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Supply chain network equilibrium with strategic financial hedging using futures

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ABSTRACT

In this paper, we develop a network equilibrium model for supply chain networks with strategic financial hedging. We consider multiple competing firms that purchase multiple materials and parts to manufacture their products. The supply chain firms' procurement activities are exposed to commodity price risk and exchange rate risk. The firms can use futures contracts to hedge the risks. Our research studies the equilibrium of the entire network where each firm optimizes its own operation and hedging decisions. We use variational inequality theory to formulate the equilibrium model, and provide qualitative properties. We provide analytical results for a special case with duopolistic competition, and use simulations to study an oligopolistic case. The analytical and simulation studies reveals interesting managerial insights.

1. Introduction

Supply chains today have become increasingly complex and global, which have made firms at different stages of supply chains more and more vulnerable to various risk factors. Understanding and managing these risks as well as their impacts on supply chain operations and profitability have become a business imperative for many companies. Therefore, supply chain risk management has drawn increasing attentions from both academians and practitioners.

In this research we focus on using futures to hedge foreign exchange risk and commodity price risk in supply chains. A survey by Scott (2009) showed that foreign exchange risk was ranked as the second most important risk factor by the risk management executives of 500 global companies. The fluctuations of currency values can cause significant loss to firms that are engaged in global trades. For example, in January 2015, the chief executive officer of Procter & Gamble warned that the appreciating value of dollar would result in a 5% reduction of the company 2015 sales and a 12% reduction in profit (Narvaez, 2015). For another example, in 2016 the British companies rushed to hedging their foreign exchange risk to protect themselves from the growing "Brexit" risk (Nag, 2016). Moreover, supply chains are also affected by the commodity price risk directly by the raw material prices and indirectly by the energy and transportation cost (Zsidisin, Hartley, & Gaudenzi, 2016). For example, in 2011 the consumer production company, Kimberly-Clark, suffered sales and profit decline partially due to the increasing wood pulp price (Zsidisin & Hartley, 2012). Commodity prices can be very volatile in the global market. For instance, from August 2003 to March 2004, soybean prices increased by 74% from $237 to $413, and then dropped to $256 within the next two years (Zsidisin & Hartley, 2012). For another instance, from April 2010 to April 2011, the price of silver tripled in the commodity market (Zsidisin & Hartley, 2012).

According to a study of over 7000 nonfinancial firms from 50 countries, about 60% of the surveyed firms have conducted some form of hedging using financial derivatives (Bartram, Brown, & Fehle, 2009). Our research focuses on the use of futures to hedge foreign exchange and commodity price risks. In the world largest futures and option market, CME Group, (Chicago Mercantile Exchange and Chicago Board of Trade), futures are the dominant form of derivative contract for foreign exchange rates and commodity prices. For example, as of October 2017, for foreign exchange rate, the ADV (average daily volume) of futures is 832,165 and the ADV of options is 78,688; for metals, the ADV of futures is 506,049 and the ADV of options is 47,462; and for commodities and alternative investment, the ADV of futures is 1,116,089 and the ADV of options is 249,468 (CME Group, 2017). CME also provides detailed guides for businesses at different stages of supply chains to engage in financial hedging.

Our paper falls in the research stream of supply chain risk hedging, which uses two main approaches: operational hedging

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and financial hedging (see, e.g., Van Mieghem, 2003). Operational hedging uses operational and processing flexibility to mitigate supply chain risks. Such operational flexibility may be incorporated in various supply chain decisions, such as, facility locations, multisourcing, subcontracting, etc. For example, Huchzermeier and Cohen (1996) investigated the value of operational flexibility under exchange rate risk. Kazaz, Dada, and Moskowitz (2005) studied the selection of production policies with the option of postponing allocation decisions under foreign exchange risk. Goh, Lim, and Meng (2007) studied a multi-stage supply chain network with foreign exchange risk, demand and supply risk, and disruption risk using a stochastic model.

Financial hedging, on the other hand, uses financial markets and financial instruments, such as, forward contracts, futures and options, to counterbalance various risk factors. Financial hedging has long been studied in the area of finance. For a detailed and complete review of financial derivatives and financial hedging strategies, we refer the audience to the textbook by Hull (2002). Studies in the literature have also investigated the relationships between operational hedging and financial hedging, and the strategies to integrate the two approaches. Mello, Parsons, and Triantis (1995) studied a multinational firm that had production sourcing flexibility and financial hedging tools to mitigate foreign exchange risk. Ding, Dong, and Kouvelis (2007) also investigated the integration of financial hedging and operational hedging for an international firm. The firm in the study was allowed to hedge foreign exchange risk by optimally using financial options and/or delaying production allocation at different markets. A mean-variance approach was used to model the risk-averse behavior of the firm. Van Mieghem (2003) discussed the literature regarding capacity management under uncertainty. The paper reviewed capacity investment models, and compared financial and operational hedging methods. Caldentey and Haugh (2009) designed a Stackelberg game to study the flexible supply chain contracts between a producer and a retailer with and without financial hedging. The authors showed that the producer preferred the flexible contract with hedging while the preference of the retailer depended on the model parameters. Hommel (2003) used a real option approach to show that operational hedging created through operational flexibility provided a strategic complement to any financial hedging based on variance minimization. Moreover, operational flexibility also affected the composition of the financial hedging portfolio. Chowdhry and Howe (1999) studied the conditions under which multinational firms would reduce risk exposure by operational hedging. The paper found that firms would use operational hedging only when they were exposed to both exchange rate risk and demand risk. The paper also discussed the plant location and capacity decisions under different conditions of demand and foreign exchange rate. In addition, the authors showed that the firms could execute the optimal financial hedging policy with call and put and forward contracts. Chen, Li, and Wang (2014) used the mean-variance approach to study a firm's capacity planning problem with financial hedging when it had potential suppliers in multiple low-cost countries and was exposed to foreign exchange risk and demand uncertainty. The paper investigated the benefits of hedging strategies in different scenarios. The authors also found that the financial and operational hedging could interact each other to maximize the firm utility. Chod, Rudi, and Van Mieghem (2010) studied a firm capacity investment under demand uncertainty. The paper considered two risk factors: mismatch between capacity and demand and profit variability. It showed that operational flexibility could mitigate the mismatch risk while financial hedging could mitigate profit variability. The paper showed that whether operational flexibility and financial hedging could be complements or substitutes depended on the type of the operational flexibility. Zhao and Huchzermeier (2015) reviewed the literature, and proposed a risk management framework for the integration of operations-financial interface models. The paper also investigated the conditions under which operations and finance should be integrated, and presented categorizations of operational and financial hedging. In addition, the authors discussed the connections between relationship analysis and approach choice. Zhao and Huchzermeier (2017) studied a multinational corporation that could use production switching, capacity reshoring, and financial hedging to mitigate supply-demand mismatches and exchange rate risk. The authors decomposed operations and finance to optimize the mean-conditional value-at-risk. The paper found that the financial and operational hedging could be complements in optimizing the profit and risk. In addition, the paper showed that the two hedging methods were substitutes in risk reduction, and coordination was important to minimize the substitution effects. Park, Kazaz, and Webster (2017) investigated how a firm could mitigate global economic risk through production hedging, pricing, and financial hedging under exchange rate and demand uncertainty. Their model assumed that the firm maximized the expected profit with the consideration of a value-at-risk constraint. Gamba and Triantis (2014) studied a dynamic integrated risk management strategy consisting of liquidity management, financial hedging, and operational flexibility, and analyzed the impacts of different components and their interactions on risk management. Caldentey and Haugh (2006) developed an optimal control model that allowed a firm to dynamically optimize the operation policy and hedging strategy based on financial markets.

Note that these studies in the literature typically focused on the optimal strategies of a single firm or a single supply chain consisting of a firm and its supplier. Our research differs from the above studies in that our model is based on a network equilibrium approach that allows multiple heterogenous supply chains with or without financial hedging instruments to compete in a non-cooperative manner. Our approach allows one to investigate the interaction between supply chain decisions and financial hedging decisions in large and realistic competitive markets. In particular, the contributions of our research to the literature are as follows:

1. Our study is the first attempt to model the financial hedging decisions and operation decisions of heterogenous firms in large scale supply chain networks. We prove the existence of the equilibrium solution to the general network model. We also prove the monotonicity of the model which guarantees that the algorithm used in the paper converges to the equilibrium solution.
2. For a special case of the model we provide and discuss closed-form analytical results regarding how volatility and the basis risk affect two competing supply chain firms' profitability and risks, which have not been reported in the literature.
3. Our general network model provides a flexible, realistic and powerful approach which can be applied to study large-scale real-world problems. Our simulation case studies based on the general network model discovered findings that could not be revealed by the analytical results.
4. Our study generates interesting managerial insights which can help managers and policy-makers better understand the connections between financial hedging and other activities in supply chain networks in a competitive environment.

In this paper the supply chain firms' risk averse behaviors are modeled using the classic mean-variance approach. The mean-variance framework was originally developed by the Nobel Laureate Harry Markowitz in his seminal work of portfolio selection, which has become part of the foundation of the modern finance theory. The mean-variance approach provides very good approximation to a variety of utility functions and nonnormal probability distributions, and suggests "good recommendations"

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