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Three-echelon supply chain coordination with a loss-averse retailer and revenue sharing contracts

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ABSTRACT

This paper studies supply chain coordination via revenue sharing contracts in two different supply chain structures. First, for a three-echelon supply chain with a loss-averse retailer, a loss-neutral distributor, and a loss-neutral manufacturer, we derive the three players' optimal policies, and find that compared with a loss-neutral scenario, the loss-averse retailer gains fewer profits and a lower utility. Additionally, compared with the loss-neutral scenario, the loss-averse retailer orders less when it faces a high overage cost and orders more when it faces a high shortage cost. Second, for a two-echelon supply chain consisting of a loss-averse retailer and a loss-neutral distributor, we provide the two players' optimal policies. Third, we derive coordination conditions for the two supply chain structures, and quantify the differences between the three-echelon supply chain and the two-echelon supply chain. Furthermore, we find that Pareto improvement can be achieved under revenue sharing contracts.

1. Introduction

Due to the accelerating pace of technology innovation, the lifecycle of high-tech products (e.g., computer software and hardware systems) has shortened substantially. This trend has resulted in increases in market demand uncertainty and risk for supply chains. To keep risk (e.g., financial loss) within a certain level, retailers would rather maintain a low inventory, even when they are aware that increasing their inventory level might result in greater profit at times. This type of decision-making behavior is identified as loss aversion, one of the key features in the Prospect Theory (Kahneman and Tversky, 1979), which states that people are more sensitive to losses than to gains of the same size. In addition, the perception of gains or losses relates to a specific reference point. Many experimental studies and managerial decision-making practices under uncertainty (MacCrimmon and Wehrung, 1996; Fisher and Raman, 1996; Schweitzer and Cachon, 2000; Ho and Zhang, 2008; Feng et al., 2011) have asserted that enterprise managers' decision-making behaviors deviate from expected profit maximization due to loss aversion. In the scope of vertical supply chain collaboration, a supply chain leader, such as a large manufacturer, can diversify its assets across multiple firms, thereby likely becoming risk-neutral (Wiseman and Gomez-Mejia, 1998; Wang and Webster, 2007). Followers, such as small retailers whose security of business and income depend highly on their principal, are normally loss-averse (Wang and Webster, 2007). In most supply chain models, decision makers are assumed to be loss-neutral, which maximizes the profit (or the expected profit) in an uncertain environment (Xing et al., 2013). These observations imply that existing research findings that rely on loss-neutral behavior assumptions may not apply to supply chains that include loss-averse players. Consistent with the definition of loss-averse from Kahneman and Tversky (1979), we define the term loss-neutral as having the same sensitivity to the same amounts of loss and gain. Therefore, it is very important to study the effect of loss aversion on supply chain members' decisions and supply chain performance, under various scenarios. In this paper, we model loss as the specific risk that supply chain players should consider in their decision-making.

For decentralized supply chains, many efforts have been made to improve overall competitiveness via vertical coordination. Research has proven that revenue sharing contracts are advantageous in achieving coordination for various types of supply chains (Cachon and Lariviere, 2005). Mortimer (2008) estimates that revenue sharing contracts can increase the industry's total profit. Although the importance of revenue sharing contracts has been recognized in the field of supply chain management (see Section 2), loss aversion behaviors have not been well addressed under revenue sharing contracts. To provide practical, viable managerial insights, this paper analytically models and

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characterizes the supply chain coordination problem with a loss-averse retailer in the context of revenue sharing contracts. In addition to the two-echelon supply chain that has been widely observed in various industries, the three-echelon supply chain structure is also common and has received a large amount of attention (Munson and Rosenblatt, 2001; Khouja, 2003). Accordingly, we study the coordination problem in a two-echelon supply chain and a three-echelon supply chain, and conduct a comparative analysis of the two supply chain structures, regarding coordination conditions.

Regarding supply chain coordination with loss-averse players, two previous research projects relate to our study. Wang and Webster (2009) studied gain/loss-sharing-and-buyback contracts in a two-echelon supply chain, and demonstrated that the optimal decisions for loss-neutral supply chains are inapplicable for supply chains with loss-averse members, even under a full information setting. Giannoccaro and Pontrandolfo (2004) studied both two-echelon and three-echelon risk-neutral supply chains under revenue sharing contracts, and emphasized decision and coordination condition deviations caused by supply chain structure changes. Wang and Webster (2009) failed to consider revenue sharing contracts, and Giannoccaro and Pontrandolfo (2004) failed to consider loss aversion behavior in their study. To the best of our knowledge, this paper is the first work that analytically models and characterizes the supply chain coordination problem with a loss-averse retailer in the context of revenue sharing contracts. The major contributions of this work can be summarized as follows:

(1) We develop revenue sharing contract models for a three-echelon supply chain with a loss-averse retailer. We derive the retailer's and distributor's optimal ordering policies, as well as the manufacturer's optimal production policy.
(2) Given a loss-averse retailer, we study the optimal decisions and coordination conditions for a two-echelon supply chain (see Corollary 5).
(3) We analyze the difference between the optimal ordering policies of a loss-averse retailer and those of a loss-neutral retailer. We further discuss the effect of loss aversion on the retailer's utility and order quantity, and the wholesale prices of the distributor and the manufacturer. We find that, compared with the loss-neutral scenario, the loss-averse retailer gains fewer profits and a lower utility.
(4) We derive the three-echelon supply chain coordination conditions and compare them with those of a completely loss-neutral three-echelon supply chain and a two-echelon supply chain with a loss-averse retailer. We show that, to coordinate the supply chain, the distributor and manufacturer need to lower wholesale prices to induce the retailer to maintain a specific order quantity when the retailer's shortage cost is lower, and they also need to increase their wholesale prices for larger profit margins as the level of loss aversion increases.

The remainder of the paper is organized as follows. Section 2 summarizes the related literature. Section 3 identifies model assumptions and notations used in the paper. Section 4 discusses the loss-averse retailer's optimal ordering policy in the three-echelon supply chain with revenue sharing contracts. We provide the loss-neutral distributor's optimal ordering policy in Section 5 and the loss-neutral manufacturer's optimal production policy in Section 6. Section 7 provides the supply chain coordination conditions and compares various supply chain structures. Section 8 concludes the paper by identifying future research directions.

2. Literature review

In this section, we focus on existing studies of loss aversion and revenue sharing contracts in the supply chain domain.

While loss aversion behavior was observed decades ago, this concept was not applied to supply chain study until recently. Schweitzer and Cachon (2000) and Agrawal and Seshadri (2000) are among the first works that studied a loss-averse newsvendor problem. Schweitzer and Cachon (2000) showed that a loss-averse newsvendor without shortage cost orders strictly less than a risk-neutral newsvendor, and the optimal order quantity decreases with the degree of loss aversion. Wang and Webster (2007) considered a decentralized supply chain, where a single manufacturer sells a perishable product to a single retailer with stochastic demand. They found that a gain/loss (GL) sharing provision decreases the retailer's order quantity and total supply chain profit, and mitigates the loss-aversion effect. They also presented a distribution-free GL-sharing-and-buyback contract that can achieve supply chain coordination and an arbitrary allocation of the expected supply chain profit between a manufacturer and a retailer. Wang and Webster (2009) extended the model of Schweitzer and Cachon (2000) by taking into consideration the shortage cost and summarizing comparative statistics of cost and price variations. They showed that a loss-averse newsvendor may order more than a risk-neutral newsvendor if shortage cost is considered. Later, Tapiero and Kogan (2009) investigated loss-averse retailer's order policies with random prices in a complete market and information asymmetry. They showed that if a loss-averse retailer maximizes a utility (profit) function, then its assessment of future prices is affected by the risk-averse attitude, which introduces a bias in its ordering policies. Wang (2010) investigated a loss-averse newsvendor game for which they identified a unique Nash equilibrium in order quantity. They also found that loss-averse behavior decreases the newsvendor's total order quantity. If the loss aversion effect is strong enough, it may lead to a lower total inventory level in a decentralized supply chain than a centralized supply chain. In addition to loss aversion, the risk attitude of a retailer towards demand uncertainty also plays an important role in his/her decision. Agrawal and and Seshadri (2000) studied the impact of uncertainty and risk aversion on price and order quantity in the newsvendor problem. They considered two models: one in which a change in price affected the scale of the distribution and on in which a change in price only affected the location of the distribution. They showed that in comparison to a risk-neutral retailer, a risk-averse retailer in the first model would set a higher price and order less; in the second model, however, a risk-averse retailer would set a lower price. Xiao and Yang (2008) investigated price and service competition between supply chains with one risk-neutral supplier and one risk-averse retailer under demand uncertainty. They found that a retailer with higher risk sensitivity would have a lower his optimal service level and retail price. Additionally, the substitutability of two products affects the rival's risk sensitivity. Caliskan-Demirag et al. (2011) formally modeled a retailer's risk aversion by adopting the Conditional-Value-at-Risk decision criterion, and analyzed the manufacturer's rebate amount decisions and the risk-averse retailer's joint inventory and pricing decisions in a game theoretic framework. They also demonstrated structural results on the uniqueness and existence of equilibrium, and characterized Nash equilibrium decisions. Ma et al. (2012) investigated channel bargaining with a risk-averse retailer. They showed that there exists a Nash-bargaining equilibrium for the wholesale price and order quantity with equal and unequal bargaining powers. Huynh and Pan (2015) studied operational strategies for a supplier and a retailer with risk preference under Vendor Managed Inventory (VMI)