OUT OF SIGHT, OUT OF MIND?
MODELING THE IMPACTS OF FINANCIAL SQUEEZE ON EXTENDED SUPPLY CHAIN NETWORKS

ABSTRACT

Firms increasingly put financial pressure on their suppliers, also called squeezing. Suppliers react and adapt to financial squeeze as autonomous agents, causing complex ripple effects across the extended supply chain network. To capture intertwined and highly interactive effects among suppliers, we use agent-based models. We explore the impact of financial squeeze on supply chain network structure and operational outcomes. Results suggest that financial squeeze affects the stability of the supply chain network and the effect varies depending on the location of the suppliers. Firms located at the bottom of the supply chain network suffer most from financial squeeze, and the magnitude of the effect increases as one goes further upstream. In addition, as existing suppliers exit the network and new suppliers enter, three network archetypes (Empty Nest, TransitUp, and StableDown) emerge. We identify the condition and operational consequences associated with these three archetypes. Our findings are informative to managers at buyer firms about the impacts of squeezing strategy on their extended supply chain partners, who often times are out of their immediate purview.

Keywords: Financial squeeze; extended supply chain network; complex adaptive system; value creation and value capture; agent-based modeling.

1. INTRODUCTION

1.1 Research Motivation

Financial squeeze refers to a buyer's actions that force suppliers to reduce their prices. In our research context, financial squeeze differs from the more familiar bargaining process or negotiation strategies in that it is habitually unilateral and does not necessitate involvement or agreement from both sides; instead, a buyer imposes financial squeeze onto its supply network. Financial squeeze is a strategy that has been widely used by buying firms to capture a more substantial portion of the supply chain value creation (Bloom and Perry 2001; Colias 2014;

Johnsson and Robison 2018; Murfin 2014; Sedgwick et al. 2008; Strom 2015; Waller, Johnson, and Davis 1999). In the automotive sector, buyers have long pressed suppliers for lower prices. The "Lopez Effect" is perhaps one of the early examples of financial squeeze. Ignacio Lopez notoriously perfected this squeezing practice in the early 1990s, when he took control of the purchasing department at General Motors (GM) and ruthlessly demanded lower prices from suppliers (Keith et al. 2016; Roemer 2006). GM is not alone, as the Lopez Effect is prevalent among other automobile manufacturers as well. A former procurement executive at Fiat-Chrysler Automobiles (FCA) commented on the prevalence of financial squeeze in the automobile industry:

> *Yes, it [financial squeeze] has been for all automobile companies at one time. The only exceptions would be Honda and Toyota. . . . FCA is doing it today. If you don't give price reduction, you do not get opportunity to quote on future businesses. . . . We have a document called the Source Package with technical data, volume requirement, manufacturing assumptions, etc. A part of it is commercial terms. We put in the Source Package the year over year cost reduction of x%. [Authors' note: We removed the actual number from the quote]*

The outcomes of financial squeeze have been mixed. While some buying firms have reaped the benefits of a financial squeeze (Johnsson and Robison 2018), others have encountered deterioration in operational performance (LeBeau and Pohlman 2014). Such deterioration eventually impacts revenue generation and profit capture in a negative way (McCracken 2006). As one example, GM, where the Lopez Effect was first implemented, filed for bankruptcy in 2009 with US$173 billion in liabilities. It was regarded as the largest industrial bankruptcy in history (Bigman 2013). In another instance, Carrefour and Tesco recently established a purchasing alliance to cut costs, tightening a squeeze on their suppliers in an initiative that, according to the Director of FoodDrinkEurope, has "a detrimental effect on the whole food supply chain" (Vidalon and Davey 2018). Further, Nestle attempted to squeeze retailers early in 2018, but the effort backfired, with some of its products being pulled off the shelves (Mulier and Chambers 2018).

While we now grasp that a competitive, transactional approach can cause a long-term negative impact on buyer–supplier relationships (Liker and Choi 2004), this understanding is mostly focused on the management of dyadic buyer–supplier interaction. The implications for the extended supply chain network are still poorly understood. This is especially true if we consider the supply network as a Complex Adaptive System (Choi, Dooley, and Rungtusanatham

2001; Nair, Narasimhan, and Choi 2009; Pathak et al. 2007) in that suppliers, as adaptive agents, learn as they respond to changes in the environment. A financial squeeze from the buyer firm could cause complex non-binary and non-linear reactions as it propagates through the adaptive agents located at various locations of the supply network (Bode and Wagner 2015; Pathak et al. 2007). In this sense, our study relates somewhat to previous research on supply chain solvency, pricing, trade credit, and financial distress that illustrates how supply chain interactions influence supply chain outcomes (Battiston et al. 2007; Blome and Schoenherr 2011; Bode, Hübner, and Wagner 2014; Bode and Wagner 2015; Boissay and Gropp 2007; Hertzel et al. 2008; Mizgier, Wagner, and Holyst 2012; Wadecki, Babich, and Wu 2012; Yang, Birge, and Parker 2015).

1.2 Research Questions and Contributions

Despite the abundant literature on how the OEM (original equipment manufacturer)–supplier relationship and different power bases impact the performance of the parties involved (Cai and Yang 2008; Chae, Choi, and Hur 2017; Hofmann 2011; Krause and Ellram 2014; Kull and Ellis 2016; Mahapatra, Narasimhan, and Barbieri 2010; Nyaga et al. 2013; Sanders 2008), there has been limited work on the emergent effects of financial squeeze at a network level. A more nuanced understanding in this context is critical because buying companies typically neglect or are unaware of the emergent network dynamics on the extended supply network. Supply management initiatives and dynamics at the dyad level of interaction do not necessarily carry out to the supply network level. The managerial action and visibility of a buyer over its supply chain are limited (Carter, Rogers, and Choi 2015), and what lies beyond the buyer's purview emerges (Choi and Krause 2006). Therefore, while focusing on the buyer–supplier dyad to examine squeezing initiatives informs managerial practice, it also limits our understanding (Li et al., 2020). We know remarkably little about whether, and how, "emergent outcomes" driven by buyers' financial squeeze affect the structure and performance of the extended supply chain network.

Our research aims to reduce this gap by answering the following two sets of research questions. *First, how does a buyer's financial squeeze affect the structure of its supply network?* Specifically, how does financial squeeze impact the entrances and exits at each echelon of the buyer's supply network? What are the emergent patterns at the network level? *Second, how does buyer's financial squeeze affect the operational and financial performance of supply network* *members?* Specifically, how does it impact the number of unfulfilled orders, revenue, and profit at each echelon of the buyer's supply network? To answer these questions, we approach the extended supply chain as a complex adaptive system (CAS) (Choi, Dooley, and Rungtusanatham 2001) and model the network dynamics of the buyer's financial squeeze using an agent-based model (Bonabeau 2002). Our findings suggest that financial squeeze affects the stability of the supply network and that the effect varies depending on the location of the suppliers. We also derive three network archetypes and identify the conditions and operational consequences associated with them.

Our study makes the following key contributions. First, to the best of our knowledge, this is the first study to investigate the impacts of financial squeeze from the viewpoint of an extended supply chain network. While squeezing suppliers may be a common sourcing practice, supply chains have become increasingly fragmented (Akkermans and Dellaert 2005) and consequently interdependent (Halldorsson et al. 2008, Sambasivan et al. 2011); therefore, the dynamics at the system level, and suppliers' reactions in an attempt to adapt to the squeeze, constitute a novel, essential, and hitherto unexamined phenomenon. Further, as most of our knowledge focuses on supply management initiatives and impacts at the dyad level, this study improves our understanding of value creation and value capture at different echelons of the supply network. This understanding is critical for managers at the buyer firm to pick up early warning signs (Bode, Hübner, and Wagner 2014), and to make strategy adjustments toward troubled suppliers in their extended supply chain network, who are typically out of their immediate sight.

We organize the rest of the paper as follows. In the Theoretical Background section, we explain the value creation and value capture concepts and identify important concepts that relate to our modeling. While doing so, we highlight our contribution to literature. Next, in the sections on Model Set-up and Methodology, we present empirical justifications for the set-up of our agent-based model and describe the simulation details. We report the results of our agent-based model in the Results section. Lastly, we discuss our findings and conclude with insightful remarks.

2. THEORETICAL BACKGROUND

2.1 Value Creation, Value Capture, and Buyers' Financial Squeeze Strategy

Value creation and value capture are critical aspects of a firm's competitive strategy (Mizik and Jacobson 2003). They are interrelated but distinct concepts that firms need to balance properly

(Bowman and Ambrosini 2000; Mizik and Jacobson 2003). In a supply network, firms co-create value for their customers with help from their suppliers (Porter 1980; Priem and Swink 2012; Ramirez 1999; Skilton 2009). Firms need to maintain a sufficient and capable supply base in order to meet their downstream customers' needs (Adner and Zemsky 2006; Priem 2007). This implies that a significant portion of a firm's revenue stems from the value created by its suppliers (Pitelis 2009; Priem 2007). Value capture refers to the process through which the buyer appropriates a share of profit from its suppliers. Value captured is the difference between the exchange value (i.e., revenue) that a firm receives from customers and the exchange value (cost) that the firm pays suppliers for the resources needed to produce the product (Makadok and Coff 2009). Financial squeeze is a value-capture strategy.

Financial squeeze fits into the large stream of literature on value capture through cost reduction in a supply network. Buyer firms are pressured to reduce costs to remain competitive (Yusuf et al. 2004). No matter what type of relationship a buyer has with a particular supplier, the buyer faces the decision of whether to stay with the supplier or to switch to an alternative supplier to realize lower purchasing costs (Mudambi and Mudambi 1995). In order to maximize profit, a buying firm is continuously searching for sources that offer more favorable prices (Dwyer, Schurr, and Oh 1987; Halinen and Tähtinen 2002; Pfeiffer 2010; Ping and Dwyer 1992; Wagner and Friedl 2007; Wagner and Johnson 2004; Yusuf et al. 2004). As procurement cost represents the largest share of a firm's total costs (Killen and Kamauff 1995), cost reduction in a firm's supply network becomes a critical managerial concern (Bharadwaj and Matsuno 2006; Handfield et al. 2006; Tate et al. 2016). Our research contributes to literature on cost reduction by taking a unique network perspective and exploring the impact of habitual cost reductions on a buyer firm's supply network.

2.2 Financial Squeeze and the Ripple Effect across Extended Supply Chain

Financial squeeze initiated by the focal buyer firm causes a ripple effect along the extended supply chain. Following Ivanov, Sokolov, and Dolgui (2014) and Dolgui, Ivanov, and Sokolov (2018) and adjusting to our research context, we adopt a working definition of the ripple effect of financial squeeze as a series of spreading changes across multiple echelons of the supply chain caused by supply chain agents reacting to financial squeeze imposed by the focal buyer on its supply network. These changes include performance of supply network agents as well as supply network structures at each echelon of the supply network (Ivanov, Sokolov, and Dolgui 2014).

Existing research has discussed how financial distress or bankruptcy events propagate in supply chains and networks (e.g., Battiston et al. 2007; Hertzel et al. 2008; Mizgier, Wagner, and Holyst 2012; Yang, Birge, and Parker 2015; etc.). For instance, Battiston et al. (2007) simulated the trade–credit relationships in the propagation of bankruptcies. Boissay and Gropp (2007), Hertzel et al. (2008), and Yang, Birge, and Parker (2015) show the chain effect of how the bankruptcy potential of one firm affects the operational strategies and performance of all parties in its supply chain through supply chain interactions. Similarly, Mizgier, Wagner, and Holyst (2012, p. 2) simulated how local defaults of supply chain agents spread through the supply chain network and "form avalanches of bankruptcy." Wadecki, Babich, and Wu (2012) show that the subsidy a buyer provides to its distressed suppliers depends on the supply chain structure. These studies provide support for the ripple effects of financial distress across the extended network. We build on this stream of research and examine how the buyer firm's financial squeeze propagates throughout the extended supply network. We note that while financial squeeze can be considered as a type of financial distress, it differs from the bankruptcy case in an important way. Supply network agents are more active in responding to financial squeeze and have a wide set of options available to them to respond, such as accepting the squeeze (Carnovale et al. 2019; Cusumano and Takeishi 1991), cost reductions (Kopfer et al. 2005), rejecting the squeeze (Bruno 2014; Gates 2013), and switching suppliers (Johnsson and Robison 2018).

2.3 The Complex Adaptive System Perspective

A complex adaptive system (Choi, Dooley, and Rungtusanatham 2001) has four critical attributes. First, it contains multiple agents with different goals, behaviors, and constraints (Anderson 1999; Holland and Miller 1991). Second, the agents are inter-dependent (Bar-Yam 1997) and display non-linear interactions among themselves (Casti 1994). Third, the agents display self-adaptation or self-organization behavior when they interact with the environment (Drazin and Sandelands 1992; Gell-Mann 1994). Finally, patterns of change emerge at the system level due to agents' self-adaptation and self-organization behaviors (Anderson 1999; Epstein 1999; Kauffman 1995).

The seminal theoretical insights of Choi, Dooley, and Rungtusanatham (2001) laid the foundation for examining supply chain phenomena from a complex adaptive system perspective. Since then, a stream of research has adopted CAS as a theoretical perspective to investigate challenging supply problems (Borgatti and Li 2009; Carter, Ellram, and Tate 2007; Carter, Rogers, and Choi 2015; Holweg and Pil 2008; Marchi, Erdmann, and Rodriguez 2014; Nair, Narasimhan, and Choi 2009; Pathak et al. 2007; Sawaya et al. 2015). For instance, Nair, Narasimhan, and Choi (2009), Kim (2009), and Datta and Christopher (2011) used agent-based modeling to investigate supply chain coordination. Giannoccaro (2015) examined the relationship between learning and adaptation in supply networks located within industrial districts. Albino, Fraccascia, and Giannoccaro (2016) explored the role of contracts in forming industrial symbiosis networks. More recently, Touboulic, Matthews, and Marques (2018) used a CAS perspective to examine the complex processes behind the evolution and diffusion of carbon reduction strategies in supply networks, while Zhao, Zuo, and Blackhurst (2019) investigated firms' adaptive strategies against disruptions in a supply chain network.

Similar to Choi, Dooley, and Rungtusanatham (2001) and many other researchers, we approach the supply chain as a complex adaptive system to explore the emergent network dynamics of the financial squeeze. In our agent-based models, we model the buyer and the supplier firms as agents with unique sets of properties and unique sets of behavioral rules. A financial squeeze from the buyer signals a change in the environment. Agents in the supply network adapt to this change in the network environment through self-organization, where agents autonomously make decisions to adapt to or cope with the changes, without enforcement or planned behavior imposed on the system (Albino, Fraccascia, and Giannoccaro 2016; Goldstein 1999). We explore the emergent aspects of the supply chain system due to financial squeeze and the impact on network structure and value capture. As such, we explore interactions that are more nuanced and complex than simple dyadic customer–supplier bargaining, accounting not only for chain propagation but also for the complex and emerging nature of supply networks when considering financial squeeze.

3. MODEL SET-UP AND JUSTIFICATIONS

In this section, we explain the set-up of our models. We provide justification for the composition of the networks and available behaviors of the agents.

3.1 Supply Network Structures: Base Network and Nexus Networks

3.1.1 The Construction of a Base Conceptual Network

Our base model is a generic conceptual network (GCN). From the CAS point of view, supply networks emerge, rather than being planned (Choi, Dooley, and Rungtusanatham 2001). Therefore, there is not a uniform structure that fits all firms. Rather, the supply network varies (Fleischmann et al. 2000; Schilling and Phelps 2007). In Online Appendix A, we provide diagrams of four supply networks. Two are GM supply networks for interior components and exterior components. The other two are FCA supply networks for the same two types of components. As Online Appendix A shows, these networks vary in the number and location of nodes, the connections among nodes, and the length of the network. These variations exist both within and across the two companies.

These variations create a challenge for choosing one particular empirical network to represent our base model. However, we also notice patterns of similarity among the four networks. First, they all contain multiple tiers. Second, they typically source from multiple agents, although at times a single agent is used. We focus on these similarities and construct a conceptual, generic network along two important theoretical dimensions. First, the generic network has multiple tiers of suppliers. As the majority of existing research focuses on the interactions between the focal buyer and its first-tier suppliers (e.g., Friedl and Wagner 2012; Pfeiffer 2010; etc.), research insights regarding the effects on extended tiers are still lacking (Pala et al. 2014). We construct a network with three tiers of suppliers to better understand the impacts of financial squeeze and its ripple effect in the extended supply chain network. Second, the generic network must be able to represent both single sourcing and multiple sourcing scenarios, as these two major sourcing options (Richardson 1993; Treleven and Schweikhart 1988) may have different implications on the buyer’s sourcing risks and operational performance (Blome and Henke 2007; Swift 1995). A graphic representation of the generic network can be found in Figure 1.

<<Insert Figure 1 about here>>

3.1.2 The Construction of Nexus Networks

In addition to GCN, we also construct two nexus supplier networks. A nexus supplier is one that can "exert a profound impact on the buyer's performance due to how they are embedded in the interrogational networks" (Yang, Birge, and Parker 2015, p. 53). Below we provide literature background on nexus suppliers, which serves as justifications for the set-up of the two nexus networks.

Over the past few decades, companies have reduced their supplier base and have arranged suppliers in a tiered structure (Choi and Hartley 1996). In addition, they have increased their reliance on the remaining direct suppliers, which have become strategic (Ballew and Schnorbus 1994; Bamford 1994). For instance, direct, first-tier suppliers have assumed a large share of control over the quality, cost, delivery, design, and production (Ahuja 2000; Choi and Krause 2006; Florida and Kenney 1991). Focal firms have carefully selected capable suppliers and then strategically integrated them into their operations, leading to more significant value creation, lower risks, and improved performance for the focal firm (Mackelprang et al. 2014; Narayanan et al. 2011; Swink, Narasimhan, and Wang 2007; Zhao et al. 2008).

In tiered supply bases, suppliers in lower tiers with no direct ties may emerge as being critical for the focal buying firm (Choi and Kim 2008; Choi and Linton 2011; Yang, Birge, and Parker 2015). This type of criticality based on network position is likely to produce different outcomes in the network. Extant research has highlighted the impact of a firm's structural relationship with other firms in the supply network on performance (Bellamy, Ghosh, and Hora 2014; Choi, Dooley, and Rungtusanatham 2001; Kim et al. 2011; Pathak et al. 2007; Skilton and Bernardes 2015). A significant proposition from these broader research streams is that a firm's own internal attributes and direct dyadic ties to other firms are not the only factors affecting the firm's performance. Also important is the firm's structural embeddedness in its extended network beyond direct links (Ahuja 2000; Bernardes 2010; Choi and Hong 2002; Granovetter 1985; Gulati, Nohria, and Zaheer 2000). In the supply management literature, these studies suggest that the network structure and a supplier's position in the network define the supplier's criticality (Choi and Kim 2008; Kim et al. 2011).

The network position of a supplier that does not have a direct tie to a focal buyer and is several steps removed in a supply network can potentially affect the focal firm's performance (Choi and Linton 2011). Such suppliers become critical to a focal buying firm due to their ties with other organizations. The emerging literature on this multi-tier network perspective to supplier criticality identifies such firms as “nexus suppliers” (Yang, Birge, and Parker 2015). The basis for the criticality of such suppliers is their structural position in various interorganizational networks.

An operational nexus supplier, in particular, has high centrality in the supply network organized around a focal buying firm and its suppliers. Past research has recognized centrality as a node-level structural property that can identify supplier criticality (Choi and Hong 2002; Kim et al. 2011). In general, high network centrality is associated with more power, strong influence, informational independence, and more opportunities to broker between others in the network (Borgatti and Li 2009; Kim et al. 2011; Skilton and Bernardes 2015). This structural attribute of an operational nexus supplier makes it more likely to affect the operations and performance of other firms in the network, as lower-tier suppliers can supply many different network members. The structural attribute of “high degree centrality” can signal the central position that operational nexus suppliers occupy (Yang, Birge, and Parker 2015). Degree centrality indicates the number of direct customers (out-degree centrality) or the number of suppliers (in-degree centrality) a node has. Thus, while high out-degree centrality typifies an ordinary supplier shared by a large number of higher-tier suppliers, high in-degree centrality typifies a supplier that purchases materials from a large number of lower-tier suppliers (Kim et al. 2011).

An operational nexus supplier has extensive ties in a focal buying firm’s supply network (Yang, Birge, and Parker 2015), which profoundly embeds this type of supplier into the focal buying firm’s operations for producing the final product. Thus, a focal buying firm’s decision can significantly affect the operations and performance of operational nexus suppliers (Kim et al. 2011).

In summary, nexus suppliers play an important role in the buyer firm’s operational performance. To capture these important structural forms, we follow Yang, Birge, and Parker (2015) and put forward two additional supply networks with nexus suppliers. One network mimics a nexus supplier with a high in-degree centrality (NexusIn) and the other mimics a nexus supplier with a high out-degree centrality (NexusOut). To be consistent with the GCN, these two nexus supply networks contain the same number of agents as the GCN (i.e., nine agents) and the same number of tiers of suppliers (i.e., three tiers). NexusIn and NexusOut are represented in Figure 2 and Figure 3, respectively.

<<Insert Figure 2 about here>>

<<Insert Figure 3 about here>>

3.2 Suppliers' Responses to Buyer's Financial Squeeze

Facing financial squeeze, suppliers have a few different options. In our agent-based model, we model the supplier's responses as acceptance, rejection, cost reduction, switching, and passing the squeeze to the next level of suppliers. These options are based on prevalent business practices and existing literature, supplemented by interviews with subject matter experts. Below we describe these responses.

First, a supplier may choose to accept the squeeze and reduce its contract price accordingly, whether or not the supplier has a positive and satisfactory profit margin after the squeeze (Carnovale et al. 2019; Cusumano and Takeishi 1991). Another option is for the supplier firm to improve its efficiency to reduce its internal operation costs and pass a portion of the cost savings to the buyer firm. Existing literature has a heavy emphasis on this practice, often in the context of buyer–supplier collaboration (Kopfer et al. 2005; Spekman, Kamauff, and Myhr 1998).

Besides accepting the squeeze and cost reduction approach, suppliers also have the option to pass the pressure of the financial squeeze to their upstream suppliers. For example, if a buyer squeezes a first-tier supplier, this supplier can subsequently pass this squeeze to the second-tier suppliers. This is exactly what GM asked its suppliers to do in its latest attempts to reduce supply network cost (Colias 2014; Sedgwick et al. 2008). GM asked its 2,700 global suppliers to streamline their own supply chains to cut prices on their products.

Lastly, suppliers can choose to reject the squeeze and exit the supply network (McCracken 2006). They can do so voluntarily or involuntarily. For example, when Ford squeezed its parts supplier Collins & Aikman Corp., this supplier voluntarily exited Ford's network by cutting deliveries. This supplier's exit forced Ford to shut down one of its assembly plants in Mexico for a period of time (McCracken 2006). There are also many examples of suppliers forced out of the buyer's supply networks involuntarily due to non-compliance with the cost-reduction targets (Johnsson). For example, under Boeing Company's Partnering for Success Program, United Technologies Corp., a supplier for engines, brakes, and landing gears for Boeing, was put on Boeing's "no-fly list" and barred from bidding on new programs when United Technologies Corp. rejected the price reduction demanded by Boeing (Johnsson and Robison 2018).

When a supplier rejects the squeeze and exits the supply network, its downstream buyer firm has an option of switching out this existing supplier with a new supplier. This was the case for Boeing. When United Technologies Corp. rejected its financial squeeze, Boeing awarded a contract to Herox-Devteck Inc., a small Canadian company (Johnsson and Robison 2018). We note that the switching option is only available to some supply network agents who have upstream suppliers. For raw material suppliers located at the bottom of the supply network, this option is not available. In this sense, the availability of the switching option is correlated to the structural property of a supply chain agent and only applies to supply network agents who are at least one step removed from the raw material suppliers.

To add validity to our model design, we interviewed six subject matter experts on the possible actions that supplier firms will take when faced with financial squeeze from the buyer firm, and the sequences of the actions. These experts all occupy leadership positions in procurement in their respective organizations with an average industry experience of 30.17 years, including an average of 23.33 years in procurement-related roles. Online Appendix B provides the profiles of these subject matter experts. The list of interview questions is presented in Online Appendix C.

The interviewees confirmed the set of possible responses we document above. Further, they pointed out that often the use of certain options is context-dependent. For example, when asked if a supplier will accept a squeeze even if the price is below the cost of production, one procurement executive answered: "*It depends. . . . Sometimes if a supplier is 'hungry' enough, it may accept a low-price contract to utilize the extra capacity.*" Another executive gave a different answer: "*At times there are a limited number of suppliers available, therefore, it is unlikely that a supplier will accept a price that is lower than their production cost.*"

While these contextual factors make it challenging to identify one uniform set of responses that fit all situations, consensus does surface. First, if profit margin allows, suppliers are willing to cooperate with the cost reduction requests from the buyer firm, either by lowering their own prices, passing on the squeeze to their suppliers, or working with the buyer firm to achieve cost reductions. As one SME put it: "*It takes efforts to set up relationships. . . . Once you have it, you will try to maintain it by working with your customers*." Second and relatedly, rejecting a financial squeeze and exiting the supply network is the last option a supplier firm would consider. As one executive put it: "*An outright rejection [of price reduction request] hurts* *feelings for both parties [buyer and supplier]. . . and is one of the last resorts*." We followed the insights from the interviews and modeled suppliers' responses accordingly. Specifically, we model acceptance as the first response, if a supplier has a reasonable amount of profit after the squeeze. We model rejection as the last response. In between, we model cost reduction by either reducing internal cost or switching to a less expensive sub-tier supplier. Appendix 1 depicts the responses of supply chain agents at each echelon of the supply network.

4. METHODOLOGY

In order to explore the emergent aspects of the supply chain as a complex adaptive system, and to investigate and comprehend the impact due to buyer's financial squeeze, we develop three plausible agent-based models representing the three types of supply networks introduced in the previous section: GCN, NexusIn, and NexusOut. The implementation details are discussed below. A summary of the research approach and findings is provided in Table 1.

<<Insert Table 1 about here>>

4.1 GCN Independent Path Models, Comprehensive Model, and Nexus Supplier Models

Our base model is GCN. Because suppliers can utilize a variety of strategies in addressing financial squeeze from the buyer firm, we take an incremental approach and first build independent path models. In these independent path models, suppliers respond to financial squeeze with one of the following strategies: acceptance, cost reduction, switching lower-tier suppliers, or rejecting the squeeze. As we are simulating an extended supply network with multiple tiers, in each of these independent path models the suppliers have an additional option to pass the squeeze to their lower-tier suppliers. This is true except for raw material suppliers, who do not have the option of passing the squeeze on or switching suppliers, as they are positioned at the bottom of the supply network. These independent path models provide us a practical way to dissect different responses from the supplier firms and help us understand and interpret the independent effects of each response type.

Once we have gained an understanding of the independent effects, we then put forward a comprehensive model, where we relax the constraint that a supplier can only respond to financial squeeze with one strategy. In the comprehensive model, the suppliers can choose to respond to a price cut by a combination of strategies, i.e., accepting the squeeze, cost reduction, switching suppliers, and rejecting the squeeze. This comprehensive model is more realistic and provides an integrated view of the impacts of financial squeeze on supply network structure and firm performance. Lastly, we conduct the simulation in two supply networks with nexus suppliers (i.e., NexusIn and NexusOut).

4.2 Agent Attributes and Their Influences over Decision-Making

The attributes used to represent the agents in our supply network include agents' positions in the network, their cost structure, and their size. Agents' decisions to adapt to the environmental changes (i.e., financial squeeze) depend on their attributes. Below, we explain these attributes and their influences over an agent's decision-making.

4.2.1 An Agent's Position Attribute

An agent's position refers to the location of an agent. It influences the agent's available actions and decision-making. First, the position that an agent occupies in the network determines the range of options the agent has available in terms of or in the face of financial squeeze. An agent in the middle tiers of the supply network has a full range of response options available: accepting the squeeze, passing on the squeeze, reducing cost, switching suppliers, and rejecting the squeeze. In contrast, the agents in the bottom layer (i.e., the raw material suppliers) do not have the options to pass along the squeeze or to switch suppliers.

Second, an agent's network position corresponds to its degree centrality score, which in turn influences an agent's decision-making in rejecting a squeeze. An agent with a high degree centrality score increases its propensity to reject a squeeze imposed by the upper-tier suppliers. Our three network structures (GCN, NexusIn, and NexusOut) provide variations in agents' positions and degree centrality scores. Specifically, in-degree centrality scores are calculated for the GCN network (there is no variation in the out-degree centrality scores for this network). In-degree centrality score is also used for NexusIn network. Out-degree centrality score is used for NexusOut network. The degree centrality score (DCS) and standardized degree centrality score (Standardized DCS) are defined as follows (Costenbader and Valente 2003):

- In-DCS = Total number of outgoing edges from the buyer to the supplier
- Out-DCS = Total number of incoming edges from the supplier to the buyer

- Standardized DCS = In- or Out-Degree Centrality Score / (Network size -1)

4.2.2 An Agent's Cost Structure Attribute

An agent's cost structure has three major components: the unit variable cost, the fixed cost, and the switching cost, if switching occurs. The unit variable cost is the price an agent pays to acquire raw material or components from its immediate upstream supplier, i.e., it is the unit price charged by its upstream supplier(s). For simplicity, we set the mean unit variable cost at the raw material level at 1 and the quantity (Q) at 100, with a normal distribution (Hurley 1998; Ranganathan and Ananthakumar 2014). The total internal cost to a raw material supplier is then calculated as the unit variable cost plus the fixed cost per unit (i.e., total fixed cost divided by Q; Aguado 2009). The unit price a raw material supplier charges its customers reflects the total internal cost multiplied by a markup. This is consistent with cost-plus pricing (Schneider 1985) which is one of the most widely used pricing strategies (Avlonitis and Indounas 2005; Guilding, Drury, and Tayles 2005). The variable cost at higher tiers of the supply network is driven by the unit price at the raw material level. Online Appendix D explains the formula and provides two examples for the calculation of unit variable cost and unit price at different tiers of the supply network. Table 2 presents the basic cost structures used in our simulation models.

<<Insert Table 2 about here>>

The fixed cost denotes cost associated with operations. While fixed cost varies widely across industries (Zalkuwi et al. 2015), we set the fixed cost as 1.7 times the variable cost to simulate an industry with a relatively high fixed cost such as the automobile industry (Biesebroeck 2007; Klier 2004; Wells Jr 1980), where financial squeeze is prevalent.

The third cost component is switching cost which incurs to a buyer if it decides to switch out an existing supplier. Past research has shown that switching activities incur a transaction cost (Monteverde and Teece 1982) and this cost is correlated to fixed cost (Li, Zhu, and Liang 2019). Thus, switching cost is derived by multiplying the fixed cost by a switching coefficient, *CoeffSW*. If a supply network agent transacts with an existing supplier, there will not be any switching cost.

An agent's cost structure impacts the agent's decision-making in a complex way. First, it influences the likelihood of an upper-tier agent's decision to switch suppliers. When an upper-tier supplier imposes a price cut, one of the responses from the lower-tier supplier is to reduce its fixed cost. The upper-tier supplier then compares the cost structure of lower-tier suppliers with the market and if it cannot find a lower price from the market, it will stay with the lower-tier supplier. If the upper-tier supplier is able to locate a lower-cost alternative, then it will switch away from the exiting supplier. In this sense, the cost structure influences the competitiveness of the suppliers, which subsequently influences the switching behavior of their upper-tier buyers. Second, an upper-tier agent's switching behavior will also influence that agent's cost structure. In this case, an agent's switching behavior will increase the transaction cost, which is explicitly modeled as "switching cost" in our models. The inclusion of switching cost increases the total costs and the resulting price an agent offers to its customers. In turn, a higher price influences the competitiveness of such an agent among suppliers located in the same tier.

4.2.3 Relative Size of the Agent

In the base model the size of an agent is fixed, and then we relax this constraint in the random size model. Because the size of an agent is relative and companies in the supply base vary in size (Cox 2001; Koufteros, Cheng, and Lai 2007), in the random size model we assign the size of each agent based on a random draw from a uniform distribution with a minimum of 0 and a maximum of 1. The relative size is then used to compute the propensity to reject a squeeze. Recall that an agent's centrality score also influences an agent's decision to accept or reject an offer. Thus in the random size model, the propensity to reject is a joint decision based on the summation of its degree centrality score and its relative size. This summation is then compared to a randomly drawn number, P_b (described in the section on Behavioral Rules) and an agent will reject a squeeze if the summation is larger than the random number, and accept the squeeze, otherwise.

4.3 Agent Actions

When an agent (buyer) squeezes its suppliers, the upstream agent (supplier) responds with a limited number of actions in order to adapt. These actions are conditioned by the general position of the company in the network, as described in our model. The range of actions included in our model, or the set of simple rules that govern the system, is based on empirical research (please refer back to the section on Suppliers' Responses to Buyer's Financial Squeeze for a description of the range of options available to suppliers). Table 3 indicates the types of action an agent performs. We describe these actions below.

<<Insert Table 3 about here>>

4.3.1 Compute the current profit margin %.

Each firm computes the profit margin % as follows:

Profit margin % = (Unit Price – Fixed Cost/Q – Purchasing Cost)/Unit Price (1)

In equation 1 above, Unit Price is the price a supply network agent charges its downstream trading partners (i.e., buyers). Purchasing Cost is the price the supply network agent pays its upstream trading partners (i.e., suppliers). Fixed Cost is the total fixed cost incurred to the agent (thus, Fixed Cost/Q is the fixed cost per unit; Aguado 2009). Q is the quantity that the supplier sells to the buyer. For the sake of simplicity, we assume that Q remains the same in each buyer–supplier relationship.

4.3.2 Compare the current profit margin % with the target.

We set each firm's target gross profit margin as 0.25. While gross profit margin varies by industry, the average manufacturer's gross profit margin varies between 25% to 35%, with expensive items tending to have a lower gross profit margin (Bresnahan and Reiss 1985). Each firm verifies that the current profit margin % is higher or lower than the target.

4.3.3 Squeeze the supplier/s.

Pursuing its target profit margin, a firm tries to impose a price reduction on its own suppliers. Its proposed reduced purchasing price is computed as follows:

Reduced Purchasing Price = Original Purchase Price(1-target) – Fixed cost/Q (2)*

Note here that the reduced purchasing price is the new price a buyer will pay for a component/material sourced (thus, the new unit variable cost for the buyer firm) in order to achieve a 25% profit margin. When an agent has more than one supplier, all suppliers are squeezed in proportion to the ratio between the supplier prices on the total purchasing price of the buyer.

4.3.4 Accept the squeeze.

The upstream supplier accepts the price reduction imposed from the buyer firm. The price it charges its buyer is updated to the Reduced Purchasing Price.

4.3.5 Reduce fixed cost.

Suppliers improve their own operating efficiency by reducing the fixed cost. The reduction is made to meet their own target and to formulate the lowest possible quote to the customer. The fixed cost is compressed by multiplying itself by a coefficient, P_{cr}. This coefficient is a randomly generated number. We provide more detail on this coefficient in the following section, on Behavioral Rules. The new fixed cost is computed as follows:

$$Fixed\ Cost\ Compressed = FixedCost * P_{cr} \qquad (3)$$

4.3.6 Reject the squeeze.

A firm rejects the financial squeeze and maintains its current price charged to its customers.

4.3.7 Switch the supplier.

A firm finds a new supplier from the market to replace the existing supplier if the market price is lower than the reduced price from the existing supplier. The new supplier from the market will accept the squeezed price. The existing agent exits from the network and a new agent enters the network and occupies the same network position. The market price, *MarketPrice*, is calculated as a ratio between the squeezed price that a buyer would like to spend on the supplier over P_{sw}, where P_{sw} is the buyer's propensity to switch. We provide more details on this parameter in the section immediately below.

$$MarketPrice = Reduced\ Purchasing\ Price/P_{sw} \qquad (4)$$

4.4 Behavioral Rules

Appendix 1 describes the behavioral rules for each agent. For better visibility, we break down the behavioral rules to separate agent types: buyer logic, supplier (non-raw material supplier) logic, and raw material supplier logic. For simplicity, we embed the non-raw material supplier's comprehensive logic (please refer to Supplier-Comprehensive diagram) as one step in the buyer's logic. Similarly, we embed raw material supplier's comprehensive logic (please refer to Raw Supplier-Comprehensive) as one step in the non-raw material supplier's comprehensive logic. Further, for each supplier type (raw material supplier and non-raw material supplier), we break down the rules to each independent path and a comprehensive model with paths combined.

The rules differ based on the agent's location in the supply network and based on who the agent interacts with. For example, the focal buyer sits on top of the supply network and can squeeze the first-tier suppliers. However, it will not receive any financial squeeze. A non-raw material supplier, in contrast, can both receive a squeeze from its customer (i.e., the focal buyer) and/or pass on the squeeze to its own suppliers. Depending on the reaction from upstream, these suppliers can then choose to either pass the squeeze, reduce their own fixed cost, reject the squeeze, or switch to new suppliers. Raw material suppliers are situated at the last echelon of the supply network and will not be able to pass the squeeze anywhere, nor will they be able to switch their suppliers; they must decide to accept or reject the squeeze.

We use four parameters to regulate agents' behaviors and to build different scenarios in order to achieve our exploratory goals. The first parameter, P_{sq}, denotes the probability that a firm squeezes upstream suppliers. A buyer firm can apply different strategies to adapt to cost-cutting pressure and reach its desired profit goal, which results in various probabilities of financial squeeze of its supply base. Therefore, we model propensity to squeeze with P_{sq} in the range of [0, 1]. The initial value of P_{sq} is set to be 0.5 for the base model. In the post-hoc analysis, we also model our agents as adaptable agents who learn from their past experience; thus this P_{sq} value will move up and down one step (each step = 0.05) based on the performance of past squeezes on profit. The learning logic is depicted in Appendix 1 as well.

The second parameter, P_{sw}, denotes the probability that a firm will switch its suppliers. While existing research offers a diverse view on the advantages (Elmaghraby 2000; Segal 1989; Trevelen and Schweikhart 1988) and disadvantages (Samuelson and Zeckhauser 1988) associated with switching suppliers, in reality firms will engage in search for alternative access to material and resources and the degree of supplier switching behavior varies (Pfeiffer 2010; Wagner and Friedl 2007). The value of P_{sw} is based on triangular distribution with a minimum of 0.8, a maximum of 1, and the peak at 1. Triangular distribution is used in situations when there are many uncertainties surrounding key parameters in the analysis (Davidson and Cooper 1980). As such, triangular distribution is one of the most commonly used distribution forms in risk analysis (Jamrus et al. 2015; Johnson 1997). We use the right triangular distribution where the peak value is the same as the maximum value to simulate that switching is likely, if an existing supplier rejects the squeeze from the buyer firm. We mentioned earlier that a buyer will switch out a supplier if the reduced price from the supplier is higher than the market price, and the market price is calculated as a ratio between the squeezed price that a buyer would like to spend on the supplier over P_{sw}.

The third parameter, P_{cr}, denotes the potential that a firm is able to reduce its fixed cost. When the economy is good, firms tend to expand and incur higher administrative cost (Peng and Luo 2000). When there is strong pressure for cost reduction, a firm can improve its own business processes to reduce fixed costs (Spence 1984) as an alternative to squeezing suppliers. Similar to the construction of P_{sw}, P_{cr} follows a triangular distribution with a minimum of 0.8, a maximum of 1, and the peak at 1. Again, here we use triangular distribution as a rough proxy to a random variable with an unknown distribution (Jamrus et al. 2015; Johnson 1997). This value is then multiplied by the exiting fixed cost to calculate the new fixed cost, which subsequently influences the reduced price a supplier offers to its customers.

The last parameter, P_b, denotes the probability that a firm will accept or reject the squeeze from its customer. We first calculate an agent's rejection power, P_r, based on its centrality score and size. We then compare this rejection power to P_b. If the rejection power is greater than P_b, an agent will reject the squeeze. The calculation of the rejection power is denoted in Online Appendix E, which takes a range of values between 0 to 1. To match the range of the calculated rejection power, the value of P_b is drawn from a uniform distribution with a minimum value of 0 and a maximum value of 1.

4.5 Simulation Setting and Computational Environment

We developed the simulation program in MATLAB scripts (MATLAB R2013b). All simulations were conducted on a CPU with Intel(R) Core (TM) i5-7200U (@ 2.50 GHz) having 8 GB RAM and running Windows 10 operating system.

4.6 Output Measures

Each simulation contains 1,000 iterations and we ran each simulation 100 times. These values are set so as to guarantee that the measurements computed over time are stationary and results are statistically stable. We record changes in the network in terms of the number of suppliers exiting the supply network and/or new suppliers entering the network. We also examine the effect of the financial squeeze in terms of value created (i.e., revenue), value captured (i.e., profit), and the number of unfulfilled orders. We report average outputs for measurements taken.

At the buyer firm level, we track buyer's cumulative revenue, then compute revenue per unit of time (*Revenue_u*), as well as buyer's cumulative profit, and then compute profit per unit of time (*Profit_u*) as a measure of value capture. The revenue and profit measures are computed as follows:

$$Cum\_Revenue_t = \sum_{i=1}^{t} Price_i * Q_i \qquad (5a)$$

Or

$$Cum\_Revenue_t = Cum\_Revenue_{t-1} + Price_t * Q_t \qquad (5b)$$

$$Cum\_Profit_t = \sum_{i=1}^{t} Price_i * Q_i - FixedCost_i - PurchasingCost_i - SwitchingCost_i * k \qquad (6)$$

(k=1 when there is a switch, k=0 when no switch is made)

$$Profit\_u = Cum\_Profit_t / t \qquad (7)$$

$$Revenue\_u = Cum\_Revenue_t / t \qquad (8)$$

At each firm level, we track the number of total exits, *Cum_Exits*, total number of new relationships due to switching strategy, *Cum_NewRelationships*, and total number of unfulfilled orders, *Cum_UnfulfilledOrders*. Then, we compute the ratio of unfulfilled orders (*UnfulfilledOrders_u*) as follows:

$$UnfulfilledOrder\_u = \frac{Cum\_UnfulfilledOrders}{\sum_1^t Order_t} \qquad (9)$$

5. RESULTS

We organize the results section by network impact and operational impacts. First, we present the impacts of financial squeeze on supply network structure, in terms of the number of exits and the number of new relationships. The former represents the count of suppliers who sever their relationships with their respective downstream buyers and exit the supply network. The latter represents the count of new suppliers who make entrances into the supply network. Second, we present the impacts of financial squeeze on network agents' operational outcomes, in terms of unfulfilled orders, revenue, and profit. A summary of the findings is presented in Table 1.

5.1 Implication of Financial Squeeze on Network Structure

We examine the impact of financial squeeze on the number of exits and new entrances at each tier of the supply network. We report results for three supply network types: GCN, NexusIn, and NexusOut.

5.1.1 Generic Conceptual Network

Independent Path Models. The independent path models inform us about the unique impact of each type of supplier response to financial squeeze. Table 4 reports the results of the independent models, where Table 4A reports the number of exits and Table 4B reports the number of new entrances.

<<Insert Table 4 about here>>

Independently, suppliers' action of *cost reduction* results in a large number of exits across the supply network. This is true at both the upper-tier level and the lower-tier (raw material suppliers) level. However, the impact is greater at the raw material level than at the upper-tier level. Because we are testing the independent effects of cost reduction, we constrain the suppliers from other response options. Therefore, while existing suppliers exit the supply network, there will be no new entrances under this option. Thus, this independent action of cost reduction will most likely cause a significant reduction of the supply base, especially at the raw material level.

Independently, suppliers' *switching* action caused some exits of network agents at all levels of the supply network. Similar to the observation made above, the impacts are much greater at the lower-tier level than at the upper-tier level. We note that in the switching-only option, a switch will be made if the market price is lower than the current supplier price without any cost reduction (a constraint of the independent model). Therefore, the number of exits represents situations where a lower market price has been found and subsequently a new supplier enters the supply network. Thus, there is an identical number of exits and new entrances for the switching-only model. Compared to results from other independent models, we note that the switching-only action causes the least amount of disturbance to the supply network as a whole, and especially to suppliers situated at the top tier of the network.

Independently, suppliers' *rejection* action caused a large number of exits at both the upper-tier supplier level and the raw material supplier level. Because the rejection-only option constrains a buyer from switching out suppliers, there will be no new entrances under this option. Thus, we expect a large amount of agents exiting the network without sufficient replacement by new agents. Similar to the cost-reduction model, we expect to see a significant reduction of the supply base.

Independently, suppliers' acceptance-only action caused the least amount of exits or new entrances. We acknowledge that this result is due to the model constraint, which limits the available options of the supply network agents from other responses, including preventing the raw material suppliers from rejecting the squeeze and exiting the supply network. We proceed with an exploratory analysis and discover that in the acceptance-only option, approximately 21% of the transactions lead to negative profit for the raw material suppliers. In a realistic business setting, if a supplier loses money on 21% of its transactions over an extended period of time, it is highly unlikely that it will remain in the supply network. However, if a supplier exits the supply network, it will violate the assumption of no-exit in this independent path. Thus, the solution to this path model is highly unrealizable, and therefore we do not proceed with further interpretation of this option.

Comprehensive Model. The comprehensive model relaxes the constraints that a supplier is limited to only one type of response to financial squeeze. Here, the supplier can respond in a combination of actions of acceptance, cost reduction, switching, and rejection, which is a more realistic depiction of suppliers' response. We report the results of the comprehensive model on the supply network structure in Figure 1.

Figure 1 shows that there are more severances of relationships at the lower-tier (raw material suppliers, RM1 to RM5) level than at the upper-tier level (S11, S21, and S22). Raw material suppliers are positioned at the bottom of the supply network. As such, compared to upper-tier suppliers, they are lacking two options that are available to upper-tier suppliers. First, they do not have the option to pass on the squeeze to their suppliers to shoulder some of the impacts of price reduction. Second, they do not have the option of switching out suppliers by sourcing at a lower price from the market. Due to the limitation of options, they suffer more from failed attempts to meet the price reduction target, which leads to a higher number of exits from the supply network.

Figure 1 also shows that there are more additions of new relationships at the raw material supplier level than at the first-tier supplier level. This is correlated to the differences in the frequency of exits. When there are more severances of relationships, there will be more opportunities for new suppliers to enter the supply network.

Overall, financial squeeze leads to turbulence behaviors at each echelon of the supply network, as a large number of existing suppliers exit the supply network and a large number of new suppliers enter. Here two patterns emerge. First, the number of the switches (exits and new entrances) goes up as we go further upstream. The switching activities are least frequent at the first-tier supplier level and most severe at the raw material supplier level. Second, the magnitude of changes in switching activities greatly increases at the bottom echelon of the supply network. To validate this effect, we fitted a linear regression model with a quadratic term. In this model, we treat the number of exits as the dependent variable, and the tier and the squared term of the tier as the independent variables. Ordinary Least Square (OLS) estimation is used.

$$Y = B_0 + B_1X + B_2X^2 + \varepsilon \qquad (10)$$

The inflection point occurs at the following value of the predictor X (Weisberg 2005):

$$X_{\text{inflection}} = -B_1/2B_2 \qquad (11)$$

We randomly sampled 160 observations from our simulation runs. The result supports the existence of a quadratic term and is statistically significant at the $p<.001$ level. We report the regression results in Table 5.

<<Insert Table 5 about here>>

We compare the number of exits between the independent models and the comprehensive model. Individually, each independent action has some tradeoffs. When combining these individual responses together, the comprehensive model leads to an overall reduction of the number of exits at the system level. In addition, the comprehensive model allows new network entrances to replace some of the vacancies left behind by the exiting suppliers. Thus, although there are many exits, the network is able to renewal itself, ensuring a relatively steady network structure.

5.1.2 Nexus Supplier Networks

A nexus supplier can have a high in-degree centrality score and/or a high out-degree centrality score. Results of the impacts of financial squeeze on these two types of nexus suppler network are shown in Figure 2 and Figure 3.

One interesting observation for the NexusIn and NexusOut networks is that, although there are a high number of exits of nexus suppliers from the supply network, the number of new entrances is limited. This is true for both NexusIn and NexusOut suppliers. Only approximately 15% of the vacancies for the NexusIn and 10% of vacancies for the NexusOut networks can be filled with new entrances. This lack of new alternatives signals a potentially important operational risk for upper-level suppliers.

5.2 Implication of Financial Squeeze on Network Agents' Operation Outcomes

We present the impacts of financial squeeze on network agents in terms of percentage of unfulfilled orders, revenue, and profit. We follow the structure in the previous subsection and present the outcomes for the following network archetypes: GCN, NexusIn, and NexusOut.

5.2.1 Generic Conceptual Network

Independent Models. Table 6 reports results of financial squeeze on the mean percentage of unfulfilled orders (Table 6A), mean revenue (Table 6B), and mean profit (Table 6C).

<<Insert Table 6 about here>>

Not surprisingly, the *rejection option* leads to the lowest profit for the supply network as a whole and negative profits for the majority of supply network agents. A root cause of the low profit is the large percentage of unfulfilled orders. In the rejection-only option, we see the highest percentages of unfulfilled orders compared to all other independent path models. These unfulfilled orders significantly reduce the revenue potential for network agents and lead to reduced profits. In essence, a rejection-only option contradicts collaborative buyer–supplier relationships (Paulraj, Lado, and Chen 2008). In the end, this type of "tit for tat" strategy leads to a lose-lose situation for all supply network agents.

Next, we examine the switch-only option. Recall that when comparing among different independent models, the switching-only option caused minimal disturbance to the network structure in terms of the number of exits and the supplier replacement. This stable network has two implications for firms' operational outcomes. First, there will be a reduction in transaction costs (which is modeled as switching cost in our simulation) in a stable supply network. We expect that the reduction in transaction cost leads to increase in profit. Second, when there is an exit during the switching-only option, there is always an alternative, better-priced supplier in the market (i.e., exit will not take place unless a better alternative from the market has been identified). Under this option, there will be the least amount of unfulfilled orders, which is related to higher revenue and, everything else being equal, higher profit. In summary, we expect to see no unfulfilled orders, and a high level of revenue and profit associated with the switch-only option.

The results from Table 6 only partially confirmed these expectations. The switching-only option leads to no loss of orders, and a reasonable amount of revenue and profit for the top-tier suppliers. The profit for raw material suppliers suffers heavily under this option. In fact, the majority of raw material suppliers obtained negative profit in these iterations. Raw material suppliers occupy the bottom of the network and have no alternative lower-tier suppliers to switch to in order to reduce cost. If constrained by the switching-only option, the raw material suppliers must accept the reduced price from their buyers, leading to negative profit.

In contrast, although the cost-reduction-only options prohibit new suppliers from entering the market, which results in unfulfilled orders, especially at the raw material supplier level, this option performs better in overall profit than the switching option for raw material suppliers. Nevertheless, we take note that the profits for raw material suppliers are significantly lower than for those at higher tiers of the supply network.

As we mentioned earlier, the acceptance-only option leads to highly unrealizable solutions. Therefore, the unfulfilled orders computed from this model are highly improbable. To understand a more realistic impact of the acceptance-only option, we proceed with a close look at a randomly chosen simulation result. Out of 1,000 transactions, network agents encounter somewhere between 19.40% (S22) to 23.10% (RM4) of transactions ended with negative profits. Please refer to Online Appendix F for a breakdown at each network agent. These negative profits occur early in the transaction circle. For example, RM4 encountered four consecutive negative profits from transactions 8, 9, 10, and 11. In such a case, RM4 is facing financial stress and it is unlikely that this agent will continue to stay in the supply network. We observed similar patterns for other supply network agents as well. While the percentage of agents facing financial stress is astonishing, this is not the focus of our study. We refer readers to Bode, Hübner, and Wagner (2014) who examined the ripple effects of financial stress in the supply network.

Comprehensive Model. Results obtained from the comprehensive model can be found on the bottom row of Tables 6A, 6B, and 6C. When suppliers use a comprehensive set of strategies to respond to financial squeeze, there is an improvement in terms of reduction of unfulfilled orders, which leads to higher revenue and higher profit.

We compared the performance outcomes of the comprehensive model and the independent models and found that the comprehensive model seems to be a happy medium. Overall, all suppliers receive the highest amount of profit under the comprehensive model. The increase in profit is especially salient for raw material suppliers, which suffer from negative profits under some of the independent path models. While the supply network as a system performs well, we notice that from a buyer's perspective, the comprehensive model performs better than any of the independent path models except for the cost reduction model. In the cost-reduction-only model, the buyer makes slightly more profit than it makes in the comprehensive model. An intuitive interpretation is that when we take away some of the options of possible responses from supplier agents, the buyer may benefit. Conversely, when suppliers have a full range of responses at their discretion, this combination of responses seems to benefit the suppliers more than the buyer firm.

Overall, large profit is found at the top-tier supplier level and low profit is found at the raw material level. Further, the reduction in profit is more severe at the raw material level than in the upper-tier level. Similar to our earlier approach, we fitted a curvilinear regression model with OLS with profit as the dependent variable and tier value as well as the squared term of tier as the independent variables. We obtained statistically significant results ($p<0.01$) for the quadratic term, suggesting that the speed of decrease in profit is accelerating at the raw material supplier level.

5.2.2 Nexus Supplier Networks

Operational outcomes of NexusIn and NexusOut networks are reported in Table 7 and Table 8, respectively. Overall, financial squeeze from the buyer firm causes unfulfilled orders for both networks, yet the patterns are different. For the NexusIn network, the impact of the squeeze is most severe at the nexus supplier agent. We recall that financial squeeze caused a lot of exits of the nexus supplier in the NexusIn network, yet there are not sufficient new entrances to fill the vacancies. A performance penalty resulting from the insufficient new entrances is that a large number of orders are unfulfilled. This in turn reduces revenue and profit for the nexus firm.

This is not the case for the NexusOut supply network. We note that financial squeeze causes a large percentage of unfulfilled orders at the upper tier of the supply network. In fact, the unfulfillment rate is highest at the downstream agents who source from the nexus supplier. As a result, the profits of these higher-tier suppliers suffer. This highlights the influence of the NexusOut supplier. Facing financial squeeze, its impact extends to nodes around it.

<<Insert Table 7 about here>>

<<Insert Table 8 about here>>

5.3 Validation Studies

Our agent-based model represents the complex logic of interactions among agents at different echelons of the supply network (please refer to Appendix 1). To enhance the internal validity of our model, we perform three validation studies. First, we run a model with zero squeeze. Second, we vary the mean price at each agent. Third, we vary the distribution form. We provide explanations and report results below.

<u>5.3.1 No-Squeeze Scenario</u>

In this validation study scenario, we set the propensity to squeeze to 0 and run 100,000 simulations of a GCN comprehensive model. Because there is no squeeze, there should not be any exits, new entrances, or unfulfilled orders. In addition, the mean revenue should be very close to the price each agent charges multiplied by the quantity (i.e., 100 units). Thus, the results of the simulation should be very close to the price structure reported in Table 2a, multiplied by 100, and subject to some random variations.

We report the results pertaining to the no-squeeze scenario in Table 9. As Table 9 shows, when there is no squeeze, the number of exits, new entrances, and unfulfilled orders are all zero. In addition, the mean revenue closely mimics the price structure reported in Table 2a multiplied by the quantity of 100, with minor variations due to random sampling. This provides some evidence that our model works as designed.

<<Insert Table 9 about here>>

5.3.2 Mean Price Variation

We build our base model according to the price structure reported in Table 2A. The construction of the price table is described in the section on An Agent's Cost Structure Attribute. In the mean price variation study, we run 10 additional models based on the GCN comprehensive model, but vary (increase and decrease) the price an agent charges, while holding the prices of the rest of the agents unchanged (except for raw material suppliers, in which case we change the prices for all of the raw material suppliers simultaneously, as they share identical price structure and network positions). If our model works as designed, we should see an increase in profit for that particular agent when the price is raised from the base price, and a decrease in profit for the same agent when the price is lowered. For example, when we increase the price agent S1 charges its buyer, we should see an increase in the profit of S1 (but not necessarily for other agents in the supply network), compared to the profit reported in the baseline model in Table 6. Similarly, when we decrease the price for S1, we should see a decrease in profit for S1, compared to the baseline model. We report the results in Table 10.

As shown in Table 10, in each case, when the price of a particular agent is increased, there is an increase in the profit for that agent and vice versa. For example, when the price of the S1 agent is increased, the profit for S1 changes from 3,761 (as reported in the comprehensive model in Table 6) to 6,253 (Table 10). Further, S1 profit is decreased to negative 1,469 when the price of S1 agent is decreased. This provides further evidence that the model works as designed.

5.3.3 Validation Study with Uniform Distribution

We modeled both the propensity to squeeze and propensity to switch using triangular forms of distribution. As we stated earlier, triangular distributions are commonly used when we don't know a lot about the model parameters. In the validation study, we adopt uniform distribution with a range of [0.8, 1] and rerun the GCN comprehensive model. If our model is robust enough, we should see results based on uniform distribution similar to those based on triangular distribution. We report the results based on uniform distribution in Table 11.

As Table 11 shows, we detect similar patterns in results based on uniform distribution. For example, the number of exits increases as one goes further upstream of the supply network, with the most exits occurring at the raw material level and the least exits occurring at the first-tier supplier level. This is the same pattern we detected when using triangular distribution. Similarly, the largest portion of the profit is seen from top-tier suppliers and the raw material suppliers have the least amount of profit when using uniform distribution. These patterns closely resemble those observed using triangular distribution.

5.4 Post-hoc Analysis

5.4.1 The Impact of Adjusting Squeeze Intensity

Our base model addresses the unilateral, constant price-cut pressure from the buyer firm, which is motivated by prevalent business practices exhibited in Boeing, FCA, GM, Walmart, etc. (Bloom and Perry 2001; Colias 2014; Johnsson and Robison 2018; Keith et al. 2016; Murfin 2014; Quinn 2015; Roemer 2006; Sedgwick et al. 2008; Strom 2015; Waller, Johnson, and Davis 1999). For example, as we mentioned in the introduction section, in FCA's Source Package, suppliers are required to agree to a fixed percentage of price reduction year over year, regardless of which supplier or results from past squeeze. Similarly, in Boeing's Partner for Success program, a fixed price-cut target was given to its supply base, regardless of the specific context of the supplier.

In a post-hoc analysis, we investigate an alternative approach to this constant mandate of a fixed percentage of cost reduction. What happens if a buyer firm adjusts the propensity of squeeze based on past performance? Would the buyer be better off? We thus implemented a competing logic with learning in mind (please refer to learning logic diagram in Appendix 1). In this alternative model, a buyer firm observes the results of past financial squeezes on operational performance (profit) and makes adjustments. The initial propensity of squeeze is set to be 0.5. If the mean profit from past squeeze approaches is higher than that from past non-squeeze approaches, a focal buyer would increase its propensity to squeeze by a factor of 0.05. Otherwise, the propensity to squeeze will be reduced by a factor of 0.05. Here we take the buyer's perspective and examine the impact of a learned approach to putting price-cutting pressure on suppliers vs. a blanket mandate of price cut. Results show that the learned approach has a slight advantage on revenue and profit for the buyer firm. Specifically, the learning model generates an average profit of 14,254 for the buyer firm, which is slightly higher than the average profit in the non-learning model at 14,169. Similarly, the learning model generates a revenue of 56,353, which is slightly higher than the average profit from the non-learning model at 56,348. We call for future research to examine the best approach to adjust squeezing propensity. Various machine-learning algorithms may be employed to adjust the squeezing intensity to optimize buyer profit.

5.4.2 The Impact of Agent Size

Our base model does not distinguish the effect of the size of the agent. Yet extant literature attests to the effect of size in price negotiations (Ellison and Snyder 2010). In the post-hoc analysis, we simulate a scenario where the size of the supply network agents varies. Here we randomly assign a size to each supply network agent. Thus, we simulate a scenario where both the size and the network centrality score jointly impact the propensity to reject a squeeze. Results on the network structure are reported in Tables 4A and 4B. The results on agent performance are reported in Tables 6A, 6B, and 6C. Overall, we don't see a large variation in impacts on network structure or operational performance.

6. DISCUSSION AND CONCLUSION

6.1 Discussion

Financial squeeze can be seen as a type of environmental change. Agents then respond to this environmental change based on a set of simple rules and based on their attributes such as size, network position, and pricing structure. Through interaction with other agents and with the environment, agents adapt to the environmental change and network patterns emerge.

Our results suggest that buyer's financial squeeze affects the structure of the extended supply chain as a system. They also suggest that buyer's financial squeeze can have unintended effects from a supply network perspective.

First, we examined the impact of financial squeeze on the network structure. Financial squeeze administered by the focal buyer firm impacts the stability of the supply network in that it causes a large number of suppliers to sever their relationships with the existing supply network and at the same time facilitates the entrance of new suppliers. Our results suggest that the impact of financial squeeze on the network structure varies depending on where a firm is located in the supply network. Firms located at the bottom of the supply network suffer most from financial squeeze. The magnitude of the effect of financial squeeze on the number of suppliers exiting the supply network increases as one travels upstream. This finding holds across different network types and different combinations of supplier responses.

An intuitive explanation is that top-tier suppliers enjoy two structural benefits. First, they are situated closer to the source of the financial stress and therefore receive the signal of environmental change (i.e., financial squeeze) early. This allows top-tier agents to better dissipate the financial stress to a larger audience, including their direct suppliers, and via these direct suppliers to multiple layers of indirect suppliers. The higher the network position an agent occupies, the larger the number of nodes it can access, either directly or indirectly. Via these nodes, a top-tier supplier can extract pooled resources such as excessive profit margin from its supply network. Lower-tier suppliers, on the other hand, receive the signal of financial stress late in the supply network and will not be able to find as many network nodes to spread the burden of the financial stress. Second and relatedly, beyond the pure number of nodes, suppliers at the top tier have more options to diffuse the impact of the financial squeeze than the lower-tier suppliers, especially raw material suppliers. Raw material suppliers are situated at the bottom of the supply structure and therefore cannot pass on the squeeze or switch suppliers. Based on our findings, we advance that:

Proposition 1*: Sustained squeeze strategies increase the exit of suppliers at each echelon of the supply network, with extended suppliers at the bottom of the supply network suffering the most. The frequency of network exits is curvilinearly related to the network tier in which a supplier resides, such that the magnitude of exits gets higher as we go further upstream.*

This insight is managerially very relevant, because top-tier suppliers typically lack purview of tiers further away from them. However, sourcing practices focused on financial squeeze may increase the risks of disruption due to the impact of squeeze applied to suppliers further upstream, on the supply network location most vulnerable to squeeze. On the general level, our research informs purchasing executives of the potential damaging effects of financial squeeze on players who are typically “out of sight and out of mind,” and reminds these executives to incorporate the ecological perspective when making decisions that might impact their supply network.

Second, we discover a few emergent network archetypes in response to financial squeeze. We summarize these archetypes in Figure 4 and describe them below.

<<Insert Figure 4 about here>>

The first archetype is *empty nest.* An empty nest is characterized by a high number of existing suppliers leaving the network and a low number of new suppliers entering the network. In our research, an empty nest emerges under two conditions. First, at the system level, if network suppliers are restricted to cost reduction or to rejection as their only options to cope with financial squeeze, it will lead to a large number of suppliers exiting the network without replacement. This can happen in an industry with high switching barriers such as the oil and gas sector. Second, at the network node level, if squeeze is passed on to a nexus supplier, it will lead to the exit of the nexus supplier and the downstream buyer will have a hard time recruiting replacements (see Yang, Birge, and Parker 2015 for a case example.) Empty nest has performance implications. Importantly, it leads to a high frequency of unfulfilled orders, which can indirectly impact the revenue and profit of nodes around it. However, the negative impact associated with empty nest is not limited to the immediate effects. In the long run, a persistent shortage in the supply base can disrupt the continuity of business processes for the buyer firm and can cause frequent delays in production process. In addition, a shortage of supply base limits the choices of suppliers and increases risks of poor quality at the supply source (Chopra and Sodhi 2004). These disruption and quality issues can in turn erode shareholder value of the firm (Hendricks and Singhal 2008).

The second archetype is *transit network.* A transit network is characterized by a high number of existing suppliers exiting the network and a high number of new suppliers entering the network. A transit network can be seen as one that is turbulent. However, due to the high number of new entrants, it constantly renews itself and therefore is also dynamically stable. A transit network can be further categorized as TransitUp or TransitDown. The former indicates that transit states happen upstream in the supply network (i.e., close to the raw material suppliers), while the latter indicates downstream transit states (close to the customer). In our research context, we witness the emergence of TransitUp when a supplier takes a combination approach to price squeeze. This is true for all three network types (GCN, NexusIn, and NexusOut). The performance implication for TransitUp is the high transaction costs associated with the severance of relationships. As a result, profit is usually an issue for raw material suppliers in a TransitUp network. Unfulfilled orders are typically not problems for the TransitUp network, due to its ability to renew itself. We did not witness a TransitDown pattern in our research context.

The last archetype is a *stable network* that is characterized by low exits and low entrances. It can be further distinguished as StableUp and StableDown. In the former, the region of stability resides in the upstream supply network, while the latter refers to downstream. In our research context, a StableDown network emerges when suppliers are constrained to only respond to financial squeeze by switching suppliers. This can happen to firms that take a conservative approach to initiating a change of suppliers or to firms where other options such as cost reduction are not viable. We see low level of entrance and exit activities happening at the downstream of the supply network, suggesting long-term stable relationships among agents. Agents in a StableDown network enjoy low unfulfillment ratio, and relatively high revenue and profit.

Proposition 2*: Financial squeeze signifies an environmental stress to the supply network. Through the agents' interactive and adaptive behaviors, the following network patterns emerge: Empty Nest, TransitUp, and StableDown. Empty nest is correlated with high order unfulfillment rate. TransitUp is correlated with low profit for lower-tier (i.e., upstream) suppliers and StableDown is correlated to low unfulfillment rate, high revenue, and high profit for upper-tier (i.e., downstream) suppliers.*

6.2 Conclusion

Financial squeeze leads to turmoil in the supply network. The number of switching activities represents the frequency of incorporating new suppliers and the discontinued relationship with existing suppliers, i.e., the entrance and exit behaviors in a supply network, and these behaviors influence a firm's bottom line. It costs to establish and cultivate relationships between a buyer firm and a supplier firm. An excessive number of new entrances will incur a high switching cost, or cost that is associated with setting up the contract, buyer's initial investment in supplier certification and onboarding, and relationship building (Nielson 1996). A high switching cost will erode the buyer firm's profit and thus reduce value captured by the buyer firm. On the other hand, an excessive number of exits will decrease resources available to the buyer firm and increase the probability of material shortages. Unless a buyer can source necessary supplies, it may not be able to continue the production process, resulting in a loss of sales or reduction in value creation.

Similar to findings from previous research on supply chain solvency, pricing, and trade credit (e.g., Boissay and Gropp 2007; Wadecki, Babich, and Wu 2012; Yang, Birge, and Parker 2015), which show, for instance, that credit default propagates along trade-credit chains, our results suggest that financial squeeze also has a chain propagation effect. However, contrary to that research, which shows that liquidity shocks are transmitted down trade-credit chains until they reach firms that ultimately absorb the shocks, our results suggest that the squeeze can be transmitted down the chain until financially weak suppliers exit the network. Future research is needed to examine this outcome further.

6.3 Contribution and Implications

In this study, we explore emergent aspects of the supply chain system due to financial squeeze and the impact on network structure and value capture. Past literature has investigated buyer–supplier relationships and the effects on performance (Cai and Yang 2008; Chae, Choi, and Hur 2017; Friedl and Wagner 2012; Hofmann 2011; Krause and Ellram 2014; Kull and Ellis 2016; Nyaga et al. 2013; Pfeiffer 2010). However, this stream of literature focuses on the dyad or triad (Li and Choi, 2009) level and there has been limited work on the system-level effects of financial squeeze. This is a major limitation, because the managerial action and eyesight of a buyer over its extended supply chain are limited (Carter, Rogers, and Choi 2015), and cannot account for what lies beyond the buyer purview (Carter, Ellram, and Tate 2007; Carter, Rogers, and Choi 2015; Choi and Dooley 2009; Choi and Krause 2006). Therefore, while focusing on the buyer–supplier dyad to examine issues surrounding squeeze has advanced our knowledge, it also critically limits our understanding.

Our research suggests that although extended suppliers are typically out of the sight of the focal buyer firm, they should not be out of mind. Rather, financial squeeze that seemingly has been administered to the first-tier suppliers will be propagated down the supply network and reach the extended suppliers. What is more, the impacts of financial squeeze can be amplified the further it travels and cause detrimental impacts on the operational performance of network agents located at the bottom of the supply network.

Our research provides valuable insights to managers at buyer firms. Before a negative impact can be mitigated, it must first be recognized. The complexity of the supply network often prevents a clear understanding of the consequences of an event administered to a network. Our research provides a way to explain the consequences of a financial squeeze and points out the locations of the supply network that are most susceptible to these consequences. Managers should be warned to closely watch and pick up early warning signs of distress from the extended supply network. Such an understanding can help mitigate risks that may not be immediately noticeable.

Our research answers the call to utilize the CAS lens to explore dynamics in a supply network. Specifically, we examine a prevailing and consequential, yet under-researched, practice in the supply network from a systems perspective: the strategy of financial squeeze. We are among the first, if not the very first, to explore the potential impact of financial squeeze on a buyer firm's extended supply network, on its order fulfillment rate, on its revenue, and on its profit. In addition, we examine the manifestation of the impacts across different network types. This helps to better understand the nuances of the effects. Lastly, our model simulates the delicate balance between financial squeeze strategy and value created and captured. It helps a buyer firm to understand the consequence of price reduction in a complex supply network.

6.4 Limitations and Future Research Directions

This study opens up many avenues to extend our results. First, we built a generic conceptual model as the base of our research, supplemented by two additional network types. We recognize that the results are contingent on the specific design choices of the model. Yet supply networks have diverse sizes, shapes, and configurations. Future research can analyze the impact of financial squeeze on other types of supply network to examine how network topology might influence the effect of financial squeeze. In addition, future studies can follow an inductive approach to examine the mechanisms underlying our observations, as well as a deductive approach to test the observations.

Our research examines the impact of financial squeeze on network structure in terms of switching activities, which provides a reasonable proxy for the entrance and exit of suppliers. A follow-up study could incorporate other elements of the network, such as tie strength and network centrality and embeddedness, and examine how financial squeeze impacts these structural elements of a supply network. Future research can also build on our results to examine the effects of high network supplier turnover on the network value creation process. As suppliers discontinue their activities in the network, new suppliers may either inject innovation or lower quality, with unexpected consequences downstream to the buyer. Future research can also identify and investigate the effectiveness of potential cost reduction strategies that may be adopted in different network locations, as our results suggest different impacts further upstream compared to downstream.

Financial squeeze is a prevalent yet under-researched sourcing practice. However, studies to date that can inform this practice are restricted to the dyad level. The complex adaptive system perspective provides the opportunity to understand better the systemic behavior, impact, and potential consequences of financial squeeze on supply networks. This topic is very consequential as network value chains continue to fragment across the globe. We believe and hope we may have laid the foundation for a fruitful and exciting research stream aimed at exploring many aspects of network financial squeeze.

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