European Journal of Operational Research 250 (2016) 457–469

Contents lists available at ScienceDirect

European Journal of Operational Research

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

Production, Manufacturing and Logistics

Bullwhip effect and supply chain costs with low- and high-quality information on inventory shrinkage

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ARTICLE INFO

Article history:
Received 24 November 2014
Accepted 3 November 2015
Available online 10 November 2015

Keywords:
Supply chain management
Bullwhip effect
Inventory inaccuracy
Information quality

ABSTRACT

Inventory inaccuracy is the mismatch between the recorded inventory and the physical inventory, which is severe and widespread in industry. A few studies have investigated the bullwhip effect with the existence of inventory inaccuracy. The development of information technologies has provided companies with access to accurate inventory information in real time. This will surely affect the bullwhip effect and supply chain costs. The aim of this paper is to build an analytical model to systematically investigate these effects. We consider a retailer–manufacturer supply chain in which the retailer faces inventory shrinkage, which is the main cause of inventory inaccuracy. Both the situations with accurate real-time inventory information, i.e., high-quality information, and the situation with statistical inventory information, i.e., low-quality information are studied. We examine the relationships between the bullwhip effect, information distortion and supply chain costs with different levels of information quality. The results of our analysis enrich the existing literature on the bullwhip effect. First, we show that the bullwhip effect is magnified along the chain when higher-quality information on inventory shrinkage – specifically real-time rather than statistical data – is obtained. Second, we show that the magnification of the bullwhip effect does not necessarily result in higher costs. Third, we demonstrate that higher-quality information increases the benefits of information sharing. Our paper provides new insights into the causes, extent and economic dynamics of order variability in the presence of inventory inaccuracy, and may thus suggest ways of more effectively managing the bullwhip effect and inventory.

1. Introduction

Inventory inaccuracy is the mismatch between the recorded inventory and the physical inventory. There are three main causes of inventory inaccuracy: misplacement, shrinkage and transaction error (Atali, Lee, & Özer, 2005). Recent studies have shown that inventory inaccuracy is widespread in the industry, and has significant consequences (Agrawal & Sharda, 2012; Bai et al., 2012; Kök & Shang, 2007). DeHoratius and Raman (2008) quantify the inaccuracy and report that 65% of nearly 370,000 inventory records gathered from multiple stores owned by a leading retail chain are inaccurate, and that the average difference between the recorded inventory and the physical inventory is 35% of the target inventory. IBM Business Consulting Services calculate the loss due to shrinkage as 1.75% of retailers' US$58-billion revenue, and between 0.22% and 0.73% of manufacturers' total revenue (Alexander et al., 2002). Compared with misplacement and transaction error, shrinkage is the most significant cause of inventory inaccuracy (Kök & Shang, 2014; ECR Europe, 2003).

A common method of addressing inventory inaccuracy is to optimize ordering decisions by integrating the inventory discrepancy into the order-making process. Unsurprisingly, the amount of information available on the error will affect the ordering decision and the corresponding costs. To determine the extent of inventory inaccuracy, two pieces of information are needed: the electronically recorded inventory and the physical inventory in the warehouse. The recorded inventory is relatively easy to obtain, as it is stored in an information-technology (IT) system and can be rapidly retrieved. There are two ways of obtaining the physical inventory, as follows.

In a traditional identification (ID) system, such as a barcode-based system, a periodic cycle count can be conducted to obtain the physical inventory. As individual cycle counts are usually associated with high inspection costs, most companies can only afford a couple of cycle counts per year, which thus occur much less frequently than orders. The average inventory error can be estimated from the historical data obtained from cycle counts. In this way, the information

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http://dx.doi.org/10.1016/j.ejor.2015.11.004
0377-2217/

available when ordering decisions are made is often inaccurate and imprecise, which corresponds to the low information quality case.

The other method of obtaining information on the physical inventory is to track the inventory using advanced ID technologies such as radio-frequency identification (RFID). RFID has two main beneficial advantages: high-frequency monitoring and non-line of sight reading, which yield inventory information that is both accurate and timely (Dai & Tseng, 2012). This method ensures that the recorded inventory is always consistent with the physical inventory, providing the decision maker with accurate real-time information on the inventory, which corresponds to the high information quality case. (Please note that our focus is not changing the physical flow of the products, although the advanced ID technologies may help reduce the inventory error, such as preventing thefts. Instead, we aim to examine the effects on supply chain performance of getting more accurate and real-time information.)

For example, consider a retailer facing a shrinkage problem due to random inventory loss. The retailer orders once a week, and conducts a periodic review system. In a barcode-based inventory system, the optimal physical cycle count is once per quarter. Comparing the historical cycle count data with the recorded inventory in the IT system reveals that the average shrinkage is 100 units per week. The manager can address this discrepancy by adjusting the size of the order every week to compensate for the shrinkage (Kang & Gershwin, 2005). As the decision maker is only aware of the average shrinkage, the compensation is a fixed number, which cannot capture the dynamics of the shrinkage. RFID-based systems allow the retailer to monitor their physical inventories in a more timely manner. When each weekly order is made, the exact amount of the shrinkage that has occurred during the week is known. The decision maker can promptly adjust the size of the order to compensate precisely for the week's shrinkage, and thereby more accurately meet the demand of external customers.

As technologies continue to improve and their costs to decrease, obtaining accurate real-time inventory information is becoming increasingly cost-effective. As a result, more and more retailers are guided by high-quality information in their daily operations and decision making. The increased accessibility of high-quality inventory information is expected to enhance supply chain management and give rise to various new business models and management mechanisms. Therefore, it is important to investigate the effects of accurate real-time information on operational decisions and supply chain performance.

In this paper, we explore the effects of high-quality information in a supply chain with an inventory-inaccuracy problem. Specifically, we investigate the effects of access to accurate real-time inventory information rather than inventory statistics. (Note that we do not consider the following two 'naïve' cases, which respectively fail to reflect industry practice and amplify the effects of accurate real-time information: (1) the decision maker is not aware of the inventory error in his own place and (2) the decision maker is aware of the inventory error, but takes no action.) We measure the effects of information quality on supply chain performance in two dimensions: (1) the bullwhip effect and (2) holding and shortage costs. Next, we explain why these two performance indicators were chosen, and outline the differences between our work and the existing literature on the bullwhip effect and inventory inaccuracy, respectively.

First, most studies of inventory inaccuracy investigate single-stage systems. Only a few researchers address inventory inaccuracy in a supply chain, and none specifically consider order-variability transfer along a chain, *viz*., the bullwhip effect (Heese, 2007; Kök & Shang, 2014; Rekik, 2011; Rekik, Sahin, Jemai, & Dallery, 2008). Few researchers working on the bullwhip effect address inventory discrepancy (Fleisch & Tellkamp, 2005). Only a few papers specifically analyze the effects of inventory inaccuracy on the bullwhip effect. Sodhi and Tang (2011) assume that the actual order quantity deviates from the desirable order quantity, and examine the incremental effect of inaccurate order placement on the bullwhip effect. Bruccoleri, Cannella, and Porta (2014) focus on the inventory inaccuracy caused by behavioral aspects of workers, and show that traditional inventory management policies to address bullwhip effect are not effective for this kind of inventory error. Cannella et al. (2015) consider a k-stage collaborative supply chain. They show that the bullwhip effect is monotonously increasing in the level of the inventory error, and even a small amount of such error may notably increase the supply chain costs. All the above-mentioned works have contributed to show the impacts of inventory error on the bullwhip effect, but they do not differentiate between inventories with higher and lower levels of information quality. Therefore, the decision maker's response to information of differing quality remains unclear, along with the effect of such information on his order variability. We must also ask how an ordering decision based on accurate real-time information affects the decision maker's upstream partners, and whether such a decision amplifies or attenuates the bullwhip effect.

Second, as inventory error affects inventory level, orders based on inaccurate inventory calculations may result in surplus and/or out-of-stock products, which in turn affect the company's holding and shortage costs. Therefore, holding and shortage costs are widely used as indicators of financial performance by researchers investigating inventory inaccuracy (Kök & Shang, 2014; Sahin & Dallery, 2009; Sahin, Buzacott, & Dallery, 2008). To the best of our knowledge, researchers addressing inventory inaccuracy in relation to cost calculation rarely incorporate accurate real-time information into the optimization process, and compare the effects of information quality on the corresponding costs (see Section 2 below). How does accurate real-time information affect a given party's holding and shortage costs? Is a decision made in the presence of real-time information economically beneficial or harmful to other parties in the supply chain? How does such a decision affect the overall cost incurred by the supply chain? As the answers to these questions remain unclear, further investigation is needed.

In summary, few researchers examining the effects of inventory inaccuracy on supply chain performance differentiate between levels of information quality. We aim to fill this gap by specifically investigating the effects of accurate real-time information on the bullwhip effect and supply chain costs.

Furthermore, information sharing has been shown to be one of the most effective methods of alleviating the bullwhip effect (Dominguez, Cannella, & Framinan, 2014). Most researchers in this field focus on the effects of demand-information sharing. However, the recent development of RFID and Electronic Product Code networks has increased the visibility of accurate real-time inventory information in supply chains (Bottani, Roberto, & Andrea, 2010). Various new models of operation, such as Vendor Managed Inventory, Collaborative Forecasting and Replenishment and buy-online, pick-up-in-store, require inventory information to be shared (Cannella & Ciancimino, 2010; Cannella, Ashayeri, Miranda, & Bruccoleri, 2014; Gallino & Moreno, 2014). It is thus imperative to investigate the influence of information quality on the effectiveness of inventory-information sharing.

To this end, our research questions are as follows.

(1) How does accurate real-time information affect the bullwhip effect in a supply chain?
(2) How does accurate real-time information affect the costs incurred by a supply chain?
(3) How does accurate real-time information affect the benefits of information sharing?

In this paper, we consider a decentralized supply chain comprised of a retailer with a shrinkage problem and a manufacturer. We first develop a basic model to capture the effects of different levels of information quality on the bullwhip effect and supply chain costs when no information is shared. Next, we extend the model to show how