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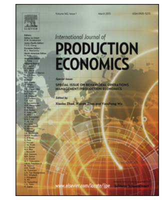

Providing a measure for bullwhip effect in a two-product supply chain with exponential smoothing forecasts

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ABSTRACT

In this paper, a two-product and two-echelon supply chain is considered in order to quantify the bullwhip effect. Demands of the products are correlated and are represented by a first order vector autoregressive model. Retailer uses “order up to” ordering policy for replenishment of stocks and utilizes exponential smoothing forecast method to predict demand in lead-time period. According to the mentioned assumptions, an equation is derived for bullwhip effect measurement and then a numerical example is presented for a better perception of the bullwhip effect behavior when the parameters change. A comparison of the bullwhip effect measure has been done when two main forecasting methods i.e. exponential smoothing and moving average are used and empirical results are provided. At last, a cost analysis is conducted based on shortage and holding cost under different bullwhip effect measures.

1. Introduction

Supply chain consists of all segments in completion of customer needs. A supply chain commonly has many echelons including component suppliers, main factory, wholesalers, retailers and customers. We have three kinds of flow in a typical supply chain: goods; money and information (forwarding and backwarding). Coordination between various stages of supply chain is very important and taking actions together increases total supply chain profits. Supply chain coordination indicates that each echelon of the supply chain considers influence of its actions on the other sections of the supply chain. Without coordination, many undesirable events can occur in the supply chain like exceed in inventory, delay in order fulfillments and total costs of supply chain. A phenomenon, in which many researchers focus on it, is called bullwhip effect. Bullwhip effect refers to conditions that order variance increases while moving from customer to main manufacturer. In this paper we provide a formula for measuring and then controlling of bullwhip effect in a two-stage supply chain in case of two-product and consequently remarkable results are explained in the next sections.

2. Related work

Amplification of demand is a major obstacle to achieve coordination and for creation of harmony within different stages of supply chains. Many companies have observed increasing fluctuation in orders while moving up from downstream sites to upstream sites. The result is decrease of profitability in supply chain. After Forrester studies on demand amplification in 1958, many of the researchers continued investigations on this phenomenon. In addition, a few case studies are performed in various industries around the world (like P&G, HP, Barilla) and existence of demand amplification has been proved in their supply chains. Lee et al. (1997) introduced five basic causes of this phenomenon: demand forecast updating; order batching; price fluctuation; rationing and non-zero lead-time. Understanding these reasons of the bullwhip effect is useful for reduction of its influences. Sucky (2009) divided research on the bullwhip effect into several main classification. His categories were according to measurement of the bullwhip effect, causes of it, case studies, reducing methods for bullwhip effect, behavior of bullwhip effect based on change in parameters and simulation study and at last experimental validation of the bullwhip effect. Costantino et al. (2015a) analyzed the papers according to the role of forecast updating on the bullwhip effect and categorized research based on methodology of study, ordering policy, forecasting method, performance measure, supply chain model, demand model and presented research focus and their results.

In the last decade, papers have provided issues for modeling and quantifying bullwhip effect and its solutions. Moreover, investigations on the role of forecasting method, ordering policy, information sharing, and lot sizing rules are conducted in different statues. Chen et al. (2000a, 2000b) quantified bullwhip effect in a single product supply chain and provided a measure for bullwhip

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ratio in case of moving average and exponential smoothing forecasting. Dejonckheere et al. (2003) suggested a control theory approach for measuring bullwhip effect and proposed a new common replenishment rule that can decrease bullwhip effect. Disney and Towill (2003) introduced an ordering policy that results in taming bullwhip effect. Due to the importance of forecasting methods on the bullwhip effect, many research works have been conducted on the influence of it and developing suitable forecasting methods for bullwhip effect reduction. Zhang (2004) considered several forecasting methods for an inventory control system. The results showed that forecasting methods affect the bullwhip effect. He also presented three measures for bullwhip effect based on each forecasting system. Kim et al. (2006) investigated stochastic lead-time and studied the role of information sharing on the bullwhip effect reduction. Chandra and Grabis (2005) measured bullwhip effect when order size is calculated according to multiple step forecasts using autoregressive models. Luong (2007) investigated effects of lead-time and demand process factors on bullwhip effect when MMSE forecasting method is used. Luong and Phien (2007) research was based on the order of autoregressive demand pattern. They got an interesting result and found that bullwhip effect is not always a straightly function of lead-time. They showed that in some instances, bullwhip effect could be reduced when lead-time increases. Gaalman and Disney (2009) investigated the behavior of the order up to policy for ARMA(2,2) demand process with arbitrary lead-time. Jaksic and Rusjan (2008) demonstrated that using some replenishment rules we could decrease the bullwhip effect. Zhang and Burke (2011) perused compound causes for the bullwhip effect based on an inventory system with multiple price-sensitive demands. Their research was conducted on two bullwhip effect measures: demand stream individually and aggregated demand.

Ma et al. (2013a) research was concentrated on the bullwhip effect according to orders and net inventory. They considered a price-sensitive demand function in which the price follows an AR (1) pricing process. Moreover, they derived the analytical expressions of the bullwhip effect on inventory with three forecasting methods: MMSE, MA and ES. In addition, they presented a new performance measure of the bullwhip effect based on the weighted sum of the order variance and inventory variance amplifications. Ma et al. (2013b) considered influence of information sharing in a usual supply chain with three levels and a cost sensitive demand. They quantified bullwhip effect and concluded that market demand scale does not influence the value of information sharing. Moreover, the significance of value of information sharing was investigated based on the value of relevant parameters (such as correlation on underlying overall market pricing process over time, product price sensitivity coefficient and so on). Wang et al. (2014) studied bullwhip effect based on consumer price forecasting perspective. They derived two expressions for bullwhip effect measure in cases of linear and iso-elastic demand functions and found that consumer-forecasting behavior can decrease the bullwhip effect.

Fu et al. (2014) studied centralized and decentralized model predictive control strategies for inventory position control and decreasing of the bullwhip effect in a four-stage supply chain. They provided a closed-form equation of an optimal ordering decision for each echelon. Costantino et al. (2015b) used simulation approach to investigate the impact of information sharing on ordering policies. They comprised traditional (R, S) policy and a combination of (R, D) and (R, S) policies and performance of the second method approved in terms of bullwhip effect and inventory variance under various demand models. Due to the importance of information sharing and for investigation on the influence of information visibility on the total supply chain performances for local and global service level, Costantino et al. (2014) conducted a research using a simulation study.

Costantino et al. (2015a) evaluated a novel forecasting method, named SPC-FS, based on control chart approach. They conducted a simulation analysis to evaluate and compare SPC-FS with moving average and exponential smoothing in a four-echelon supply chain employing the order-up-to inventory policy and AR(1) demand process. The simulation results showed that SPC-FS shows better performance to the traditional forecasting methods on the bullwhip effect measure and inventory variance.

Although many research works have been conducted on the bullwhip effect but lack of studies is felt in some area. In this paper, we continue our research for studying of the bullwhip effect in a two-product supply chain. Approximately focus of most of the previous papers is around single product supply chains and researchers have changed common assumptions (like forecasting system, demand model, cost sensitive conditions and so on) and quantified and analyzed bullwhip effect based on new assumptions or investigated the influence of a property (such as information sharing) in the single product supply chains.

A rough review of papers shows that few papers quantified and analyzed bullwhip effect in multi-product supply chain. Chaharsooghi and Sadeghi (2009) considered a two-product supply chain and quantified bullwhip effect measure using statistical approach when moving average forecasting method is utilized by retailer and demand process following VAR(1) model. They concluded that there is no explicit expression for the bullwhip effect ratio, when statistical method is used for quantifying the bullwhip effect. Consequently, bullwhip effect measure could be calculated for only limited cases. Ma et al. (2015) presented equations to quantify the bullwhip effect in two interacting supply chains. Two supply chains were parallel and encountered a market demand. They found that in a low marginal rate of substitutability or in a high marginal rate of complementary, bullwhip effect can be reduced. Sodhi et al. (2014) developed the traditional economic order quantity model for maintenance-repair-and-overhaul (MRO) customers under stochastic purchase price and used it to show how price variance leads to bullwhip effect for the MRO manufacturer. They also considered the case of multi-product and multiple customer segment condition in their research. As a result, it can be concluded that due to real situations of the supply chains in which a supply chain may support and produce more than one product, more studies in this research area are needed and our contribution is this. We have provided interesting results about behavior of bullwhip effect ratio for two products. We consider a two-echelon and two-product supply chain consisting one retailer and one producer and use VAR (1) process for demand modeling. Demand of two products is correlated and ordering policy is based on order up to policy and forecasting system follows exponential smoothing method. A measure for bullwhip effect is provided and a numerical example is presented for better analytical perception. A comparison between two basic forecasting methods is conducted. Moreover, a slight cost analysis is shown in the last section.

3. A two echelon and two product supply chain

In this research, a measure for bullwhip effect in a two-stage supply chain with one retailer and one producer is provided. Retailer encounters market demand and orders it to the producer based on supply chain ordering policy. Therefore, product flow is from producer to the retailer and demand information flow is from retailer toward producer. There are two products in the supply chain and so retailer meets demand of two products. Fig. 1 shows proposed supply chain.