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Research on bullwhip effect in energy-efficient air conditioning supply chain

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ABSTRACT

This paper investigates the energy-efficient air conditioning supply chain, which is composed of one supplier (MIDEA) and two retailers, i.e. SUNING and GOME. With a view of market share, we measure the impact of retail prices variability in the two-echelon supply chain on the bullwhip effect. SUNING and GOME are assumed to possess the autonomy of choosing prices and separately acquire various market shares, according to which the relationship between the two prices is simply quantified. The order-up-to inventory policy and the moving average forecasting method are respectively employed by the two retailers. Furthermore, we cast light on how factors like price, market share, lead time, and autoregressive coefficient affect bullwhip effect. The results indicate that it's inadvisable to conduct large fluctuation on price. Besides, demand dates that are more historical may actually reduce the bullwhip effect. We also find that the bullwhip effect will be bigger when the competition becomes fiercer, and there's a necessity for retailers to take measures to reduce the influence of competitors' prices.

1. Introduction

Known as the "electricity eating tigers", the air conditioning always contributes to a large part of total power consumption. According to a survey, air conditioning power consumption accounts for 15% of annual total electricity consumption of the whole society. In order to conserve energy and reduce emissions, MIDEA developed ECO energy saving frequency conversion air conditioning in 2012 and opened up the market of domestic energy-saving air conditioning products. It is statistically shown that total sales of ECO possessed by MIDEA were more than 12 million units by the end of 2015. Hence, electricity consumption can be reduced for more than 1.2 billion KW/H, which means that 500,000 tons of standard coal and 1.21 million tons of carbon emissions are saved in this way. Data provided by Zhong Yikang show that the total sales of air conditioning were 42.12 million units in 2014, with a year-on-year growth of 4.3%. The scale of retail sales reached 145.4 billion yuan, and increases by 3.2% every year. China's air-conditioning industry faced unprecedented complex market environment, leading to a more significant dislocation of supply and demand, which makes high inventory a common phenomenon in 2015. Existed reference like Zeng et al. (2010) claimed the significance to research the cleaner production on business performance. Therefore, the bullwhip effect in Energy-efficient air conditioning supply chain has a growing necessity to be studied.

The bullwhip effect emerges from the enlarging information distortion due to ineffectiveness information achieving when the information flows from the final clients to the original supplier, which leads to a growing variability in the demand information. The downstream retail price is one of the major factors that cause the bullwhip effect.

As for industrial dynamics, Lee et al. (1997a,b) was the first to call the amplification phenomenon as the bullwhip effect. He pointed out that demand signal processing, non-zero lead-time, order batching, supply shortages and price fluctuation are four important factors to cause the bullwhip effect. Graves (1999) quantified the bullwhip effect for the supply chain in which demand pattern follows an integrated moving average process. The bullwhip effect for supply chain was quantified by Chen et al. (2000a,b) using the demand forecast methods of moving average and exponential smoothing techniques respectively. Chen et al. proposed a hypothesis that members of the chain possess

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the base stock policy as their inventory system. They also found that the order variance increases with the increasing lead time and the number of members in the chain, and decreases with the level of information sharing. Zhang (2004) depicted the impact of each parameter on the bullwhip effect with a first-order autoregressive demand process using forecasting methods like MMSE, MA and ES. Ertunga and Özelkan (2008) investigated the "reverse bullwhip effect in pricing" (RBP) under conditions that price variation being amplificated as moving from the upstream suppliers to the downstream customers in a supply chain. Based on the non-serial supply chains hypothesis, Ha et al. (2011) discussed supply chain coordination and information sharing in two competing supply chains. Nepal et al. (2012) conducted an analysis of the bullwhip effect and net-stock amplification in a three-echelon supply chain based on step changes in the production rates during a product's lifecycle demand. Jaipuria (2013) highlighted two integrated approaches of DWT and ANN to improve the forecasting accuracy by comparing with ARIMA model and validating with real-life data. Wang, (2014) discussed the impact of consumer price forecasting behavior on the bullwhip effect and found that consumer forecasting behavior can reduce the bullwhip effect. Ouyang and Yanfeng (2014) launched an experimental study and found that advanced demand information can reduce supply chain costs. Akhtar Tanweer (2014) proposed an optimization model to mitigate the bullwhip effect in a two-echelon supply chain. Fu (2014) derived analytic expression of bullwhip effect based on control theoretic concept. He also took advantage of new bullwhip metric to compare conventional and MPC ordering policies and came to the conclusion that MPC ordering policy outperforms the traditional ordering policies on reducing bullwhip effect. Ma (2015) offered insights into how the bullwhip effect in two parallel supply chains with interacting price-sensitive demands and the comparision to the situation where there's a single product in a serial supply chain. Duan (2015) examined the effect of own and substitute products on a focal product's bullwhip effect and estimated the existence and magnitude of the bullwhip effect at the product level. He came to the conclusion that the bullwhip effect is not only affected by a product's own factors but also by those of its substitute products. Ma et al. (2016) analyzed the effect of price-sensitive demand model on the bullwhip effect with considering the complexity dynamic behavior of the supply chain system. Ma and Wang (2014) investigated the non-cooperative dynamic game model in the closed-loop supply chain.

Dai et al., (2016) investigated the effect of low- and high-quality information and inventory shrinkage on the bullwhip effect and costs. The outcome showed larger bullwhip effect with real-time information does not result in higher costs. Using a moving average method for demand forecasting, Khosroshahi et al., 2016 quantified the bullwhip effect in a 3-stage supply chain with multiple retailers and analyzed the impact of service levels on the bullwhip effect. Chiang et al., 2016 centered on an empirically simulated investigation of the impact of demand forecasting methods on the bullwhip effect through using the data from U.S. auto industry. Forecast accuracy, aggregate forecasting, and responsive forecasting were addressed to investigate the bullwhip effect in the Chevrolet auto market in this research.

SUNING and GOME are two largest retailers of MIDEA air conditioning. Hence establishing a two-echelon supply chain model with one supplier and two retailers is appropriate to simulate the system. This paper mainly discusses the impact of market share, which related to the retail price, on the bullwhip effect. We finally get the expression of the bullwhip effect by using algebraic analysis and numerical simulation. The impact of every parameter on the bullwhip effect is also analyzed. Then we come to the conclusion that different market share result in the variation of the bullwhip effect, which is related to price, lead-time and demand autocorrelation. The fiercer the competition is, the bigger the bullwhip effect will be. We also find that the retailers should take measures to reduce the influence of competitors' prices taken for their products. The result also indicates that a large fluctuation on price shouldn't be conducted and demand dates that are more historical may actually reduce the bullwhip effect. The structure of this article is as follows. Section 2 presents a two-echelon supply chain model with two retailers whose prices both follow the AR (1) process and they both apply the order-up-to stock policy. In Section 3, we quantify the bullwhip effect with MA forecasting method. The impact of every parameter on the bullwhip effect is analyzed in Section4. Finally, Section 5 shows a conclusion of the article and the vision of the future about the studies on bullwhip effect.

2. A supply chain model

To quantify the bullwhip effect, firstly, we have the demand process determined. In the earlier literature on the measurement of the BWE, various demand processes were presented, such as AR (1), ARMA (1,1) and ARMA (p, q), ect. Among the above processes, AR (1) demand process is the most appropriate approach for Energy-efficient air conditioning market. Secondly, this paper chooses the optimum inventory policy, which is known as the order-up-to inventory policy. In this replenishment strategy, the inventory position is examined in each period and the orders are issued in order to increase the inventory to the OUT level. Finally, most of the existing papers consider the MMSE and ES forecasting method, in this research the MA forecasting method is depicted instead.

2.1. Price autoregressive process

This research will depict a two-echelon supply chain with one supplier and two retailers, while both of the two retailers employ the order-up-to inventory policy and AR (1) price autoregressive process. The two retailers order and replenish the stock from the same supplier in each period t. The bullwhip effect will be quantified in this simple supply chain model.

The supply chain model is shown in Fig. 1:

We assume that there are only two retailers in the market. Each of the customers chooses their own retail price from the retail prices made by two retailers. Hence, the possibility of the

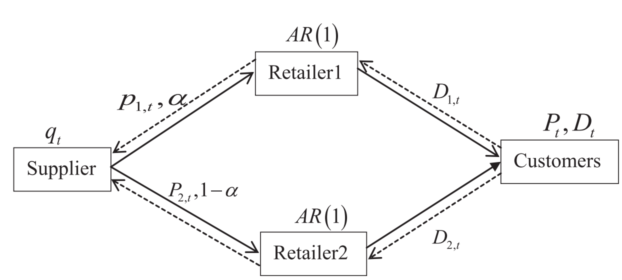

Fig. 1. Supply chain model.

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