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Structural drivers of upstream supply chain complexity and the frequency of supply chain disruptions

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ABSTRACT

A great deal of research has focused on supply chain risk management, but the question "Which supply chain characteristics increase the frequency of supply chain disruptions?" has not received much attention from empirical research. This is a relevant question, because firms seek stability in their operations, and therefore managers need to know how the structure of their supply chains affects the occurrence of disruptions. The present study addresses this issue with a specific focus on upstream supply chain (supply-side) disruptions. Drawing on the literature on supply chain complexity, we devise and test a model that predicts the frequency of supply chain disruptions based on a multi-dimensional conceptualization of upstream supply chain complexity. Not only do the empirical findings suggest that all of the three investigated complexity drivers – horizontal, vertical, and spatial complexity – increase the frequency of disruptions, but also that they interact and amplify each other's effects in a synergistic fashion.

1. Introduction

"If you are in supply chain management today, then complexity is a cancer you have to fight." This statement from a former vice president of supply chain operations from Coca-Cola North America (Gilmore, 2008), expresses the commonly held belief both among practitioners and scholars that supply chain complexity is one of the most pressing problems in modern supply chains and a key impediment to performance (Bozarth et al., 2009; Choi and Krause, 2006; Mariotti, 2008). High levels of complexity in the inter-connected flows of materials, funds, and information between firms have not only been blamed for decreasing supply chain efficiency, but also identified as a key precursor of supply chain disruptions (Chopra and Sodhi, 2004; Craighead et al., 2007; Narasimhan and Talluri, 2009). For example, Toyota's recent product recall crisis has been explained, at least in part, as the result of a surge in supply chain complexity (Cole, 2010).

Supply chain disruptions have the potential to cause heavy short- and long-term losses in shareholder value, sales, and reputation; they may also damage relationships between customers and suppliers (Hendricks and Singhal, 2003; Sheffi, 2005). Consequently, many scholars have advised firms to tackle the risk of supply chain disruptions as aggressively as they do financial risks and to reassess their supply chain designs from a risk perspective (Sodhi et al., 2012). So far, however, relatively little is known about the link between the *structural characteristics* of supply chains and the risk of disruptions. From an empirical perspective, only a few studies have examined this relationship. Papadakis (2006), for example, suggested that when a disruption strikes, make-to-order (MTO) supply chains are more vulnerable than make-to-forecast (MTF) supply chains are. Hendricks et al. (2009) found negative stock market reactions to supply chain disruptions to be more severe for firms that are more geographically diversified, less vertically related (i.e., high level of outsourcing), and equipped with little operational slack. Using a similar methodology, Schmidt and Raman (2012) reported that supply chain disruptions are more damaging to shareholder value if shareholders attribute the disruption to factors within the focal buying firm or its supplier network. All three studies identify several supply chain characteristics that affect a firm's losses *if* a disruption actually occurs. While these are valuable insights, they address only the magnitude of impact of disruptions (Holton, 2004). The other important element of risk remains largely unexplored: How frequent (or likely) are supply chain disruptions, given a certain supply chain structure? This is an important question, because firms seek stability in their operations (Katz and Kahn, 1978; Thompson, 1967), and therefore managers

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need to know how the organization of their supply chains affects the occurrence of supply chain disruptions. To the best of our knowledge, only the recent study by Marley et al. (2014) has investigated this relationship using a normal accident theory perspective to predict the occurrence of "every-day" downstream supply chain (demand-side) disruptions.

The purpose of this study is to advance our understanding of the relationship between supply chain characteristics and the frequency of supply chain disruptions. We address this issue within a manufacturing industry context and with a specific focus on upstream supply chain (supply-side) disruptions. Based on the initially highlighted complexity perspective, we hypothesize and test a proposed theoretical model that links structural drivers of upstream supply chain complexity with the number of supply chain disruptions experienced by buying firms over a 12-month period. Drawing on the literature on supply chain complexity (Bozarth et al., 2009; Choi and Hong, 2002; Choi and Krause, 2006; Manuj and Sahin, 2011), our model identifies three structural drivers (or dimensions) of upstream supply chain complexity – horizontal, vertical, and spatial complexity – and suggests that not only each of these variables increases the frequency of supply chain disruptions, but also that each one also intensifies the effects of the other two in a synergistic (superadditive) fashion. The results, received from count regression analyses, offer support for our model and yield relevant theoretical and managerial implications.

Given that the phenomena under investigation are supply chain disruptions, the following section discusses this term and defines it within the scope of this study. Further, to understand the linkage between supply chain structure and disruptions, we review the literature on supply chain complexity, which will be the basis for the subsequent development of hypotheses. The research methodology and the results are then presented. The remaining sections discuss the results from both scholarly and managerial perspectives. We conclude by describing the limitations of the study and by making recommendations for future research.

2. Background

2.1. Supply chain disruptions

Of the numerous risks that firms face, the risk of supply chain disruptions arises from the vulnerabilities of the inter-connected flows of materials, information, and funds in inter-firm networks. To some extent, all firms depend on external sources and supply chain relationships (Pfeffer and Salancik, 1978), and are consequently exposed to this type of risk.

The extensive corresponding literature is not always consistent in its terminology, but several studies have advanced the conceptual clarity of the terms used in the fields of supply chain risk management (e.g., Bode et al., 2011; Craighead et al., 2007; Ellis et al., 2011; Rao and Goldsby, 2009). In these works, a *supply chain disruption* is typically viewed as a discrete event that causes the losses for the affected firms. Craighead et al. (2007, p. 132), for example, defined supply chain disruptions as "unplanned and unanticipated events that disrupt the normal flow of goods and materials within a supply chain [...] and, as a consequence, expose firms within the supply chain to operational and financial risks." Supply chain disruptions involve at least two tiers in a supply chain, but, beyond this commonality, they may be highly heterogeneous in their characteristics and may emerge from a variety of sources, internal and external to a supply chain (Rao and Goldsby, 2009; Sodhi et al., 2012). A delayed shipment of non-critical material on the supply side, for example, may represent a less serious disruption than a major product recall on the demand side. For this reason, it is conceptually helpful to distinguish minor, repetitive problems of coordinating supply and demand from more major events that significantly threaten the normal course of business operations of a focal firm (Chopra and Sodhi, 2014; Kleindorfer and Saad, 2005).

For the purpose of this study, we restrict our focus to the latter and to the upstream supply chain. Based on the related literature (Bode et al., 2011; Craighead et al., 2007), we define a supply chain disruption as the combination of an unintended and unexpected triggering event that occurs somewhere in the upstream supply chain (the supply network), the inbound logistics network, or the purchasing (sourcing) environment, and a consequential situation which presents a *serious* threat to the normal course of business operations of the focal firm. This scope sets the stage for a large set of issues, including quality problems with suppliers, delivery outages, supplier defaults, labor strikes, or plant fires; all of which can vary considerably in their causes, characteristics, and effects.

2.2. Supply chain complexity

Complexity is an elusive construct that plays an important role in many academic disciplines. The term is usually discussed in connection with a system of elements and referred to as a system attribute (e.g., ecosystems, stock markets, the human brain), but it has a variety of different measurements and conceptualizations depending on the specific research field (for a detailed overview, see Jacobs and Swink, 2011). In the social sciences, an influential definition was provided by Simon (1962, p. 468) who stated that a socio-technical system is complex if it is "made up of a large number of parts that interact in a nonsimple way." This definition, which has become core to many subsequent conceptualizations of complexity, highlights two defining qualities of complexity: structure and behavior (Anderson, 1999; Burnes, 2005; Perrow, 1984; Senge, 2006). The former is often termed *structural complexity* (also *static* or *detail complexity*) and refers to the number and variety of elements defining the system. The latter is often called *dynamic complexity* (or *operational complexity*) and refers to the interactions between the elements of the system. In practice, these aspects are often closely interrelated, because the larger the number of varied elements, the greater is the possible number of interactions and thus the variety of behaviors and states the system may exhibit. This is especially true of supply chains (Bozarth et al., 2009; Manuj and Sahin, 2011; Skilton and Robinson, 2009).

Complexity is an important theme in the supply chain literature[2] in which there is a general consensus that supply chains have become increasingly complex over the last decades and that this complexity is not a desirable feature. Supply chain complexity has been argued to decrease the performance of operations (Bozarth et al., 2009), complicate decision making (Manuj and Sahin, 2011), and precipitate disruptions (Chopra and Sodhi, 2014; Craighead et al., 2007; Narasimhan and Talluri, 2009). Within this literature, there are two sub-streams that take a unique perspective on complexity in supply chains. One stream investigates supply chains as complex adaptive systems that have the capability to learn and adapt to changes in their environments (Choi et al., 2001; Pathak et al., 2007). Here, the specific focus is on the interactions of the autonomous elements defining the supply chain system, with the goal of understanding the principles and the adaptive behavior of the entire system (Dooley and Van de Ven, 1999). A second stream examines supply chains as complex social networks and uses methods from social network analysis to understand how relational ties are formed and how these ties affect social capital, resource access, convergence, and contagion in supply chains

[2] For example, in 10% percent of all articles (56 out of 547, without editorials) published in the *Journal of Operations Management* from 2001 to 2013, the terms *complexity* or *complex* appear at least once in the abstract or title.