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Mean-risk analysis of radio frequency identification technology in supply chain with inventory misplacement: Risk-sharing and coordination

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ABSTRACT

This paper investigates the application of radio frequency identification (RFID) technology to eliminate the misplacement problems in the supply chain, which consists of a risk-neutral manufacturer and a risk-averse retailer. By considering both fixed cost and tag cost of RFID implementation, we study the agents' incentives to adopt RFID in both uncoordinated and coordinated cases. We focus on analyzing the impact of risk attitudes on the agents' incentives and on the supply chain coordination. The central semi-deviation is adopted to measure the retailer's risk attitude. In the uncoordinated case, we find that, in order to induce the retailer to adopt RFID, the manufacturer must assume more fixed cost if the retailer is more risk-averse. In the coordinated case, we first show that the standard revenue sharing contract does not always coordinate the channel. If the channel is coordinated, we observe that the agents' incentives will be perfectly aligned and independent of the risk attitudes, if the revenue sharing ratio equals the fixed cost sharing ratio. Then we propose a risk-sharing contract that offers the risk protection to the retailer, to achieve the channel coordination. An interesting finding is that the manufacturer's incentive will not decrease with the tag cost, if she takes much risk from the retailer. The corresponding impacts of RFID adoption on the two contracts are also analyzed in this paper. Finally, a case study in a tobacco industry is presented to show the real RFID cost in practice.

1. Introduction

Nowadays, the inventory misplacement is still a significant issue in the retail stores. Raman et al. [1] claimed that the lost sales due to misplaced products caused the retailer's profits reduced by 25%. Kang and Gershwin [2] note inaccuracies in 51% of the records used by one retail firm and claim that the proportion of inaccurate records ranges from 30% to 80% across stores. Dehoratius and Raman [3] report that 65% of the inventory records in retail stores were inaccurate by examining about 370,000 inventory records. Thus, more and more managers take into account the adoption of radio frequency identification (RFID) to eliminate inventory misplacements, based on the benefits of its ability to improve visibility in supply chains [4,5].

Academic research on RFID has proliferated significantly over the last few years. Much of the research has assumed the agents in the supply chain are risk neutral; i.e., they maximize their respective expected profits without risk consideration. However, the risk of failure may appear, such as the benefits obtained by RFID implementation cannot balance the increased cost. Thus, the results in the risk-neutral case may be viewed as unrealistic by the risk-averse decision makers.

This paper considers the RFID application in a supply chain consisting of a risk-neutral manufacturer and a risk-averse retailer, who faces the inventory misplacement issue. The retailer considers investing in RFID technology to eliminate misplacements. For a risk-averse person, he will be reluctant to accept a bargain with an uncertain payoff rather than another bargain with a more certain, but possibly lower, expected payoff. The retailer should balance the gain from improving inventory management and the increased investment cost, with further consideration on his risk aversion tolerance. However, the manufacturer only considers how to maximize the expected profit without risk consideration, since the manufacturer is risk-neutral. On the other hand, in order to induce both agents to adopt RFID for more profits, the manufacturer should propose the effective coordination mechanisms for the win–win

Abbreviations: RFID, radio frequency identification; MV, mean–variance; CSD, central semi-deviation; SSD, second-order stochastic dominance; PDF, probability density function; CDF, cumulative density function

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cooperation. The risk neutrality assumption on the part of the manufacturer is reasonable. Gan et al. [6] indicated that the manufacturer was able to diversify his risk by serving a number of independent retailers, which was quite often in practice. Since the retailers are independent, the supply chain can be divided into a number of sub-chains, each consisting of one manufacturer and only one retailer. In this case, it is enough to study a supply chain consisting of one manufacturer and one retailer.

Even though substantial literature has been developed on both the improvement of inventory management with RFID application (see [7], and references therein) and risk-averse analysis of channel coordination (see [6,8–10], and references therein), very little effort has been spent in analyzing the impact of agents' risk attitude on RFID application and on the coordination contracts with RFID adoption. Actually, this paper is motivated by a case of RFID application in a tobacco industry in China (the case study will be detailed discussed in Section 6). In that case, the agents were more concerned with the loss than the gain from the innovation. The significant problem faced by them is, how to share the investment cost and profits. Hence, a mean-risk framework is proposed to capture this issue. The mean-risk framework is similar to the traditional mean–variance (MV) model, while the risk is measured by the central semi-deviation (CSD), which is widely used in the financial operation research. Different from MV model, the upside of variance is not taken into account as the retailer's risk in CSD model. Intuitively, the upside of variance can be viewed as the surprising gains from investment. The most investors only care about the downside losses rather than upside gains. Thus, CSD is more intuitive and comprehensive to reflect investor's risk attitude. Ogryczak and Ruszczynski [11] and Ahmed et al. [12] also discussed the difference between CSD and the other risk measurement models, such as Value at Risk (VaR) and Conditional Value at Risk (CVaR). They pointed out that only CSD and CVaR can be consistent with second-order stochastic dominance (SSD) rules. In addition, from the following discussion in Section 2, it is shown that CSD will be more flexible since the value of the model's parameter can be adjusted for different risk measurements. However, our concern is not to argue how much better CSD is than the other models. Rather, we just use CSD for risk measurement. Actually, our model is also suitable for the traditional variance measurement.

The first contribution is that we take a few steps in analyzing the impact of the agent's risk attitude on the incentives to adopt RFID technology, which is the gap in the existing literature. Another contribution lies in the proposed risk-sharing contract to coordinate the supply chain, which is suitable for CSD model. This contract could be viewed as an improvement of the work in [6]. In this paper, the major research questions we try to address are:

1. Do the agents have incentives to invest in RFID technology in a decentralized supply chain?
2. How to propose a cost sharing contract to align the agents' incentives in the risk-averse case?
3. How to propose an effective coordination mechanism to coordinate the supply chain?
4. How does the risk attitude affect the coordination mechanism and the agents' incentives?

The above problems and the corresponding sections can be summarized in the following Fig. 1.

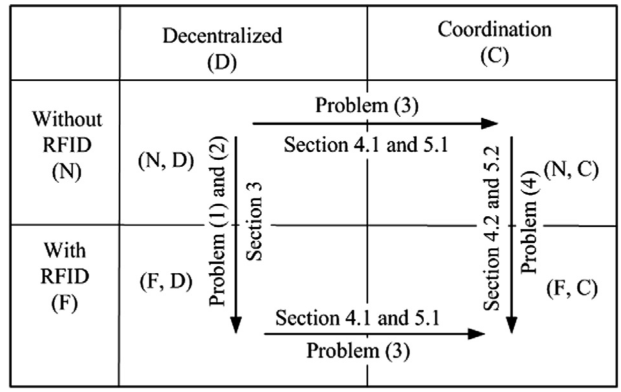

Fig. 1. Summary of the structure of the mean-risk analysis.

The recent academic literature review on RFID technology can be found in [7,13,14]. We limit ourselves to reviewing the papers studying the impact of RFID technology on reduction of inventory inaccuracies. Kok et al. [15] indicate that the price of an RFID tag is highly related with the value of the items lost. Rekik et al. [16] focuses on the theft type errors in a finite-horizon periodic review store, and analyzes the impact of theft errors and the value of the RFID technology on the inventory system. Using single-period model, Heese [17] concluded that a decentralized supply chain would benefit more with RFID adoption. Uçkun et al. [18] concluded that if the market is characterized by highly uncertain demand, making an investment in RFID to decrease inventory inaccuracy may be ill advised. Rekik et al. [19,20] discussed the RFID adoption strategy with coordination contract to improve the performance of supply chain under inventory inaccuracy. Camdereli and Swaminathan [21] study the benefits of RFID in a two-stage supply chain experiencing misplaced inventory. The authors find that the incentives of the parties for implementing RFID are not perfectly aligned if the fixed cost is not ignored. A threshold on variable tagging cost is analyzed in their work.

Our work differs from the above articles in its focus on risk analysis of RFID adoption in supply chain and on how to propose a risk-sharing contract among the supply chain members. Gaukler [22,23] also investigated the problem of sharing RFID costs among the supply chain members. However, the author focused on the improvement of the replenishment process by RFID adoption in a retailer under the assumption of multiple replenishment and sales periods, which is quite different from our research issue. Furthermore, the author assumed that the demand followed a normal distribution with known parameters, while our model does not have this assumption.

For the study on the effects of sharing the tagging cost between supply chain members, Ustundag [24] proposed a simulation model to calculate the impact of RFID benefits on different supply chain cost factors and indicated that the different RFID implementation levels cause different benefits. However, in order to carry out more quantitative analysis and more analytical solutions, we limit our investigation in the impact of RFID benefits on the misplacement problem and take into account the decision maker's risk attitude, which is different from all the previous papers. For more research efforts to use simulation model for integrated analysis of RFID benefits, refer to [25–27].

Risk aversion issues in inventory and capacity management have received a lot of attention in the past decades. The analysis approaches are including MV model, utility functions, VaR, etc. Since our mean-risk framework is inspired by MV approach, we next focus on reviewing this stream of the literature. For the research to use other risk aversion models, refer to [28–31] and references therein. Chen and Federgruen [32] study a MV tradeoff analysis on several basic inventory models, and found that the optimal order quantity is less than or equal to the newsboy point if the decision maker is risk-averse. Choi et al. [33] carry out a mean–variance model for the newsvendor problem in the risk seeking case, and found that the optimal order quantity will be larger than that in the risk-neutral