Int. J. Production Economics 162 (2015) 115–124

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

Disentangling diversification in supply chain networks

Kamil J. Mizgier [a,*], Stephan M. Wagner [a], Matthias P. Jüttner [b]

[a] Chair of Logistics Management, Department of Management, Technology, and Economics, Swiss Federal Institute of Technology Zurich, Weinbergstrasse 56/58, CH-8092 Zurich, Switzerland

[b] Swiss Finance Institute and University of Zurich, Plattenstrasse 14, CH-8032 Zurich, Switzerland

ARTICLE INFO

Article history:
Received 24 November 2013
Accepted 14 January 2015
Available online 22 January 2015

Keywords:
Supply chain risk management
Network theory
Disruption management
Reduced form model

ABSTRACT

We propose a model for the quantification of business disruption risk in a global supply chain network. To calculate the loss distribution induced by supply chain disruptions for a focal firm, we apply a bottom-up modeling approach. On the firm level, we model production disruptions of various hazard events in reduced form. We incorporate the network structure explicitly and define the loss propagation between the firms. Via Monte Carlo simulation, we analyze the effects of different model specifications and network structures on the loss distribution of the focal firm. We show that diversification effects can lead to counterintuitive results when we consider the network structure and the correlations of hazard events. Our methodology and findings enable more informed and transparent decisions for supply chain design.

1. Introduction

As a result of fiercer competition, growing customer needs, accelerated globalization of markets and rapidly developing technology, almost all industries have experienced massive pressure to make intrafirm and interfirm business processes more efficient and/or more responsive. Firms outsource manufacturing and research and development (R&D) activities, source in low-cost countries, reduce inventories and slack, streamline the supply base and collaborate more intensively with other members of the supply chain. Naturally, the potential cost reductions and improved operational efficiencies achieved through these management decisions come at a cost: supply chain networks (SCNs) are becoming large, and densely interconnected, which increases the production-inherent complexity and uncertainty. Therefore, predictions regarding output losses from production breakdowns in the supply chain are difficult to make due to the interaction of firms and the dispersion of losses through the network. For example, the 2011 disastrous events in Japan have demonstrated the vulnerability and interconnectedness of the world's supply chains. As a consequence of these events, high-tech, computer and automotive manufacturers were exposed to disruptions of supply sources and shortages of second and third tier electronic parts suppliers.

This paper introduces a conceptual framework for the field of disruption risk management in SCNs. We propose a generic model for calculating the loss distribution due to time-structured disruptions in a given network. For each firm in the network, we allow a variety of hazard events which can be idiosyncratic (e.g., machine malfunction) or systematic and affecting more than one firm (e.g., natural catastrophes). We describe the interaction of different hazard events on the firm level and account for the time required for resolving the disruption using renewal-reward processes. The interaction and dispersion of disruption losses across firms are obtained by incorporating the network topology explicitly. The latter modeling aspect allows us to reproduce contagious effects; i.e., idiosyncratic disruptions may affect other firms in the SCN by propagating through existing linkages among firms. By incorporating systematic hazard events and network topology (contagion), we cover two fundamental aspects of interdependency among firms in SCNs that are essential for estimating the loss distribution from disruptions in each node in the network. We implement the model and investigate some idealized examples via a Monte Carlo (MC) simulation. We concur with Nair et al. (2009, p. 788), who argue that simulation "is well suited to examining the complex pattern of decision making by agents (buyers and suppliers) in a network over time". In this research, we show the effects of different possible model specifications on expected losses and other distributional measures. Then, we analyze typical and relevant settings for SCN design. In particular, we are interested in the impact and direction of certain diversification strategies (e.g., reallocation of purchasing volume among the suppliers or choosing an alternative supplier in another geographical region).

Our approach is different from the existing methods for supply chain risk modeling, because we include the structure of the SCN explicitly and allow a broad set of hazard events. First, this necessitates that we specify the mechanics as the interaction of hazard events not only on the firm-level but also across firms.

* Corresponding author. Tel.: +41 44 632 7362; fax: +41 44 632 1526.
E-mail address: kmizgier@ethz.ch (K.J. Mizgier).

http://dx.doi.org/10.1016/j.ijpe.2015.01.007
0925-5273/

Second, we focus exclusively on losses from supply chain disruptions. Therefore, we obtain predictions on losses from different hazard categories and provide managerial implications related to diversification effects and supply chain design. Third, we introduce definitions and theoretical concepts as stochastic processes in an accurate and complete way.

This paper is organized as follows: Section 2 discusses the existing literature. The formal model is then introduced and described in Section 3. In Section 4 we discuss the diversification effects. In Section 5 we implement the model, analyze some stylized examples and perform a sensitivity analysis. Section 6 elaborates on the implications for managerial practice. Finally, we give an overview of the relevant findings and draw conclusions.

2. Literature review

In recent years a growing number of researchers and practitioners have put supply chain risks on their agendas, motivated in particular by catastrophic events that resulted in disruptions of global supply chains and negatively impacted major parts of the economy. The vast majority of contributions and deduced managerial recommendations in the literature are of normative nature, anecdotal or case study-based. For instance, firms that aim to follow a single sourcing strategy in order to benefit from larger economies of scale are more likely to be negatively affected when disruptions on the inbound supply chain occur (Chung et al., 2010). The premise that diversification reduces risk seems to be intuitive when we think of portfolio theory (Markowitz, 1952). However, it is insufficient in the context of SCN's substantiated quantification. To our knowledge, the majority of previous research has focused on a simple setup of buyer–supplier relationship, thus neglecting the structure of the SCN (as highlighted by Choi and Wu, 2009). Ultimately, it is not obvious whether the evolving network structure exacerbates or mitigates the effects of those hazard events on the production process. On one hand, a diversified supplier structure – e.g., across countries or more generally across different hazard events – can be helpful to dampen the impact of single production disruptions. On the other hand, the linkages among firms induce contagion effects – i.e., single disruptions propagate, and therefore the consequences may be more pronounced and harmful. Thus, a better understanding of the described mechanics and how supply chain design affects the inherent risk exposure is very important.

Banks (2005) provides a comprehensive analysis of catastrophic risk management from the perspective of the financial industry. However, it is not only prominent macro-events that lead to costly supply chain disruptions. A substantial body of recent literature reports on events at the supply chain level that resulted in serious problems for the involved firms (e.g., Whitney et al., 2014). Numerous proposals for best practices and guidelines for risk mitigation and business continuity planning that aim to create secure, robust, and/or resilient supply chains have therefore been published (e.g., Tang, 2006; Craighead et al., 2007). The influence of disruptions on the performance of the supply chain is investigated, for instance, by Chen and Yano (2010). Reactive strategies for supply chain disruption management are studied by Shao and Dong (2012). Their findings support the application of reactive strategies to supply chain disruptions by supply chain managers, and provide guidance to minimize the loss of profits and customers during the disruption. The negative effects of supply chain disruptions on operational performance are investigated by Hendricks and Singhal (2005). They find that firms which experience supply chain disruptions report on average 6.92% lower sales growth, 10.66% higher cost and 13.88% higher inventories. Mitigation and contingency strategies are thoroughly discussed by Tomlin (2006). With a discrete-time Markov process to model supply chain disruptions, the author compares the effectiveness of different risk mitigation strategies in a simple setup with one buying firm and two suppliers. Depending on the length of the disruption, mitigation, rather than contingent rerouting, tends to be best in the case of rare supply chain disruptions. In another study, Hult et al. (2010) investigate supply chain investment decisions under high risk conditions. They extend the real options theory to the case of multiple firms in the supply chain.

More relevant for our work is the literature concerning SCNs and their analysis as complex systems which draws on multiple academic disciplines and methods (Sanders and Wagner, 2011). Jackson (2008) gives a very extensive overview of the economic and social network literature. Here, we are primarily interested in the consequences and managerial implications of given SCNs. Cossin and Schellhorn (2007) present a model of credit risk in a network economy. Based on the example of the U.S. automotive industry, they develop a structural model of cash-flow risk that causes interdependencies between firms. Allen et al. (2006) propose an agent-based model to improve the resilience of SCNs in a dynamic environment. In the context of SCN dynamics, Mizgier et al. (2012) examine how companies default. The authors use an agent-based modeling approach to describe the interaction among heterogeneous agents. This model has been recently extended by Chong et al. (2014) to incorporate diversification effects during economic downturns. Another focus in this research area is the optimal design of SCNs in uncertain economic environments. Sodhi and Tang (2009) survey various modeling and solution choices developed in the asset liability management literature and discuss their applicability to supply chain planning. Klibi et al. (2010) present a review of optimization models proposed in the literature and provide the foundations for a robust SCN design methodology. They highlight the need for new SCN multi-hazard modeling techniques necessary for efficient decision making under uncertain conditions.

Another trend in the literature is the calculation of problem-inherent losses for network structures. Nagurney and Qiang (2009) present a comprehensive study of the network approach to deal with interdependencies and uncertainties in economic and social networks. Operational activities that are essential to a bank's business model are modeled and studied in Leippold and Vanini (2005). Instead of incorporating network topologies explicitly, another common approach to capture default dependencies in credit portfolios is to use copula functions (Li, 2000). Wagner et al. (2009) apply this approach to supplier networks and illustrate the significant impact of default correlation on a supplier portfolio. In a simple setup of a network with one stage of suppliers, Babich et al. (2007) recommend that once the suppliers are chosen, reducing their correlation will be advantageous. For example, they may attempt to sell to different customers, use different production technologies and/or procure from different raw material sources in order to reduce exposure to common country-specific risks or common catastrophic events.

A generic supply chain disruption profile is well documented and described by Sheffi and Rice (2005). Deleris and colleagues (Deleris et al., 2004; Deleris and Erhun, 2005) explicitly study supplier networks where disruptions in the production process are modeled in reduced form. Their main idea is to introduce two separate models, a hazard model for describing the disruptions on the firm level and an operations model that incorporates the network topology by characterizing the interaction between the firms in the SCN. For the integration of these building blocks, they employ the theory of Generalized Semi-Markov Processes (GSMP), on which we give more details later in this paper. The estimation of the loss distribution is then conducted via a Monte Carlo (MC) simulation. Deleris et al. (2004) focus on disruptions caused only by fire and hence their analysis does not reflect the actual risks experienced by firms in the network, where various types of risk may exist. Deleris and Erhun (2005) extend the set of hazard events and base the risk assessment (loss of volume) on a flow model of the network. Both