positing of coordination as an enabler of robustness and agility supports previous studies on supply chain agility as a concept and provides new evidence that advance coordination is critical to the attainment of resilience within a supply chain. We found coordination to have a significant positive influence on both proactive and reactive strategies of supply chain resilience, even when proactive strategies of robustness were hypothesized to mediate the relationship between the process of coordination and the development of agility in a supply chain. Speed in action has been noted as an important characteristic of agile supply chains (Christopher & Peck, 2004; Hohenstein et al., 2015; Manuj & Mentzer, 2008; Wieland & Wallenburg, 2013). For supply chains to adapt and reconfigure themselves, at any rate, in response to an unexpected event, the coordination between firms has to be frictionless. Thus, coordination is an imperative process in building supply chain resilience, and our results confirm this relationship.

Unique to this study is the supposition that supply chain robustness is a mediator to the construct of supply chain resilience. The theoretical development of supply chain robustness as a construct has received little research attention (Durach et al., 2015). This study is believed to be the first that posits supply chain robustness as a mediating construct. Our results support our hypotheses that proactive strategies influence the reactive capability of a supply chain. We suspect that our results make intuitive sense: the more supply chain is able to resist and avoid (Durach et al., 2015) change, the less it has to react to unexpected events by changing. For supply chain managers, the conclusion to be drawn is that maintaining high states of readiness are imperative to being able to react to disruptions within supply chains.

Finally, the results of this study confirm that ICT is not a panacea for firms to fortify themselves against disruption. Supply chains have both social and technical dimensions (Robert F. Lusch, 2011; Mentzer, DeWitt, Keebler, Min, & et al., 2001) in what capability must be pursued and developed for operations to effective in all situations. Our results indicate that building relationship processes between firms is more important than the technology through which those relationship processes are conducted. Our results on the influence of technology are statistically insignificant, but also provide further evidence that while ICT may be an enabler of supply chain capabilities, the real impact for firms rests within their management of relationship competencies (Fawcett et al., 2011).

Limitations and Future Research

One of the aims of this research was to minimize limitations while contributing to existing bodies of literature devoted to interfirm relationships, supply chain resilience, and ICT. While our study is not without limitations, the ones we have identified are opportunities for future research. First, our study consists of responses obtained from a survey research firm. Criticism may be levied against the validity of this type of data collection method, but increasingly, business professionals are demonstrating survey fatigue, as is widely known. Thus, different data collection methods could be an avenue to building on the research presented herein. Additionally, we did not differentiate between service-oriented and product-oriented firms. Delineating the results obtained from this study based on these two orientations may provide a fruitful avenue for future research. As information technology is often evolving, future research could include a longitudinal study on the advantages cloud-based computing offers to firms that adopt the technology. Another opportunity for future research is to ascertain whether managers at different levels of the supply chain have the same knowledge and perspective of the influence of their information technology systems (Fawcett et al., 2011). Future research into this area could explore these differences.

Second, our research model is a continuation of extant research aiming to develop a theoretical model of supply chain resilience. Our model combines the different constructs of the models developed by Wieland and Wallenburg (2013) and Gligor and Holcomb (2012). Both of their models propose other constructs that with continued refinement, could substantially contribute to the concept of supply chain resilience. Our study also extends existing literature by finding support for the influence of supply chain robustness on supply chain agility. Previous literature (Wieland & Wallenburg, 2012) has stated that the two constructs are independent; while our study finds support that the steps taken to fortify a supply chain to withstand disruption positively influence decision-making in the face of uncertainty. Future exploration into the development of supply chain robustness as a construct could be a substantial contribution to the research within supply chain management and resilience.

Third, the constructs within our model were all reflective (Chin et al., 2008), as is common with past research on supply chain resilience. We propose that a better theoretical model of supply chain resilience may actually be formative where indicator items combine to form the constructs of robustness, agility, and resilience. Possible manifest variables could be centered on interfirm relationships, firm resources, and industry characteristics. We believe that numerous opportunities exist for the pursuit of a formative model of supply chain resilience.

In sum, research in ICT is constantly evolving, and research into supply chain resilience remains its infancy. There is much to be gained by continually advancing research into both areas. We hope that our work serves as a starting point for other supply chain management scholars.

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IMPACT OF DATA ANALYTICS AND HUMAN COGNITION ON SUPPLY CHAIN PERFORMANCE

Introduction

Using information technology (IT) within logistical operations has been shown to improve the resilience and performance of a supply chain, which explains why companies have made significant investments in IT (Hazen & Byrd, 2012). By 2019, expenditures on real-time data analytic solutions are predicted to increase three-fold as companies position themselves to better respond to changes generated by customers, competitors, and stakeholders (Gartner, 2017). IT expenditures are estimated to exceed $13 billion as companies seek to leverage emerging information technology solutions that offer more flexible and affordable strategies for managing supply chain operations (van der Meulen & Forni, 2017). But the key to implementing a particular technology is the decision-maker who applies the information it provides. As recent as last year, 28 percent of firms described their IT implementation as a failure, due to a disequilibrium between the chosen technology solution and the skills of the organization (Tait, 2017).

Under the umbrella of information technology, data analytics can help companies enhance the resilience and performance of their supply chain through scenario modeling and pre-programmed responses (Wright, 2013). Data analytics are quantitative and qualitative methods that allow for a better understanding of the business environment and for more timely decision-making (Hsinchun, Chiang, & Storey, 2012). Companies seek to improve supply chain performance by applying analytics to improve decision-making at various function levels. In the broad scope of supply chain management, logistics predictive analytics allow for estimates of past and future behavior for the movement and storage of inventory (Waller & Fawcett, 2013).

Implementing advanced data analytics (i.e., artificial intelligence) within supply chains, however, takes time and advanced skills. This explains why a majority of businesses turn to analytic solutions that still rely on humans to convert information into knowledge and action (Harrington & Gooley, 2018). Research on supply chain decision-making (Narayanan & Moritz, 2015; Steckel, Gupta, & Banerji, 2004) and inventory management (Croson & Donohue, 2006) shows that it is not always the information or analytic tool that predicts supply chain performance, but how the human decision-maker interacts with the information the tool provides. Previous studies have demonstrated that there is much more to gain by understanding how individuals cognitively use technology and how technology impacts the cognition of individuals.

Drawing on previous research by Croson and Donohue (2006) and Narayanan and Moritz (2015), this study examines the reciprocal influence of data analytics and human decision-making. Decision-makers use data analytics to solve problems and predict outcomes. Scholars posit that the success of data analytics, and data in general, rests on how the decision-maker cognitively processes information (Fawcett, Magnan, & McCarter, 2008a). Research that examines the interaction of the decision-maker’s cognitive processes and data analytics is missing in the literature. Even less attention has focused on this interplay within a supply chain management setting (Schorsch et al., 2017; Tokar, 2010; Wieland, Handfield, & Durach, 2016). This paper focuses on logistics predictive analytics, which Waller & Fawcett (2013) describe as “both quantitative and qualitative methods to estimate the past and future behavior of the flow and storage of inventory.” This topic allows us to address an emerging gap in research: the reciprocal influence of data analytics and supply chain decision-making.

Guided by system theory, we draw on behavioral decision theory to understand the impact of data analytics on decision-making within a supply chain setting. Specifically, we focus on how decision-makers use data analytics to cognitively select courses of action and consider the consequences of those actions. The Cognitive Reflection Test (CRT) is used to profile how the decision-maker selects a particular course of action (Frederick, 2005). Employing the Consideration of Future Consequences (CFC) scale of Joireman et al. (2012), we classify decision-makers by how they consider the future consequences of their choices. Once classified according to CRT and CFC instrument scores, decision-makers make dynamic inventory decisions using the beer game (Sterman, 1989). The beer game is a well-known supply chain simulation that allows for direct measurement of subject behavior against assumed decision rules of a four stage, serial echelon supply chain (Croson & Donohue, 2006; Sterman, 1987). Decision-makers play one of two versions of the beer game in this study. One version limits the information available to the decision-maker, while the other uses data analytics to aid the decision-maker in their comprehension of the supply chain environment. Supply chain performance for the CRT and CFC profiles are then analyzed in terms of cost at both the echelon and supply levels. Average order quantity and order variance at the echelon levels are evaluated as ancillary measures of performance (Narayanan & Moritz, 2015). We also examine the impact of data analytics on supply chain performance during normal and disrupted states of operations. We hypothesize that the presence of data analytics in the decision-making environment moderates a decision-maker’s ability to evaluate alternatives of action and link those actions to future outcomes.

The results of this study, obtained from 486 subjects who played the beer game in homogenous groups of four players, confirm previous findings about the impact of cognitive reflection (CR) on supply chain performance (Narayanan & Moritz, 2015). Our research demonstrates that how decision-makers consider the future consequences of their actions influences supply chain performance. Decision-makers high in CR have better performance, in terms of costs and order variability. Regarding temporal discounting, our results were unexpected and ran counter to previous studies regarding behavior in the context of time (Joireman, Balliet, Sprott, Spangenberg, & Schultz, 2008; Joireman, Sprott, & Spangenberg, 2005). Our study shows that rather than contributing to better supply chain performance, decision-makers who consider more distant consequences contribute to decreased supply chain performance through increased supply chain costs and order variability.

The rest of this study is organized as follows. The next section presents a review of the literature that is relevant to the concepts of supply chain behavior, behavior decision theory, and human cognition. We also develop hypotheses to determine the impact of data analytics on echelon decision-making behavior and holistic behavior of the supply chain. The subsequent section describes methodology-related issues pertaining to the experiment's environment and protocol. Then, we present and discuss our findings in relation to the existing literature on decision-making, supply chain resilience, and supply chain management. Finally, we conclude with implications for scholars and practitioners, present the study's limitations, and propose opportunities for future research.

Literature Review and Hypotheses

Supply chains are complex systems, consisting of technological and social dimensions that interact across time and space to create value for customers and stakeholders (Robert F. Lusch, 2011). In the performance of supply chains, people are considered a key resource, but their actions and decision-making abilities are often assumed. Sweeney (2013) notes the fundamental importance of the soft-wiring of supply chains—the human (social) dimension—in determining a supply chain's ability to reach its potential. He states that supply chains are developed by people to meet the needs of other people. But a number of authors have identified the fragmented and divergent nature of research on the role of micro-level human behavior in supply chain management (SCM). Examining the five top logistics journals, Tokar (2010) found only three articles published in 30 years that explored the impact of human behavior. In their systematic literature review of human resource management issues, which looked at 12 SCM-related journals, Hohenstein et al. (2014) found only 58 articles published in 16 years that investigated the influence of human resources on supply chain performance.

General systems theory (Bertalanffy, 1969, p. 38) maintains that a system is a set of diverse individual parts, interrelated and integrated for the purpose of achieving a common goal (Baldwin et al., 2010). Decision-makers and technology are the interrelated parts of a supply chain system; it is their interaction that gives a supply chain its structure and behavior (Meadows, 2008, p. 188). From a philosophical perspective, it important to manage human judgment and decision-making, both of which create variance in supply chain behavior. Thus, we must understand how individual differences result in decisions that often violate the normative theories of decision-making. To obtain this understanding, we draw on behavioral decision-theory, which has its roots in the normative principles of economic theory.

Decision Theory in Supply Chain Management

As a cross-discipline of business, SCM research has often borrowed from other research fields such as economics to explain decision-making in supply chain operations (Mentzer &

Kahn, 1995). New disciplines often borrow theories from established fields (Arlbjorn & Halldorsson, 2002) to accelerate knowledge development (Stock, 1997). Within the context of business, descriptive and prescriptive decision-making theory is derived from economics (Bartels, 1965, p. 19). Foundational principles of normative human decision-making theory can be found in Paul Samuelson's work on measuring consumer utility and consumption (Carter, Kaufmann, & Michel, 2007; Paul A. Samuelson, 1937; P. A. Samuelson, 1938; Paul Anthony Samuelson, 1947). Samuelson’s research (1947) resulted in the model of a human economic decision-maker who is perfectly rational. This model, often called “economic man” or “homo economicus,” describes an individual who possesses complete information, is sensitive to future results of the choices he makes, and has the ability to order the outcomes of decisions to maximize the desired outcome’s expected value or worth (Edwards, 1954). Samuelson and his economic man model, with all the assumptions it contains, has been the impetus for many theories used in business and SCM (Carter et al., 2007).

Despite the utility of Samuelson’s assumptions, criticisms have been levied against such a simplified explanation of human behavior. Researchers have shown that regular patterns of deviation, the result of biased human decision-making, are often part of economic decisions (Kahneman, 2003, p. 219; Kahneman & Tversky, 1979). Criticism of the economic man model has spurred behavioral decision theory, which accounts for psychological aspects of human judgment and bias in the context of decision-making. Largely based on decision science research (Simon, 1955, 1959) and psychology (Edwards, 1954, 1961), the theory of behavioral decisions tests the axioms of the economic man model from descriptive and normative points of view (Barron, 1974) in various decision-making environments. Behavioral decision theorists argue that economic theory and its mathematical theorems neglect underlying psychological dimensions and judgment biases that explain individual human behavior in complex environments (Edwards, 1954). Simon (1955) advocated for including the principles of human psychology in his behavior model of rational choice, an effort to replace economic man's universal reason with the concept of "bounded rationality," emphasizing humanity's physiological and psychological limitations. The behavior model claims that rather than always rational and utility-maximizing, human behavior is rationally intended and utility-satisfying (Simon, 1955). Simon (1979) contended:

> There can no longer be any doubt that the micro assumptions of theory–the assumptions of perfect rationality–are contrary to the fact. It is not a question of approximation; they do not even remotely describe the processes that human beings use for making decision in complex situations.

Proponents of behavior decision theory proclaimed its applicability to business phenomena (Churchman, 1961; Simon, 1979), setting a precedent for future research on human judgment in business decision-making. But behavioral-related research in SCM has been conducted at the organizational or supply chain levels (Autry, Skinner, & Lamb, 2008; Barratt, 2004; Cassivi, 2006; Day, Fawcett, Fawcett, & Magnan, 2013; Emberson & Storey, 2006; Fawcett, Magnan, & McCarter, 2008b; Gaski, 1984; Heide & Wathne, 2006; Hoyt & Huq, 2000; Humphries & Wilding, 2004; Parkhe, 1993; Vangen & Huxham, 2003; Wilding & Humphries, 2006; Williamson, 1965). The importance of understanding the judgment and cognition of the individual decision-maker on larger supply chain-related activities cannot be understated as an emerging and necessary problem within SCM. Thus behavior decision theory, with its focus on the physiological limitations of human behavior, is increasingly significant in the field of SCM (Carter et al., 2007; Carter, Meschnig, & Kaufmann, 2015; Schorsch et al., 2017).

Cognitive Theory in Supply Chain Management

Among the many psychological theories that behavioral decision theory encompasses, we draw on Dual-process theory (DPT) (Stanovich & West, 1998) to understand how decision-makers select courses of action. DPT proposes that people select a choice of action in two distinct, sequential processes. The first is intuitive cognition (Stanovich & West, 1998), a process called System 1. This series of automatic, unconscious responses is pattern-based and minimal in computational effort. The second process, System 2, is associated with deliberation and analytical intelligence (Narayanan & Moritz, 2015; Stanovich & West, 1998). The System 2 process is characterized by measured responses that are computationally complex. DPT posits that these two processes work sequentially (Stanovich & West, 1998). Kahneman (2011, p. 24) maintains that System 1 is the first to be executed in our decision-making processes and that it is always operating. System 2 monitors the responses in System 1 (Narayanan & Moritz, 2015) and either endorses or overrides these, based on rational reasoning and analytical abilities. System 2 is also called upon when System 1 is unable to form a response (Kahneman, 2011, p. 24).

Instantiating DPT's interpretation of human cognition within normative models of decision-making allows for the description of patterns of deviation in human performance. Normative decision theory assumes that an individual is aware of every possible alternative choice. DPT, in contrast, argues that people initially make choices based on intuitive reasoning, and that this choice will only change based on self-control and analytical intelligence. People with strong System 1 inclinations, or intuitive behavior, will usually select the first choice that comes to mind and forgo more computational complex reasoning. Within the beer game of Sterman (1989), decision-makers place orders that maintain a level of inventory to meet current and future demand. The receipt of inventory, however, is influenced by time delays in information and transportation. In this study, we posit that people with strong System 1 inclinations will forgo any analysis, considering the delays of the simulated supply chain system, and order only the minimum amount required to meet current demand. People with strong System 2 dispositions, or analytical reasoning, tend to override their initial choices and analytically process information available in the environment to derive higher satisfaction. In the context of this study, we believe that individuals with strong System 2 responses will make inventory choices that consider not only their current inventory position but also delays in the simulated supply chain system.

A three-question Cognitive Reflection Test (CRT) developed by Frederick (2005) was used to measure the deliberation and reflection of cognitive processes as proposed by DPT. Scores based on the CRT can be used to profile decision-makers, according to the likelihood that their selection of choices is based on intuition (System 1) or deliberate reasoning (System 2). We have opted to use the CRT since decision quality can be judged among decision-makers of differing CR. Research related to forecasting (Harvey, 2007; Moritz, Siemsen, & Kremer, 2014) and supply management (Narayanan & Moritz, 2015) has shown positive correlations between an individual's CR and performance within supply chain and logistical operations. Decisions within supply chains are often complex and may require higher cognitive abilities to determine the best alternative in an entire range of possible actions. We posit:

> *Hypothesis 1: Supply chains of decision-makers with high CR will demonstrate better performance than supply chains of decisions-makers with low CR.*

Within a system's structure, time is an important element that influences human judgment and decision-making. The predicted outcomes of a decision take place at an imagined point in time. A person's perception of time, including the subordinate concepts of time discounting and time preference, has been central to micro-economic and behavioral decision theory (Daly, Harmon, & Delaney, 2009; Frederick, Loewenstein, & O'donoghue, 2002). Decision-makers have been posited to be infinitely sensitive (Edwards, 1954; Simon, 1955). In other words, decision-makers are assumed to know all possible future outcomes. In economics, human time perception was first measured by the Discounted Utility (DU) model, which generalized that decision-makers evaluate trade-offs between choices in intervals of time (Paul A. Samuelson, 1937). The DU model, like other foundational principles of economics, ignores the underlying psychology of human decision-making. This oversight has led to many inadequacies in its description of decision-making (Frederick et al., 2002). Suggestions of the importance of time perception have penetrated organizational and SCM literature (Ellram & Hendrick, 1995), but the operationalization and treatment of the psychology of time in the broader scope of economic research leaves much to be desired (Heckman, 2007).

Construal Level Theory (CLT) is closely related to DPT but focuses on time’s influence on decision-making. CLT proposes that temporal distance to future events changes an individual’s mental representation of those events (Trope & Liberman, 2003). CLT proposes that individuals assess more future events with higher-level (abstract, simple representations) construal, while more near-term events are evaluated with lower-level (concrete, contextualized representations) construal. When it comes to predicting future events, CLT suggests that increased temporal proximity to an event leads to predictions of outcomes based on more high-level construal of the situation (Trope & Liberman, 2003). How decision-makers view time distance can increase the probability of discounting future consequences of current decisions (Zakay, 1993). If differences exist in the way decision-makers account for time in their decisions, then a decision-maker’s CFC should explain how decision-makers choose between alternatives of action. The temporal discounting of supply chain and logistical managers is a factor in supply chain performance because decisions in these processes, regarding demand management and order fulfillment, affect the supply chain's capacity to perform at a future point in time.

In profiling decision-makers on how they consider the outcomes of their choices, we use the 14-item consideration of future consequences (CFC-14) scale developed by Joireman (2012). Originally designed as a single factor, 12-item scale Strathman, Gleicher, Boninger, and Edwards (1994), the CFC-14 scale possesses two factors that measure the extent to which individuals consider the immediate and future consequences of their decisions. The first factor—consideration of future consequences-immediate (CFC-I) —measures the extent to which individuals consider the immediate outcomes of their decisions. The second—consideration of future consequences-future (CFC-F)—measures the extent to which individuals consider outcomes that may not materialize until a distant point in time. The CFC-14 scale assumes that considerations of immediate and future consequences are not opposites, and it allows researchers to explore the correlation between behavior and the weight the decision-maker places on each dimension of consequence (Joireman et al., 2012).

To the best of the authors' knowledge, the CFC-14 scale has not been used in studies of decision-making within the context of supply chain and logistical operations. The CFC-14 instrument, however, has been used to study fiscal responsibility (Joireman et al., 2005) and buying tendencies of consumers (Joireman, Kees, & Sprott, 2010). Both contexts are similar to the inventory ordering operations of supply chains, since most inventory decisions are influenced by cost. In our experiment, decision-makers select inventory order quantities that must balance near and future outcomes. Decision-makers' considerations of future consequences could be a key factor in how they select their order quantities and impact overall system-level performance of the simulated supply chain. In this study, we use the CFC-14 scale to differentiate between decision-makers who place orders to achieve immediate outcomes, such as immediate cost reductions, versus others who place orders to buffer against future potential outcomes, such as spikes in demand or disruptions in supply. We hypothesize:

> *Hypothesis 2: Supply chains of decision-makers who consider the future consequences of their decisions will demonstrate better performance than supply chains of decision-makers who consider the immediate consequences of their decisions.*

Data Analytics, Decision-Making, and Human Cognition

Information's influence on decision quality (Streufert, 1973) and supply chain performance (Gligor & Holcomb, 2012; Wright, 2013) has been extensively studied . Today, companies are increasing their use of information and communication technologies to guide and improve decision-making for supply chain and logistical operations (Lin, 2014; I.-L. Wu & Chang, 2012). But other researchers have shown that adopting information technology can negatively impact supply chain performance (F. Wu et al., 2006) because it can distract firms from concentrating on more important resources that influence performance (Barratt, 2004). Research has shown that information accessibility drives information use (O'Reilly, 1982), but decision-makers process information differently, based on their cognitive abilities (Slovic, Fischhoff, & Lichtenstein, 1977; Taylor & Dunnette, 1974).

The objective of data analytics in supply chain and logistics operations is to enhance decision-making by not only explaining the "what" of an event but also the "how" and "why" (Waller & Fawcett, 2013). The goal of supply chain and logistics data analytics is to better contextualize the decision environment and offer explanation and insight into the recommended course of action. Simon (1955) notes however, that the decision-maker influences the use of information as much as the information influences the decision-maker. Thus, we hypothesize:

Hypothesis 3: The presence of supply chain predictive analytics moderates the relationship of cognitive reflection of individuals and performance.

Hypothesis 4: The presence of supply chain predictive analytics moderates the relationship of an individual's consideration of future consequences and performance.

All activities of a supply chain involve degrees of individual decision-making (Tokar, 2010). Decisions taken within the context of organizations and businesses involve degrees of uncertainty because decision-makers lack knowledge of potential outcomes, have differing degrees in controllability of outcomes and, often overemphasize extreme outcomes (Zsidisin, 2003). How a decision-maker applies information that is gleaned from technology can determine outcomes for the company. The decision-maker's leveraging of technology, in conjunction with their own cognitive abilities, assumes greater importance in supply chain and logistical operations, because supply chains are often exposed to sources of disruption. Decisions during disruptions are often a larger driver of outcomes.

Order provides one example that illustrates the importance of decisions during disruptive supply chain events. We present the different outcomes for cell-phone companies Nokia and LM Ericsson AB in response to a lightning strike on a Philips's semi-conduct fabrication plant in New Mexico as cited by Sheffi (2005, pp. 3-8). Two companies, both affected by the same event, faced different outcomes based on the choices of decision-makers within their organizations. Decision-makers at Nokia applied information from joint information systems and communication with Philips to determine a set of actions, and then chose an action based on the consequences of future outcomes. In the end, Nokia's decision-making and action benefited the company and its shareholders who saw their end-of-year market share increase by three percent. On the other hand, LM Ericsson's outcome was the opposite. LM Ericsson AB took no action using information provided by Philips to evaluate alternatives of actions and consequences of future outcomes. In the end, they lost three percent of their market share. Decision-makers at both companies had information, but how they cognitively processed it and used it to make decisions resulted in very different outcomes.

This example reveals that the interaction of data analytics and decision-maker cognition can produce divergent outcomes. Prior research has shown that people high in CR outperform decision-makers who are low in CR when forecasts are incorrect due to external disturbances (Moritz et al., 2014). Additionally, theoretical research on decision-making under stress shows that individuals will often reduce their information processing and privilege more immediate outcomes (Zakay, 1993). The presence of analytics, though, may guide decision-makers by contextualizing the environment and providing a reference point from which to make decisions. Thus, we hypothesize:

> *Hypothesis 5: The presence of data analytics moderates the performance of supply chains composed of decision-makers low in CR after experiencing a disruption.*
>
> *Hypothesis 6: The presence of data analytics moderates the performance of supply chains composed of decision-makers with similar CFC.*

Research Approach and Methodology

This section presents our methodology for examining the impact that the interaction of data analytics and human cognition has on supply chain performance. First, we outline the environment of our behavioral experiment by explaining the simulation model used to place decision-makers in a position to make inventory ordering decisions. Next, we discuss how decision-maker CR and CFC is measured and utilized in our experiment. Finally, we explain the experiment protocol and implementation through which we investigate the interaction of data analytics and human cognition.

Experiment Environment

To study the interaction of data analytics and human cognition in the context of supply chain operations, the decision-making of human subjects was observed using the beer game developed by Sterman (1989). The game involves subjects making decisions, with each decision affecting not only the next decision, but also the decisions of other players. Practitioners and scholars have used the beer game to teach and study not only inventory management principles, but also to explore decision-making in stochastic environments (Chaharsooghi, Heydari, & Zegordi, 2008; Strozzi, Bosch, & Zaldívar, 2007).

The beer game simulation places subjects into a multi-echelon supply chain consisting of a raw material producer, factory, distributor, wholesaler, retailer, and customers. The beer game designed for this study simulates a basic pull supply chain system where ordering decisions are made in response to customer demand, and product is "pulled" through the supply chain (Chopra & Meindl, 2015, p. 10). Subjects are recruited to play echelon roles of a factory, distributor, wholesaler, or retailer. The software simulates the roles of raw material producer and market customers. All echelons in the supply chain, represented by $i = 0, \dots, 4$, interact over a series of time periods, denoted by $t = 1, \dots, T$. During each time period t, subjects are tasked with placing inventory quantity demands to their upstream echelon supplier, D_t^{j-1}, where $j = 1, \dots 5$, to be able to supply a determined amount of inventory to their downstream echelon, S_{t+1}^{i+1}, at a future time period. Inventory is only shipped to a downstream customer if the echelon shipping the inventory has sufficient inventory in stock. A backorder is incurred for an echelon if adequate inventory does not exist to fulfill current demand of the downstream echelon. Our study does not account for lost sales, thus all backorders for an echelon must be fulfilled before inventory can start to accumulate at an echelon.

Inventory levels, I_t^i, of each echelon can be expressed as a function of the previous period's inventory, shipments from the adjacent upstream echelon, and backorders and demands from the adjacent downstream echelon.

$$I_t^i = I_{t-1}^i + S_{t-1}^{i+1} - \beta_{t-1}^i - D_{t-1}^{i-1} \tag{1}$$

Backorders are calculated as a function of the previous period's inventory, shipments from the adjacent upstream echelon, and backorders and incoming demand from the adjacent downstream echelon.

$$\beta_t^i = \beta_{t-1}^i + D_{t-1}^{i-1} - I_{t-1}^i - S_{t-1}^{i+1} \tag{2}$$

The heuristics that subjects use to place orders amid the uncertainty of the game have been operationalized by Sterman (1989) through the research of Tversky and Kahneman (1974) on judgment under uncertainty. Heuristically, subjects will determine the order to be placed by anchoring their decision on the last known quantity of inventory lost to their downstream customer, D_{t-1}^{i-1} and adjusting their decisions based on subjective estimates of future demand, $\widehat{D}_t^{i-1}$; inventory, AS_t^i; and incoming shipments, ASL_t^i (Sterman, 1989; Strozzi et al., 2007). These heuristics reflect how heavily a subject considers the near-term or long-term considerations of his decision. They also represent risk to the performance of partnering subjects and the overall supply chain. Sterman (1989) posited that this heuristic decision could be represented by the following notation.

$$\widehat{D}_t^{i-1} = \hat{S}_t^{i+1} + AS_t^i + ASL_t^i \tag{3}$$

where

$$\hat{S}_t^{i+1} = \gamma S_{t-1}^{i+1} + (1-\gamma) S_t^{i+1} \tag{4}$$

$$AS_t^i = \alpha_I (I_t^{i-1} - I_t^i + \beta_t^i) \tag{5}$$

$$ASL_t^i = \alpha_{SL} (SL_t^{i-1} - SL_t^i) \tag{6}$$

Parameter γ is confidence weighting, ranging from 0 to 1, and parameter α is the subjective fractional estimate of stock that a decision-maker uses to adjust his or her actual stock back to their desired stock level (Sterman, 1989). Inventory replenishment demands cannot be negative, so the order placed with the adjacent upstream echelon is mathematically represented as the max$\{0, \widehat{D}_t^{i-1}\}$.

Costs, C_t^{i+1}, are calculated for each subject at the end of each period of play. Per period costs are calculated as the summation of holding costs, h, levied against the per period inventory level, I_t^i, and backorder costs, δ, levied against per period outstanding order quantities, β_t^i. The equation for per period cost can be found in equation seven. In this study, the holding cost of inventory was set to \$0.50 and backorder cost was set to \$1.00.

$$C_t^i = h\left(I_t^i\right) + \delta(\beta_t^i) \tag{7}$$

At the beginning of the game, subjects are given the objective of ordering inventory quantities that minimize their individual and overall supply chain's cumulative costs for the entire game. The game's overall objective is for each subject to make decisions that minimize the total costs of the supply chain incurred over all periods of play. The total cost function of each supply chain represents the primary dependent measure for this study. The cost function for an entire game can be written as follows.

$$C(T) = \sum_{i=1}^{4} \sum_{t=1}^{T} h\left(I_t^i\right) + \delta(\beta_t^i) \tag{8}$$

CRT Grouping

To evaluate the extent to which intuition and deliberation play a role in human decision-making, subjects were administered the CRT Frederick (2005) and profiled based on their scores. Using the schema of Narayanan and Moritz (2015), subjects were profiled based on the number of items correctly answered on the CRT instrument. Subjects who correctly answered two or more items in the three-question test were assigned a profile of “High.” These subjects represent decision-makers who use analytical rigor and deliberate reasoning while making decisions. Subjects who answered fewer than two items correctly were assigned a profile of “Low.” These subjects are characterized as decision-makers who display a tendency to make decisions based on intuitive responses.

CFC Grouping

Due to resource constraints, a method to reliably group subjects by the extent to which they considered the consequences of their decisions was required, also for successive trials involving new subjects. A discriminant function was developed based on the 14-item, two-factor “Considerations of Future Consequences” (CFC-14) scale of Joireman (2012). A Principal Component Analysis (PCA) on the responses of possible participants to the CFC-14 scale was performed to obtain a factor structure and corresponding coefficients to be used within a linear function to discriminate subjects based on their temporal discounting of outcomes. Prior to any experimental trials, a total of 384 responses to the CFC-14 instrument were obtained to calculate the factor coefficients to be used within the discriminant function.

A Varimax rotation was performed in the PCA to maximize the orthogonality of the two factors and the sum of variances of item loadings (Joseph F Hair et al., 2010, p. 115). The Kaiser-Meyer-Olkin measure (KMO = 0.84) indicated that the data justified the factor analysis, and Bartlett’s test of sphericity indicated sufficient correlations among the items (χ^2(df) = 1843.70, $p < 0.000$). Based on research performed by Joireman et al. (2008), the PCA was constrained to two factors, representing the CFC-I and CFC-F subscales. Total variance explained by the two derived factors was 49.17%. Factor loading scores on the future subscale of the CFC-14 scale ranged from 0.548 to 0.765. The factor loading scores for the immediate subscale ranged from 0.526 to 0.811. Each subscale demonstrated good reliability with a Cronbach's alpha for the CFC-14 subscale of 0.793 and a Cronbach's alpha for the CFC-I scale of 0.833 (Joseph F Hair et al., 2010, p. 125).

The resulting factor score coefficients along with the mean and standard deviation for each item of the CFC-14 scale are displayed in Table 8. During each experiment trial, subjects were profiled based on a standardized discriminant variate calculated with their responses to the CFC-14 scale and the values in Table 8. Subjects were profiled as either "future thinkers" (CFC-F) or "immediate thinkers" (CFC-I) based on their highest subscale score.

Table 8

Factor Coefficients, Means, and Standard Deviations

Item	CFC-I Coefficient	CFC-F Coefficient	Mean	Standard Deviation
Item 1 (F)	0.035	0.240	5.48	1.268
Item 2 (F)	0.057	0.203	4.72	1.521
Item 3 (I)	0.222	0.033	3.38	1.559
Item 4 (I)	0.208	0.023	3.34	1.570
Item 5 (I)	0.176	0.097	4.39	1.423
Item 6 (F)	0.008	0.181	5.27	1.479
Item 7 (F)	0.011	0.197	5.61	1.196
Item 8 (F)	0.098	0.199	4.40	1.354
Item 9 (I)	0.189	0.021	2.75	1.490
Item 10 (I)	0.202	0.023	2.76	1.438
Item 11 (I)	0.230	0.016	3.08	1.459
Item 12 (I)	0.203	0.040	3.68	1.401
Item 13 (F)	0.011	0.235	5.77	1.163
Item 14 (F)	0.036	0.245	5.27	1.257

N = 384
CFC-I – Consideration of Future Consequences-Immediate subscale
CFC-F – Consideration of Future Consequences -Future subscale

Experiment Protocol and Implementation

All experimental trials were conducted under the same protocol. At the beginning of each trial, attendance was taken to determine available participants. Then an 11-minute instructional video was shown to explain the structure of the supply chain, game objects, and the software interface used to play the beer game. During the showing of the video, participants were randomly placed in four-player, homogenous teams using a visual basic programming script that grouped them according to the CRT and CFC scores. In trials that counted odd numbers of subjects, some subjects were randomly assigned to individual games, where they played the role of retailer while the wholesaler echelon and market were simulated by the computer. These games were not evaluated as part of this study. Within each team, subjects were randomly assigned to one of four supply chain roles: retailer, wholesaler, distributor, or factory.

Timer: Timer Not Set.
Screen refreshes every 10 secs.

Last Order Amount Placed: 4

Last Order Amount Received: 5

Last Product Amount Received: 4

Last Product Amount Sold: 4

Place Order: 0

Login	Order Status
Factory	Pending
Distributor	Pending
Wholesaler	Pending
Retailer	Pending

Weekly Transaction History

Week	Product Received	Product Shipped Out	Your Inventory	Customer POS	Your Backlog	New Order Received	Total Needed	Unfilled Order	Order Placed	Weekly Cost	Cumulative Cost
3	4	4	12	5	0	5	5	8	0	$6.00	$18.00
2	4	4	12	4	0	4	4	8	4	$6.00	$12.00
1	4	4	12	4	0	4	4	8	4	$6.00	$6.00

Retailer Forecasts

Week 4: 6 Week 5: 6

Note: Depending on the treatment level, the bottom analytics may not have been shown to the participant. Only participants placed in Condition 2 (analytics) were shown these graphs.

Figure 3. Screen Shot of Beer Game

Each experiment was conducted using a game interface designed using the Microsoft Access desktop application. Figure 3 displays a screen shot of the interface as well as the game’s initial conditions. Following login instructions provided by the researcher, participants on each supply chain team accessed and played the game from separate computers. Game play began once all four participants had successfully logged into their echelon role.

Each game began in the third period with all roles placing orders to their adjacent upstream echelon. Starting in period four, each period started with the receipt of shipments from the adjacent upstream echelon. After each shipment was received, inventory and backorder quantities of each echelon were calculated. All delays within the game, including order processing, shipment, and production, were set to one week, meaning all echelons played with a two-week delay. Costs were incurred for each echelon at a rate of $0.50 for every item held inventory, and $1.00 for every backorder incurred. Inventory for each echelon started at 12 units with shipments in process of four units. The game advanced after each echelon placed their orders for the current period.

In contrast to the canonical settings of the beer game (see Croson and Donohue (2003) and Sterman (1989)), we constructed market demand as a non-stationary increasing quantity with a disruption at the 18th period, which represents demand-side disruption that lowers market customer demand to a quantity of six. Orders placed by echelons above the retailer role were a function of decision-making by subjects playing the game.

Periods three through six of game play were not timed to allow for subjects to become familiar with the game interface and information layout. After the sixth period, players were subjected to a 90-second timer. Starting in the sixth period of play, an order amount of zero was placed during any period in which a player did not place an order quantity before the expiration of the timer. Once all orders from the period were placed, shipments of inventory were made to each role’s downstream customer. Subjects began the game in the third period of play, and each game concluded in period 36. To mitigate horizon effects, subjects were told that each game would last for a random number of weeks, but only the first 30 weeks of each game were used for statistical analysis. At the conclusion of the game, each echelon's game data was automatically exported to a central back-end database for statistical analysis.

Experimental Results

To investigate the interaction of data analytics and human cognition, we conducted an experiment under two treatment levels based on the presence or absence of data analytics. In our baseline treatment, Condition 1, each decision-maker was only allowed to see information pertaining to only their echelon. In our data analytics treatment, Condition 2, each decision-maker was provided not only information pertaining to their own echelon, but also point-of-sale data for the retailer, supply line inventory, and charts of inventory position and demand for the adjacent echelon roles. Additionally, within this treatment, the decision-maker playing the retailer was given a Holt's model of forecasting. The Holt's model is appropriate when the underlying demand pattern contains both a level and trend component, but no seasonality (Chopra & Meindl, 2015, p. 190). Values for the smoothing constants of the retailer's forecast were optimized to minimize the mean square error of the market demand forecast. In addition to a graphical display of the forecast, a numerical value was displayed for the retailer (see Figure 3).

Participant Pool

The results presented in this section were obtained from 13 trials of the beer game collected over two academic semesters. The subject pool consisted of 486 undergraduate and graduate students enrolled in a core logistics or operations management course. The subject pool was primarily male (81%) and was composed of students majoring in business-related courses (86%). Students were recruited through course instructors with no incentive provided, except for participation credit by the instructor. In previous studies, classroom recruiting has been successfully used for the beer game to study information sharing (Croson & Donohue, 2003), problem-solving (Cantor & Macdonald, 2009), and judgment and decision-making (Narayanan & Moritz, 2015).

Analysis and Results

Prior to our analysis, we examined the data for normality and outliers within each treatment level. To test the assumption of normality, we used the Shapiro-Wilks test on the dependent measure of total supply cost within each treatment level. Given that the Shapiro-Wilks test for both Condition 1 and Condition 2 were statistically significant ($p <= 0.001$), we conclude that our data is not normally distributed.

A total of 117 games were evaluated for outliers. Previous uses of the beer game have evaluated outliers based on qualitative judgments (Sterman, 1989), quantitative measures involved differences in costs (Narayanan & Moritz, 2015), or residual tests of order variance (Croson, Donohue, Katok, & Sterman, 2014; D. Y. Wu & Katok, 2006). Outliers were evaluated using the median absolute deviation (MAD) method (Leys, Ley, Klein, Bernard, & Licata, 2013) on total cost. The MAD method was utilized since the underlying distribution of total cost was determined to be non-normal and to avoid the bias of potential outliers in using the mean as an indication of central tendency and the standard deviation as an indication of dispersion (Leys et al., 2013). Our outlier analysis resulted in 10 games under Condition 1 and 14 games under

Condition 2 being removed as outliers. The removal of these games resulted in a sample size of 40 games for Condition 1 and 53 games for Condition 2.

Before testing our hypotheses, we looked for evidence of the bullwhip effect within Condition 1 of our study. The bullwhip phenomenon occurs as decision-makers within each supply chain echelon choose actions by considering outcomes in ways that are influenced by the structure of the supply chain system (Sterman, 1989) and provides a context in which to explore decision-making. The bullwhip effect is confirmed by increases of variance in orders placed at one echelon relative to the orders placed by the adjacent downstream echelon level (Croson & Donohue, 2006). To prove the bullwhip effect, we examined graphical representations of median order weekly quantity by echelon. Figure 4 displays median order quantities for the two levels of the CRT profile placed by the 40 supply chains analyzed under Condition 1. In this figure, the amplification of order quantity can be seen moving up the supply chain as the game progresses. What begins as small order quantities from the retailer transpires into larger quantities at the factory echelon. Visual analysis reveals that order quantities of decision-makers high in CR are relatively consistent with those of individuals low in CR at all levels except the factory.

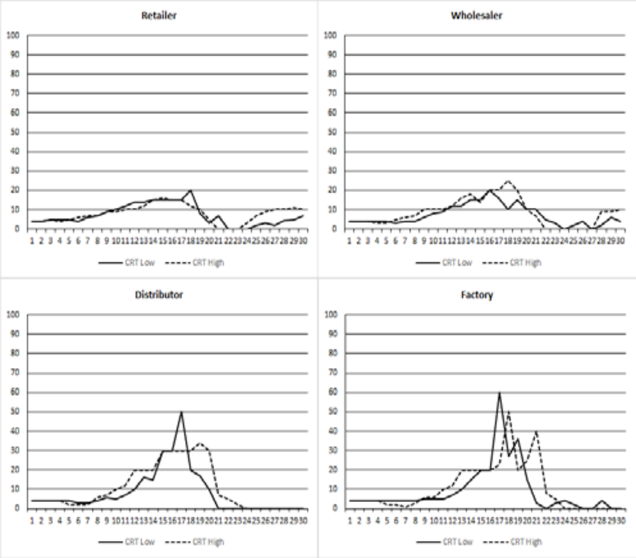

Figure 4. Median Weekly Order Quantity by Echelon (CRT Profile – Condition 1)

Figure 5 displays median order quantities for the two levels of the CFC profile. Visual analysis of these graphs reveals that decision-makers profiled as CFC-F placed larger orders in comparison to decision-makers profiled as CFC-I over the course of the game. This insight was somewhat unexpected and will be explained in the subsequent discussion of hypothesis testing.

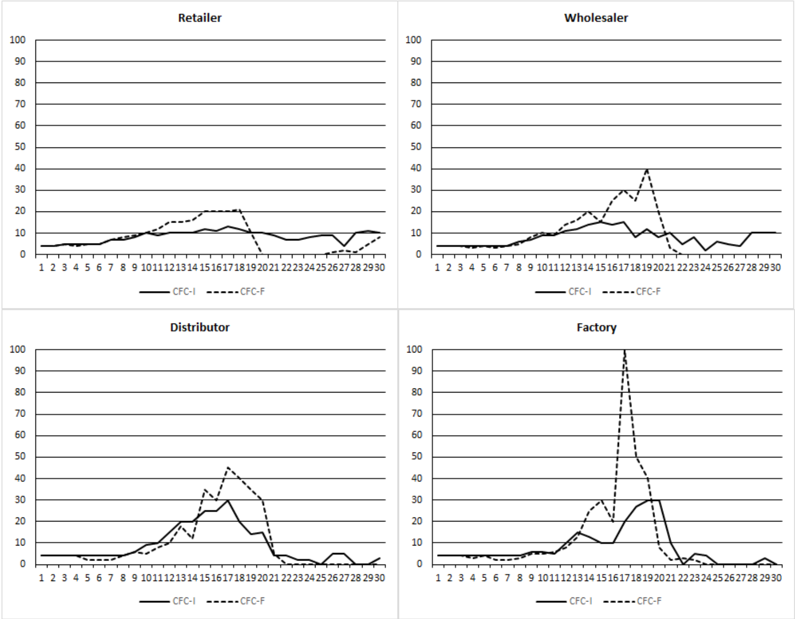

Figure 5. Median Weekly Order Quantity by Echelon (CFC Profile – Condition 1)

A non-parametric sign test (Newbold, Carlson, & Thorne, 2010) for matched samples was conducted to determine if order quantity variance increased as the echelon of focus was farther from market demand. In the non-parametric sign test procedure, a success is deemed if $\sigma_i^2 > \sigma_{i-1}^2$, where σ_i^2 is the variance of the *i*th echelon. A failure results if $\sigma_i^2 < \sigma_{i-1}^2$. The absence of the bullwhip effect would be indicated at a success rate of 50% or lower. From the results of our non-parametric sign test, it is apparent that order quantity variance is amplified up the supply chain for each level of the CRT and CFC profiles within Condition 1. As displayed in Table 9, the smallest success rate obtained is 86%, which was calculated for the CFC-I profile.

Table 9

Order Variance Amplification (Condition 1)

			Sign Test Comparison		
Profile Level	**Supply Chain Success Rate (%)**	**Overall *p-value***	**Retailer v. Wholesaler *p-value***	**Wholesaler v. Distributor *p-value***	**Distributor v. Factory *p-value***
CRT Low	90%	0.00	0.00	0.00	0.00
CRT High	95%	0.00	0.01	0.00	0.00
CFC-I	86%	0.00	0.01	0.00	0.00
CFC-F	97%	0.00	0.00	0.00	0.00

Additionally, average variance ratios displayed amplifying order variance between roles. Table 10 displays the average variance ratios for the 40 teams placed in Condition 1. Average variance ratios for decision-makers low in CR demonstrated increasing variance between echelons and larger magnitudes of variance than the average figures found for decision-makers high in CR. The results of the CFC profile were confounding. For decision-makers profiled as immediate thinking, average variance increased as it moved up the supply chain, with a sharp increase at the factory level. In contrast, average variance for future thinking profiles increased sharply at the distributor level and demonstrated a weak increase at the factory level. A possible explanation for the sharp increase at the factory level of the CFC-I profile is simply the variance of human decision-making. An explanation for the weak increases at the factory level for the CFC-F was provided by Croson and Donohue (2006), who noted that the factory enjoys a constant delivery delay under unlimited production rates, whereas all other roles can experience increasing delivery delays when stockouts occur farther upstream in the supply chain. The main finding of the average variance ratios is that order variance is increasing as the focus of investigation between echelon roles moves up the supply chain, thus confirming the presence of the bullwhip effect.

Table 10

Average Variance Ratios (Condition 1)

	CRT Profile		**CFC Profile**	
Role Dyad	**Low**	**High**	**Immediate**	**Future**
Factory/Distributor	12.0	6.1	23.2	3.2
Distributor/Wholesaler	6.1	2.8	3.8	10.7
Wholesaler/Retailer	3.4	1.9	2.9	4.8

Confirming the presence of the bullwhip effect under Condition 1, we turn our attention to our first hypothesis, which states that supply chains composed of individuals high in CR will demonstrate better supply chain performance than supply chains consisting of decision-makers low in CR. In testing our first hypothesis with a non-parametric Mann-Whitney test, we find statistical support confirming the impact of CR as first presented by Narayanan and Moritz (2015). The Mann-Whitney test performed on median (Mdn) supply chain costs, as shown in Table 11, indicate that costs were greater for supply chains composed of decision-makers low in CR (Mdn = \$5,849.00) than for supply chains composed of decision-makers high in CR (Mdn = \$2,796.50), U(39) = 63, $p < 0.01$. Furthermore, the weekly average order quantity and order quantity variance was greater for supply chains of lower CR (Mdn = 16.5) than for supply chains of higher CR (Mdn = 10), U(159) = 1,771, $p < 0.01$. We conclude that cognitive reflection has an impact on supply chain performance, and that supply chains composed of decision-makers high in CR have better performance.

Table 11

Impact of CRT on Supply Chain Performance (Condition 1)

Measure	**CRT Low**	**CRT High**	**Difference in Samples (CRT Low v. CRT High)**
Median SC Cost	\$5,849.00	\$2,796.50	p < 0.01 (W = 154, U(39) = 63)
Median Avg of Weekly Order Qty	16.5	10	p < 0.01 (W = 3,149, U(159) = 1,771)
Median SD of Order Qty	26.01	13.11	p < 0.01 (W = 3,136, U(159) = 1,758)

Note: CRT High < CRT Low

In testing for differences in supply chain performance between different CFC profiles, our findings do not support our second hypothesis and run counter to what theory informs, regarding individual behavior concerning the consequences of future actions. We find that median supply chain costs were greater for supply chains composed of decision-makers profiled as CFC-F (Mdn = \$5,066.00) than for supply chains composed of decision-makers profiled as CFC-I (Mdn = \$4,118.50), U(39) = 156, $p = 0.12$. We find a statistically significant difference between the medians of average weekly order quantity of each profile. Average weekly order quantity for supply chains composed of decision-makers profiles as CFC-F (Mdn = 14.5) was greater than the median average weekly order quantity for supply chains composed of individual profiles as CFC-I (Mdn = 10.50), U = 2,660, $p = 0.03$. Furthermore, order quantity variance was greater for supply chains of decision-makers profiled as CFC-F (Mdn = 24.23) than for supply chains of decision-makers profiled as CFC-I (Mdn = 13.96), U = 2,397, $p < 0.01$. Table 12 displays the results for this hypothesis.

Table 12

Impact of CFC on Supply Chain Performance (Condition 1)

Measure	**CFC-I**	**CFC-F**	**Difference in Samples (CFC-I v. CFC-F)**
Median SC Cost	\$4,118.50	\$5,066.00	p = 0.12 (W = 246, U(39) = 156)
Median Avg of Weekly Order Qty	10.50	14.50	p = 0.03 (W = 5,586, U(159) = 2,660)
Median SD of Order Qty	13.96	24.23	p < 0.01 (W = 5,323, U(159) = 2,397)

Note: CFC-I < CFC-F

To investigate our third hypothesis, we examine the impact of analytics on supply chain performance within each level of the CRT profile. If analytics does influence human cognition, then costs for supply chains of similar individuals should differ in this experiment’s two conditions. First, we find statistical support that data analytics moderates the extent to which decision-makers low in CR switch between intuition and deliberate decision-making. Supply chain costs for decision-makers low in CR between Condition 1 (Mdn = \$5,849.00) and Condition 2 (Mdn = \$3,017.00), U(65) = 380 were significant at $p = 0.03$. Regarding decision-makers high in CR, we find no statistical support that analytics moderates their decision-making. Supply chain costs under Condition 1 (Mdn = \$2,796.50) did not demonstrate a statistically significant difference in costs for supply chains composed of decision-makers high in CR in Condition 2 (Mdn = \$4,030.75), U(26) = 70, $p = 0.16$. The non-parametric testing of hypothesis three is displayed in Table 13.

Table 13

Impact of Analytics on Supply Chain Performance (CRT Profile)

Measure	**Condition 1**	**Condition 2**	**Difference in Samples (Condition 1 v. Condition 2)**
CRT Low			
Median SC Cost	\$5,849.00	\$3,017.00	p = 0.03 (W = 1,160, U(65) = 380)
Median Avg Weekly Order Qty	16.5	10	p < 0.01 (W = 18,453, U(263) = 6,207)
Median SD of Order Qty	26.01	9.90	p < 0.01 (W = 17,984, U(263) = 5,738)
CRT High			
Median SC Cost	\$2,796.50	\$4,030.75	p = 0.16 (W = 161, U(26) = 70)
Median Avg Weekly Order Qty	10	12	p = 0.03 (W = 2,540, U(107) = 1162)
Median SD of Order Qty	13.11	14.53	p = 0.11 (W = 2,629, U(107) = 1,251)

Note: Condition 2 < Condition 1

Turning to hypothesis 4, we investigate if data analytics influences decision-makers' considerations of the future consequences of their decisions. Regarding decision-makers profiled as CFC-I, we found that analytics has no influence on changing the way they discount the consequences of their decisions. As shown in Table 14, we find that median supply chain costs were not statistically different for supply chains composed of decision-makers profiled as CFC-I across Condition 1 (Mdn = \$4,118.50) and Condition 2 (Mdn = \$4,577.00), U(45) = 216, *p* =

0.19. However, we do find that analytics does influence supply chains of decision-makers profiled as CFC-F. Table 14 shows that differences in median supply costs were statistically significant across Condition 1 (Mdn = $5,066.00) and Condition 2 (Mdn = $2,485.00) for supply chains composed of decision-makers profiled as CFC-F, U(46) = 168, *p* = 0.01.

Table 14

Impact of Analytics on Supply Chain Performance (CFC Profile)

Measure	**Condition 1**	**Condition 2**	**Difference in Samples (Condition 1 v. Condition 2)**
CFC-I			
Median SC Cost	$4,118.50	$4,577.00	p = 0.19 (W = 406, U(45) = 216)
Median Avg Weekly Order Qty	10.50	11.00	p = 0.30 (W = 9,804, U(183) = 3,918)
Median SD of Order Qty	13.96	14.09	p = 0.30 (W = 9,803, U(183) = 3,917)
CFC-F			
Median SC Cost	$5,066.00	$2,485.00	p = 0.01 (W = 519, U(46) = 168)
Median Avg Weekly Order Qty	14.50	10.00	p < 0.01 (W = 8710, U(187) = 3,250)
Median SD of Order Qty	24.23	10.36	p < 0.01 (W = 8,253, U(187) = 2,793)

Note: Condition 2 < Condition 1

Investigating our final two hypotheses, hypotheses 5 and 6, we examine if data analytics influence the cognitive dimensions of decision-making after a disruptive event. Using total supply costs incurred after the demand disruption in our experiment, a non-parametric analysis revealed statistical support for the impact of analytics after a disruptive event on decision-makers low in CR and profiled as CFC-F. We find that median supply costs after a disruptive event have statistical significance across Condition 1 (Mdn = $4,877.50) and Condition 2 (Mdn = $2,178.00) for supply chains composed of decision-makers low in CR, U(66) = 370, *p* = 0.02. Our analysis also reveals that median supply chain costs incurred after a disruption are statistically significant across Condition 1 (Mdn = $3,922.50) and Condition 2 (Mdn = $1,773.00) for supply chains of decision-makers profiled as CFC-F, U(46) = 163, *p* < 0.01.

Table 15

Impact of Analytics on Supply Chain Performance after a Disruption (CRT Profile)

Measure	Condition 1	Condition 2	Difference in Samples (Condition 1 v. Condition 2)
Median SC Cost – CRT Low	$4,877.50	$2,178.00	p = 0.02 (W = 1150, U(66) = 370)
Median SC Cost – CRT High	$1,741.00	$3,167.25	p = 0.09 (W = 154, U(26) = 63)

Note: Condition 2 < Condition 1

Table 16

Impact of Analytics on Supply Chain Performance after a Disruption (CFC Profile)

Measure	Condition 1	Condition 2	Difference in Samples (Condition 1 v. Condition 2)
Median SC Cost – CFC-I	$3,000.00	$3,657.00	p = 0.21 (W = 410, U(45) = 220)
Median SC Cost – CFC-F	$3,922.50	$1,773.00	p < 0.01 (W = 514, U(46) = 163)

Note: Condition 2 < Condition 1

Discussion

Our results show that supply chain performance is influenced by the interaction of data analytics and human cognition. Finding support for the first hypothesis, we also reinforce the findings of Narayanan and Moritz (2015), who demonstrated that supply chain performance differs based on the CR profiles of decision-makers. Our results indicate that teams of decision-makers who utilize more deliberate reasoning out-perform teams of decision-makers who tend to rely on intuitive reasoning. Additionally, decision-makers high in CR tend to order smaller quantities with less variance, which results in lower costs.

From a temporal discounting perspective, we see that teams of people profiled as CFC-F perform worse than teams of decision-makers profiled as CFC-I. Without the presence of analytics, decision-makers profiled as CFC-I had lower costs, lower average weekly order quantities, and a smaller variance in their order quantities. A logical explanation for this phenomenon may reside in past research on CFC and fiscal responsibility. Joireman (2005) found that decision-makers profiled as CFC-F were more likely to spend on options that maximized future benefits. Howlett (2008) found that decision-makers profiled as CFC-F were more likely than decision-makers profiled as CFC-I to invest in retirement savings plans. These findings support the buffering hypothesis of Joireman (2008), which states that people profiled as CFC-F tend to exhibit safeguarding behaviors when making decisions. The objective of the beer game is to minimize total supply chain costs where costs are incurred weekly at a rate of $0.50 for every item in inventory and $1.00 for every item backordered. In our study, the true optimal order amount for a period would be the quantity required to meet the downstream echelon's demand in two future periods. Decision-makers profiled as CFC-F demonstrated higher average order quantity and variance over the course of the game in Condition 1. If these decision-makers were basing the future consequences of their order decisions on an increasing demand pattern, then the larger average order quantities might be explained as ordering behavior that attempts to maximize the capacity to fulfill future demand. This type of hoarding behavior has been witnessed in other experiments that have relied on the beer game (Croson et al., 2014). Using the CFC construct, our results may explain this type of behavior.

The results of our across-conditions analysis reveal that data analytics does influence the CR of decision-makers, but in an unexpected way. Our results indicate that decision-makers low in CR utilize analytics to the benefit of the supply chain. Performance increases in terms of decreased cost was statistically significant for decision-makers low in CR. Additionally, decision-makers low in CR had a lower average weekly order quantity and order variance than decision-makers high in CR when data analytics were present. In the study by Narayanan and

Moritz (2015), all standard mitigation strategies identified in previous research were implemented to determine if decision-maker CR still played a role in determining supply chain performance. The second condition in their study made demand known to all decision-makers (Croson & Donohue, 2006; Croson et al., 2014), provided system-wide information (Cantor & Macdonald, 2009; Croson & Donohue, 2003, 2006; Steckel et al., 2004; D. Y. Wu & Katok, 2006), reduced lead time (Steckel et al., 2004), provided training (Tokar, Aloysius, & Waller, 2012; D. Y. Wu & Katok, 2006), and was a second repetition for all players. In contrast, our subjects played a single game and the only mitigation strategy manipulated was the provisioning of information for all echelon roles in addition to a market demand forecast at the retailer. Dual process theory (Kahneman, 2011; Stanovich & West, 1998) informs us that intuition and deliberate reasoning are serial processes where deliberate reasoning is only initiated when intuition does not adequately describe the current environment or provide an answer to the problem at hand. Our results show that data analytics may actually invoke deliberate reasoning in intuitive thinkers, thus causing more deliberate reasoning and problem solving in the selection of choice. Additionally, we see that data analytics might interact with more deliberate thinkers in a manner that causes them to "overthink" the problem situation to a point that impacts supply chain performance.

Our results also reveal an interesting dynamic between data analytics and a decision-maker's CFC. Across the two conditions, we find that data analytics does not affect decision-makers profiled as CFC-I since their costs, order quantities, and order variance showed no statistical significant difference. Decision-makers profiled as CFC-F, however, show remarkable improvement in total supply chain costs through reductions of average order quantities and order variance. Research in counterfactual thinking may provide insight into why this behavior occurred for individuals profiled as CFC-F. Data analytics used in this study aided decision-makers by providing a graphical representation of the status of the supply chain and, more important, made the underlying market demand more salient to the retailer. Counterfactual thinking (Boninger, Gleicher, & Strathman, 1994) is defined as the construction and use of alternatives to reality. Our results offer insight in that the availability of data analytics helps decision-makers construct a reality other than what they perceive and, for decision-makers profiled as CFC-F, actually moderates their behavior to a level consistent with better supply chain performance. This effect of counterfactuals is consistent with research on counterfactual thinking in individuals who are more future-oriented (Boninger et al., 1994).

Finally, the results of our investigation on the influence of data analytics on human cognition after a disruption in demand are consistent with those previously discussed. Across conditions, the use of data analytics decreased costs for supply chains composed of decision-makers low in CR and profiled as CFC-F. We believe the same lines of reasoning that have been previously discussed hold true for these analyses as well.

Conclusion and Implications

This research examines the interaction of data analytics and two psychological dimensions—cognitive reflection and consideration of future consequences—and its impact on the behavior of a simulated supply chain. Our results indicate that while data analytics do moderate the abilities of decision-makers, the social (human) perspective is still largely accountable for the behavior of the supply chain. This conclusion presents some of the scholarly and managerial implications of our research. We also outline opportunities for future research, addressing the psychology of human behavior and decision-making within supply chain management.

Academic Implications

This research contributes to various domains of academic research since it examines the human behavior component of supply chain performance. It adds to a growing body of research that grew out of the dynamic decision model (Sterman, 1989) that investigates system behavior within a simulated multi-echelon supply chain. Many researchers have insisted that future research within supply chain management focus more on how micro-level human behavior causes macro-level supply chain behavior (Bendoly, Croson, Goncalves, & Schultz, 2010; Defee, Williams, Randall, & Thomas, 2010; Schorsch et al., 2017). We believe our study meets this call in two ways: through our use of behavioral decision theory and through psychometric measures of human decision-making within the context of supply chain operations.

Past research on demand order amplification by Sterman (1989), Croson and Donohue (2006), Croson and Donohue (2006), and Steckel (2004) has focused on information sharing between supply chain roles. Scholars have studied the role of forecast models on the bullwhip effect through analytical modeling (Chen, Drezner, Ryan, & Simchi-Levi, 2000; Zhang, 2004), or simulation methods (Bayraktar, Lenny Koh, Gunasekaran, Sari, & Tatoglu, 2008; Xiande Zhao, Xie, & Leung, 2002). While these studies show the positive impact of forecast methods on improving supply chain performance, human decision-makers continue to influence how systems work and perform (Gino & Pisano, 2008). Our study design bridges this sociotechnical gap by providing a human decision-maker with a forecast to use in the course of making ordering decisions. Our results indicate that the human decision-maker still plays a role in whether information is used successfully or not.

Our results both corroborate and extend the work of Narayanan and Moritz (2015), by exploring the impact of human intuition and deliberation on performance within a supply chain context. Our results demonstrate that decision-makers high in CR exhibit decision-making behaviors that result in better system-level performance. In contrast to the study of Narayanan and Moritz (2015), however, our results indicate that the presence of information does impact the CR of decision-makers. We found that presenting analytics to individuals who are low in CR can improve supply chain performance by lowering their order quantity and variance. Our results offer evidence as to how CR interacts with the mitigation strategies of the bullwhip effect.

The additional grouping of decision-makers according to the CFC-14 scale of Joireman (2012) allowed us to expand on their work to examine influential cognitive factors. Moreover, to our knowledge, this is one of the first studies to assess the influence of decision-makers’ CFC on system level performance over time. By holding all conditions constant, except the presence of information, our results prove that the extent to which decision-makers consider the consequences of their actions significantly influences their decisions and the macro-level behavior of a system. This finding is important because it provide evidence contrary to normative economic theory models, such as the discounted utility model (Paul A. Samuelson, 1937), which posits a single temporal discounting factor across all decision-makers and time. Also, our findings indicate that an individual’s CFC is an influential psychological factor in the human decision-making process.

Our use of the CFC-14 scale offers a contribution to the psychology and business literature. We provide further evidence that the extent to which an individual considers the consequences of their decisions is a multi-dimensional construct. Joireman (2008) hypothesizes that decision-makers profiled as CFC-I would be more susceptible to making decisions affecting near-term outcomes, while decision-makers profiled as CFC-F make decisions that buffer them from negative outcomes in the future. Our results show that the degree to which people consider the future consequences of their decisions does impact the performance and resilience of a supply chain.

Managerial Implications

Understanding human psychological limits has implications for supply chain managers because forecast and replenishment processes still involve human decision-makers. For practitioners, our research indicates that in the absence of complete automation, the psychological dimensions of human decision-makers continue to play an important role in the decision-making process of supply chain operations. System designers and engineers investigating the automation of human decision-making within complex systems are contending that the answer to minimizing human variability is not complete automation. Rather, an appreciation of human psychology must be developed to understand how to strike a balance between humans and computers in complex systems (Cummings, 2014). Companies may want to consider not only the technical details of how to use their forecast and replenishment systems, but also how employees interact with those systems to make decisions. Managers may find it beneficial to implement training programs aimed at promoting understanding of how cognition affects system-level dynamics such as feedback loops. The results from our investigation on CFC indicates that how decision-makers discount the consequences of actions impacts supply chain performance. It is possible that making individuals aware of how they discount consequences of choice may give salience to the impact of their choices on system level behavior.

Limitations

There are several limitations to our research. First, the use of laboratory experiments in organizational behavior has long been criticized for inadequately representing the complexity of a real-world organization (Winkler & Murphy, 1973). This criticism can be extended to experiments in study supply chain behavior, and in particular, this study. We placed human decision-makers in unfamiliar roles, asking them to make optimal decisions with varying information. However, we contend that in the real world, this is exactly what decision-makers placing inventory orders do on a daily basis. Certainly, there are more factors influencing the behavior of a supply chain that what was set forth in this experiment, but this was an opportunity to measure human cognition, which is often costly to assess in real-life contexts. While further replications and extensions of this study are warranted, we can explain all the differences in human decision-making.

Second, a potential criticism is control in our experimental trials. Yet great care was taken to ensure that each replication followed a rigorous process, executed in the same manner. Additionally, the lack of incentive for participants could be said to have impacted our results, although previous research (Katok, 2011; Narayanan & Moritz, 2015) has shown that the absence of realistic incentives does not lead to significant differences in the behavior of experimental subjects as long as other strategies have been taken to communicate the experiment's goal. Admittedly, we have taken a great risk by using a two-factor latent construct as a membership rule for the creation of supply chain teams. Our use of the CFC-14 scale as a grouping variable could be criticized for overly generalizing the conceptualization of temporal discounting and complicating our research analysis. We argue, however, that understandings of the psychological dimensions of human decision-making remain limited, and that using such a scale merits discussion about its future contributions rather than methodological limitations.

Finally, the reliance on student subjects might be considered a limitation. Sound research should always consider the scope of the theory and the primary purpose of the study when selecting a sample (Stevens, 2011). We believe that using students in this research is justified by the theories employed in this study and the purpose of the research. We have looked at psychological dimensions of decision-making and team behavior, which are not beyond the limits of what students do. While student knowledge and skills may improve with each year of schooling, in general, their decision-making is not exponentially different once they are hired into industry. We point to Croson and Donohue (2006) who state that business students in supply-chain related experiments provide insights into the decisions and behaviors of tomorrow's supply chain professionals.

Future Research

There are a number of opportunities for future research stemming from the current study. First, the complexity of the psychology of human decision-making leaves open many other human traits to explore in conjunction with the constructs of human cognition and temporal discounting. These factors might include the operationalization of constructs involving risk, self-control, or emotions. Second, the use of other mid-range psychology theories can be implemented within the context of this research. Third, numerous adjustments can be made within the context of the game to determine how temporal discounting and intuition are influenced by different demand and forecasting patterns or common order variance mitigations strategies (Lee, Padmanabhan, & Whang, 1997). Additionally, allowing for coordination and communication among decision-makers within the supply chains could offer better insight into how decision-making theory affects these processes and, in turn, how these processes affect macro-level behavior.

In summary, there is still much to learn about the influence of human behavior on supply chain performance. Our extension of research into the influence of CR, and our initial test of CFC in the context of supply chain behavior, have been encouraging. Our use of theory and measurements, however, needs further refinement, replication, extension, and critical assessment. We believe that this study expands extant research into the area of behavioral supply chain management. We hope that our work motivates other researchers to broaden the investigation of micro-level influences on the macro-level behaviors of supply chains.

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CONCLUSION

The concept of supply chain resilience has become a prevalent topic among academics and practitioners seeking to enhance the performance of their supply chain under all possible scenarios. Much of the past research on supply chain resilience has been aimed at defining the concept (Hohenstein et al., 2015) or constrained to studying either the social or technical aspects of supply chain resilience. Supply chains, though, are sociotechnical systems (Wieland & Wallenburg, 2013), but at their core they are largely reflective of human behavior (Sweeney, 2013). In order to build the resilience of supply chains, academics and practitioners need to understand the relationship between both the human and technical dimensions of supply chains. The three essays presented within this dissertation seek to contribute to the understanding of how supply chain resilience is developed through the interactions of theses dimensions. While each essay has been written to stand alone, the relate in understanding how markets and supply chains work through a lens of systems theory (Bertalanffy, 1969)

In Essay 1, the goal is to re-orient supply chain thought from a functional/procedural perspective to one of service dominant thought. This essay utilizes systemic thinking and soft systems methodology to problematize the framework of service provided by Service-dominant logic (Vargo & Lusch, 2015) in order to better understand the provisioning of service between businesses. Four unique systems paradoxes (Baldwin et al., 2010) are related to S-D logic's framework to problematize and release the tensions of service provision. The conceptual work in this paper provides a diagram of prose which adds valuable comprehension of the dynamics involved in market and supply chain performance.

Accepting of the paradoxes identified in Essay 1, Essay 2 explores how supply chain resilience is built between firms with the adoption of cloud-based technology. Cloud based technology is one of the latest information communication technologies to which firms are turning in order to implement low cost strategies of supply chain resilience. Building a relational view (Dyer & Singh, 1998) model of supply chain resilience from the works of Wieland and Wallenburg (2013) and Gligor and Holcomb (2012), this essay seeks to determine if the moderator of information system type has any influence on relational processes built between firms. This essay is also among the first to propose that the dimension of supply chain robustness mediates the agility of supply chain in responding to disruptions. The results of the work in this essay reveal that supply chain resilience is largely a relational process where the type of information system used matters little in building a resilient supply chain.

Building on the paradox of identity from Essay 1, Essay 3 explores how supply chain behavior emerges from the interaction of data analytics and decision-maker choice. Using a simulated supply chain game, decision-makers are placed under various levels of data analytics and asked to make inventory-ordering decisions. This study confirms earlier research findings that cognitive reflection is a key factor in decision-maker performance. Furthermore, we offer evidence that a decision-maker's consideration of future consequences influences supply chain performance. Moreover, we find that the availability of data analytics does moderate the cognition of certain decision-maker profiles. These findings have implications for both scholars and industry professionals who seek to apply data analytics to address supply chain problems.

Taken together, this dissertation provides further evidence that the social and technical dimensions of supply chains need to be explored jointly in order to create resilience within a supply chain and further our understanding of supply chain behavior. The contributions of these essays incrementally contribute to understanding supply chain behavior and the concept of resilience. Limitations aside, there exists numerous opportunities to build on the work contained within each paper. Doing so will not only serve to enhance the understanding of academics in to the "how" and "why" of supply chain phenomenon, but also assist practitioners in creating resilient behavior within their own supply chains.

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