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# Effect of the third-party warehouse on bullwhip effect and inventory cost in supply chains

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A B S T R A C T

In this research, we examine the impact of a third-party warehouse on the bullwhip effect in a three-stage supply chain with one supplier, one third-party warehouse and two retailers. We compare the bullwhip effect in this three-stage supply chain and that in a two-stage supply chain with only one supplier and two retailers. It is assumed that the demand process can be modeled with an AR(1) model and the base stock inventory policy is employed for both the third-party warehouse in the three-stage system and the two retailers in the two-stage system. It is found that the existence of the third-party warehouse has no influence on bullwhip effect when the lead times of the third-party warehouse and the two retailers are equal. For cases in which the third-party warehouse does not have any impact on bullwhip effect, we examine the impact of the third-party warehouse on the inventory cost in the supply chain by analyzing inventory cost savings obtained by the existence of the warehouse.



## 1. Introduction

Bullwhip effect, a phenomenon where the order variance of supply chain members increases on moving up a supply chain, still remains a critical research issue in the supply chain management. The bullwhip effect was first acknowledged by Forrester (1958), who discussed its causes and possible remediation in the context of industrial dynamics. After that, the existence of the bullwhip effect in supply chains was also recognized by several researchers such as Blinder (1982), Blanchard (1983), Burbidge (1984), Caplin (1985), Blinder (1986) and Kahn (1987). Moreover, Sterman (1989) explored and illustrated the bullwhip effect by experimenting on the well-known "beer game". In addition, Lee et al. (1997a, b) identified five main causes of the bullwhip effect, i.e., demand forecasting, non-zero lead time, supply shortage, order batching, and price fluctuation.

The bullwhip effect may be mitigated by elimination of its main causes (Lee et al., 1997a, b). Among various causes of the bullwhip effect, forecasting technique can be considered as the most important cause because the inventory system of the supply chain is directly affected by the forecasting method. This realization has led several researchers to evaluate the impact of forecasting methods on the bullwhip effect. Graves (1999) quantified the bullwhip effect for a supply chain in which the demand pattern follows an integrated moving average process. Using a first-order autoregressive, AR(1), demand process, Chen et al. (2000a, b) investigated the impact of forecasts done by simple moving average and exponential smoothing methods on the bullwhip effect for a simple, two-stage supply chain with one supplier and one retailer. Likewise, Xu et al. (2001) conducted a similar research for a demand process that is forecasted with a simple exponentially weighted moving average method. Zhang (2004) also investigated the impact of different forecasting methods, i.e., moving average, exponential smoothing and minimum mean-squared error methods, on the bullwhip effect for a simple inventory system with an AR(1) demand process. By quantifying the bullwhip effect, they showed an obvious evidence for the effect of forecasting methods on bullwhip measures. In addition, Chen et al. (2000a, b), and Zhang (2004) showed that increase in lead time enhances the bullwhip effect regardless of the forecasting methods employed. Recently, Bayraktar et al. (2008) and Wright and Yuan (2008) showed the impact of demand forecasting on the bullwhip effect and suggested appropriate forecast methods used in reducing the bullwhip effect through some simulation studies.

In a recent paper, Luong (2007) developed an exact measure of bullwhip effect based on a replenishment model, which is similar to the one used by Chen et al. (2000a, b) for a two-stage supply chain with one retailer and one supplier. It was assumed that the retailer employs the base stock policy for replenishment and that demands are forecasted based on an AR(1) process. The behavior of the bullwhip effect was demonstrated for different values of the autoregressive coefficient and the lead time. Luong (2007) also derived an upper bound for the measure of bullwhip effect and found that the upper bound value depends on the autoregressive coefficient. These results are useful in that they help in identifying

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whether the bullwhip effect is excessively high. In such cases, managerial efforts should be made to alleviate the effect.

Performance of a supply chain is affected not only by demand forecasting but also by inventory decisions. Without a proper inventory management, excessive inventory buildups, lost sales and customer dissatisfaction may occur (Bowersox et al., 2003). Moreover, inventory is an important factor that can dramatically change the performance (responsiveness and efficiency) of a supply chain (Chopra and Meindl, 2004). Therefore, many researchers have studied decision problems in inventory systems of supply chains, especially in two-stage supply chains. Previous research on inventory system models with the continuous review policy includes those of Moinzadeh and Lee (1986), Lee and Moinzadeh (1987), Axsäter (1993a), Lee and Billington (1993), and Axsäter (2000, 2005). They gave approximate and exact solutions for two-stage supply chain problems. In addition, Axsäter (1993b), Forsberg (1995), and Cachon (2001) provided exact solutions for two-stage inventory system in which the periodic review policy is used. Recently, through a simulation study, Lee and Wu (2006) showed that dynamic inventory control in batching order system helps to reduce order batching problem, one of main causes of the bullwhip effect, and inventory cost of a supply chain.

The current research is a sequel of Luong (2007). It differs from the previous paper in two ways. First, the current research aims to examine the impact of a third-party warehouse on the bullwhip effect in a three-stage supply chain with one supplier, one third-party warehouse and two retailers, while Luong developed a bullwhip effect measure for a simple two-stage supply chain with one supplier and one retailer only. Second, the impact of the third-party warehouse on inventory cost in the supply chain is also considered in the current paper. By evaluating and comparing the total inventory costs of the third-party warehouse in the three-stage supply chain and those of the two retailers in the two-stage system without the third-party warehouse, one can justify the employment or abandonment of the third-party warehouse in the supply chain.

This paper is organized as follows. In Section 2, we describe the stationary property of the AR(1) demand process in a supply chain model. In Section 3, we quantify the bullwhip effect for the AR(1) demand process, and investigate its behavior both in a three-stage supply chain with the third-party warehouse and in a two-stage system without the warehouse. Section 4 presents the total inventory costs of the third-party warehouse in the three-stage supply chain and those of the retailers in the two-stage system. We give numerical results, i.e., total inventory costs of the retailers in the two-stage system and the warehouse in the three-stage system as well as the inventory cost saved by the existence of the warehouse in Section 5. Finally, Section 6 concludes the paper with a short summary. Notation used throughout this paper is summarized in the Appendix A.

## 2. Supply chain model

We consider a three-stage supply chain system with one supplier, one third-party warehouse and two retailers in which the periodic review system is employed (see Fig. 1). In this system, the supplier distributes products of a single type to the third-party warehouse. Then, the warehouse supplies the products to retailers 1 and 2, who have market share of the customer demand, $\alpha$ and $1-\alpha$, respectively. In this study, it is assumed that: (1) retailers' orders are replenished instantaneously by the warehouse at the time when the orders are received by the warehouse; (2) there are fixed order lead times for orders placed by the warehouse; (3) the length of lead time is an integer multiple of the inventory review interval; (4) the warehouse employs a base stock policy, a simple order-up-to inventory policy; and (5) demand forecast is performed by the warehouse with an AR(1) model using the minimum mean-squared error forecasting technique. It is noted that forecasting causes variability in the order-up-to level, which results in the bullwhip effect.

At the beginning of period $t$, the supplier receives an order of quantity $q_{\mathrm{w},t}$ placed by the warehouse. The order quantity $q_{\mathrm{w},t}$ can be given as

$$q_{\mathrm{w},t} = S_{\mathrm{w},t} - S_{\mathrm{w},t-1} + D_{t-1}, \tag{1}$$

where $S_{\mathrm{w},t}$ is the order-up-to level in period $t$, i.e., the inventory position at the beginning of period $t$ (after the order is placed) at the warehouse. If the base stock policy is employed, the order-up-to level $S_{\mathrm{w},t}$ can be determined by the lead-time demand as

$$S_{\mathrm{w},t} = \hat{D}_t^{L_\mathrm{w}} + z\hat{\sigma}_t^{L_\mathrm{w}}, \tag{2}$$

in which $z$ is the normal $z$-score that specifies the probability that demand is fulfilled by the on-hand inventory, and it can be determined based on a given service level.

Since it is assumed that demand can be modeled with an AR(1) model, we have

$$D_t = \delta + \phi D_{t-1} + \varepsilon_t, \tag{3}$$

where $\varepsilon_t$s ($t$=1,2,...) are normally and independently distributed with common mean 0 and variance $\sigma^2$ (i.i.d. random variables from the normal distribution). For a first-order autoregressive process to be stationary, we must have

$$E[D_t] = E[D_{t-1}] = \mu_\mathrm{w}, \quad \forall t$$

and hence, a stationary condition can be given as

$$\mu_\mathrm{w} = \frac{\delta}{1-\phi}. \tag{4}$$

In addition, from (3), we have $(\sigma_\mathrm{w})^2 = \phi^2(\sigma_\mathrm{w})^2 + \sigma^2$, which results in

$$(\sigma_\mathrm{w})^2 = \frac{\sigma^2}{1-\phi^2} \tag{5}$$

From (4) and (5), it can be seen that in order for the demand process of AR(1) model to be stationary, the absolute value of $\phi$ should be less than 1, i.e., $|\phi| < 1$.

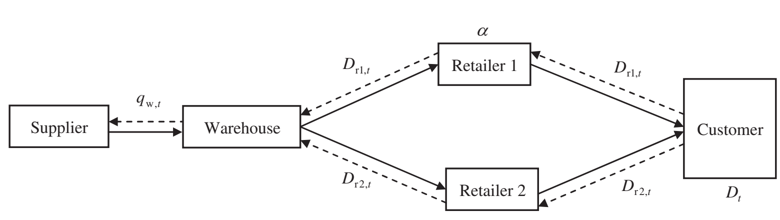


**Fig. 1.** A three-stage supply chain model.