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Impact of RFID technology on supply chain decisions with inventory inaccuracies

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ABSTRACT

Inventory inaccuracies are costly and prevalent in many industries. This paper focuses on the impact of RFID technology adoption on supply chain decisions with shrinkage and misplacement problems in the Internet of Thing (IoT). We assume that the supply chain consists of one supplier and one retailer that sell a single product to the customer. By assuming that demand is uniformly distributed, and considering the factors of the fixed investment cost, tag price and shrinkage recovery rate, both RFID and non-RFID cases are analyzed under two scenarios: (1) in the centralized supply chain, the Newsvendor model is applied to investigate the impact of applying RFID technology on inventory control policy and supply chain profit; (2) in the decentralized supply chain, the wholesale price contract is formulated to characterize the supply chain partners' decisions on ordering quantity, wholesale price and profits. We find that when the fixed cost and variable tag cost of RFID technology are shared between the retailer and the manufacturer, the retailer is much more sensitive than the supplier to the sharing proportion of RFID fixed investment cost as well as the tag price.

1. Introduction

The Internet of Things (IoT) was first coined by MIT in the late 1990s, which refers to a 'devices or sensors connected world' where objects are connected, monitored, and optimized through either wired, wireless, or hybrid systems. Thus, the real world things are connected and integrated virtually and seamlessly by information technology that the real world can be more accessible when necessary (Atzori et al., 2010, Uckelmann et al., 2011). IoT has become particularly popular through some potential representatively applications such as telemedicine monitoring, and smart electric meter reading, especially in supply chain management.

Radio frequency identification (RFID) is a widely-used key technology that is regarded as a prerequisite or essential element in the IoT. It mainly consists of three elements: a tag formed by a chip connected with an antenna; a reader that emits radio signals and receives in return answers from tags; and a middleware that bridges RFID hardware and enterprise applications (Ngai et al., 2008, Sarac et al., 2010). Using radio waves, RFID technologies communicate in real time with numerous objects at a distance without any contact. This automatic identification and data capture technology can improve the product traceability and the visibility among supply chains, and it has been publicized as a promising solution to inventory inaccuracies. Therefore, it has been paid more and more attention by researchers as well as practitioners (Kok, 2008; Rekik and Sahin, 2009; Ngai et al., 2008).

Inventory inaccuracy is inevitable and prevalent in many industries, which stands for the discrepancy between inventory records and the amount of product available for sale to customers. Dehoratius and Raman (2008) examined nearly 370,000 inventory records from 37 stores of a large public retailer with annual sales of approximately $10 billion, and they found that 65% of the records were inaccurate. Kok and Shang (2007) examined a large distribution company with an average inventory of $3 billion and found that its records were inaccurate by 1.6% of the total inventory value at the end of 2004.

Where do these inventory inaccuracies arise from? Two main sources exist, namely inventory misplacement and inventory shrinkage. Inventory shrinkage (due to theft and damage) leads to permanent inventory loss, while misplacement is temporary that the inventory can be recovered by physical audit (Atali et al., 2004, 2006). Additionally, transaction errors could also cause inventory inaccuracies, but they affect only the inventory record, leaving the actual inventory unchanged (Rekik and Sahin, 2009).

Because inventory inaccuracy exists, retailers should increase their inventory level to buffer the added uncertainty, otherwise sales may be lost due to stock-outs (Raman et al., 2001; Dehoratius et al., 2008). It has been estimated that inventory inaccuracy

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results in lost sales and inventory costs, which reduces profits by more than 10% (Raman et al., 2001; Heese, 2007). Thus, this problem has heavily effected on supply chain performance. In this paper, we focus on the impact of inventory misplacement and shrinkage, and analyze the effectiveness of applying RFID technology in the IoT when the retail supply chain encounters both inaccuracies.

Since RFID adoption may eliminate or reduce inventory inaccuracies in the supply chain, several retail chains have strongly mandated their suppliers to adopt RFID. Wal-Mart implemented an RFID-based pallet-level and case-level tracking system by early 2005, and it required its top 100 suppliers to supply their products with RFID tags on cases and pallets.[1] Other big retailers, such as Tesco and Metro, have followed suit.

Although RFID technology in the IoT has been verified to enable substantial efficiency gains at different stages of a supply chain, the associated costs are by no means negligible (Gaukler et al., 2007). In addition to variable tag costs, RFID adopters also must consider the upfront costs for deploying the new technology in the supply chain (Kambil and Brooks, 2002). For example, a typical consumer packaged goods manufacturer was estimated to spend between $13 million and $23 million on RFID, including fixed costs and variable costs, for shipping 50 million cases per year (Asif and Mandviwalla, 2005). As a result, the substantial cost of RFID in the IoT seems to prohibit widespread use at the item level. Therefore, the cost of RFID adoption will heavily affect supply chain decisions (Kearney, 2003; Thomas, 2004).

Motivated by the issue of RFID technology adoption, we jointly study inventory shrinkage and misplacement in both centralized and decentralized supply chains based on the Newsvendor model, in which the threshold values of fixed investment cost, tag price and shrinkage recovery rate are determined separately to identify the ordering policies and revenue. In a decentralized supply chain, the effect of RFID adoption on supply chain decisions is analyzed with a wholesale price contract between supply chain partners. It is intriguing to find that the retailer's revenue is much more dependent on both RFID fixed investment cost and tag price than that of the supplier, though RFID technology can benefit the supply chain partners. The main reason is that the manufacturer is the Stackelberg leader, who determines the wholesale price, while the retailer is the follower, who accepts the price and determines only the order quantity. Therefore, if the cost of RFID is not shared appropriately between the supplier and the retailer, the supply chain will perform badly even with a coordinated contract.

The remainder of this paper is organized as follows. In Section 2, we provide a brief literature review of the related research. In Section 3, we study the effect of RFID adoption on a centralized supply chain where the manufacturer and the retailer are taken as an entity. In Section 4, we consider the effect of RFID adoption on a decentralized supply chain consisting of one retailer and one manufacturer. In Section 5, we conclude our paper and point out further research directions.

2. Literature review

Generally, our work is related to three streams of research: inventory inaccuracy, RFID application and coping with supply chain problems by means of RFID technology.

The first stream is inventory inaccuracy in a retail supply chain, which is widely discussed (Fleisch and Tellkamp, 2005; Thiel et al., 2010). Classic inventory models are based mainly on the assumption of accurate inventory information however, inventory inaccuracies are inevitable. Rekik (2011) provided a general framework to model the inventory inaccuracy issue as the well-known random yield problem; and then derived the optimal ordering policy based on inventory records. An intriguing work by Heese (2007) considered inventory record inaccuracies in a supply chain model, where a Stackelberg manufacturer determined the wholesale price and a retailer determined how much to stock for sale to customers. By comparing optimal decisions between a decentralized supply chain and an integrated supply chain, the author found that inventory record inaccuracies decreased efficiency because of double marginalization in the decentralized supply chain. Sahin et al. (2004, 2009) assumed that the wholesaler was not aware of inventory errors, or chose to ignore them, in order to estimate the efficiency loss due to errors.

The second stream that is relevant to our paper is RFID application in the era of IoT, which has proliferated significantly in practice and academic study in the last decade (Ngai et al., 2008; Lim et al., 2013). This research focuses on the value of RFID by testing the availability of the new technology in a supply chain, as well as analyzing the associated costs when implementing it (Sarac et al., 2010). Ngai et al. (2010) developed a multi-stage implementation framework for RFID and evaluated it through a case study of a textile company. Further, Ngai et al. (2012) identified eight factors, from both the technology push and the need pull sides, for successful implementation. Considering the fact that the benefits and the costs resulting from item-level RFID are not symmetrically distributed among supply chain partners, Gaukler et al. (2007) presented an item-level RFID analytical model for a retail supply chain with one manufacturer and one retailer. They examined the benefit of introducing item-level RFID in the case of a dominant manufacturer and the case of a dominant retailer, respectively. They derived the break-even tag price of RFID and pointed out that when the manufacturer was the Stackelberg leader, tag cost sharing was not an issue; but when the retailer was the Stackelberg leader, tag cost sharing was necessary. Among a few studies that deal analytically with the value of RFID in inventory control, Amitava et al. (2007) reviewed the value proposition of RFID in three dimensions and attempted to recognize the problems for further investigation. Lee and Özer (2007) argued that there was a huge credibility gap of RFID values when identifying them, and also claimed how to realize these values. In addition, Lee (2010) presented a supply chain RFID investment evaluation model, and provided a basis for understanding RFID value creation, measurement, and ways to maximize the value of RFID technology. This line of research mainly considers the value of RFID in application, which can be summarized as visibility and prevention (Lee and Ozer, 2007).

The third stream related to our research is applying RFID technology to solve supply chain problems, such as inventory inaccuracies and the optimal replenishment policy, which is relatively newly presented in recent years. Inventory inaccuracies can be categorized into two types: misplacement and shrinkage. Rekik et al. (2008) studied a supply chain subjected to misplacement and found a sufficient condition on the tag price to encourage the parties to adopt RFID technology under normal demand distribution when no fixed investment cost was considered. By optimizing the holding cost under a service level constraint, Rekik and Sahin (2009) analyzed inventory shrinkage due to shoplifting (refers to stealing from a shop). They evaluated the effect of RFID technology on the inventory system, and analyzed the critical tag cost results in cost effectiveness using RFID technology. Condea et al. (2012) constructed and tested a shelf replenishment policy based on RFID data. Metzger et al. (2013) developed an inventory control policy for RFID-enabled retail shelf inventory management when considering false-negative reads due to the imperfect detection of the technology. They found

[1] http://www.inventoryops.com/RFIDupdate.htm.