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Bullwhip Effect Measure When Supply Chain Demand is Forecasting

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ABSTRACT

Demand fluctuations in the supply chain lead to uncertainty in inventory policy and thereupon the inventory costs increase. This paper considers the impact of forecasting on the demand variation in a serial three-stage supply chain including a retailer, a manufacturer and a supplier. Four forecasting methods are considered and demand variations evaluated as bullwhip effect measure. We use analytical method to derive bullwhip effect to measure demand variations in second and third stage. Results show demand fluctuations increases as one move up supply chain. And the different forecasting methods lead to increasing the variations and the more previous data using leads to more precision.
KEY WORDS: Supply chain, Forecasting, Bullwhip Effect.

1. INTRODUCTION

A supply chain consists of all parties involved in fulfilling a customer request. A supply chain usually includes the manufacturer, suppliers, transporters, warehouses, retailers and customers. Within each organization such as manufacturer, the supply chain includes all functions involved in receiving and filling a customer request.[1]

It is becoming increasingly difficult to ignore the demand variations in a supply chain. The demand variations usually stated as bullwhip effect that measured as each stage of supply chain demand variance divided by customers demand variance. In fact, as one move up the supply chain from retailer to suppliers, observe more variability in demand.

Firstly the bullwhip effect has been studied by Forrester[2] ,[3]. He studied some evidences of bullwhip effect and discussed the causes lead to this phenomenon.

Other papers demonstrated the bullwhip effect and found some evidences of inventory volatility [4], [5], [6], [7].

The Beer Game, which developed and used in teaching inventory management in MIT, reported by Sterman[8].

Lee et al. [9],[10] propose five main causes of bullwhip effect, demand forecasting, non-zero lead time, order batching, shortages and price fluctuations. To avoid the bullwhip effect, all causes should be eliminated. They considered AR(1) demand process in a simple two stage supply chain.

Metters[11] identify the bullwhip effect using an lower bound on the profitability of bullwhip effect. He measured the impact of bullwhip effect by comparing in two cases: high demand variability versus low demand variability with seasonality effect. Graves [12]

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measures the bullwhip effect for a supply chain in which demand process follows an integrated moving average.
Chen et al.[12] measure the bullwhip effect in a supply chain including two stages with AR(1) demand process observed by the retailer. The retailer forecasts future demand by moving-average forecasting method. They've derived a lower bound for the bullwhip effect.

Chen et al.[13] extend their results for exponential smoothing method. They quantified the bullwhip effect and found that it depends on both the nature of customer's demand process and the used forecasting method. They concluded the bullwhip effect would increases when the lead time increases.

Xiaolong Zhang [14] considers a simple supply chain with order-up-to replenishment system. He minimizes the mean-squared forecasting error for the demand process and concludes that different forecasting techniques lead to different bullwhip effect according to lead time and demand process parameters.

Previous studies usually quantified bullwhip effect in two stage supply chain including a retailer and a manufacturer. So far, however, there has been little discussion about three stage supply chain. In this paper we extend demand forecasting to a three stage serial supply chain, including a retailer, a manufacturer and a supplier. The retailer observed customer demands, and places an order based on lost demands of customers. The manufacturer observed the retailer orders and places the order to the supplier.

In section 2 we describe the supply chain model. In sections 3 to 6 different forecasting methods presented for measuring demand variability. We evaluate bullwhip effect in section 5, conclude in section 6 and Future studies are therefore recommended.

2. Problem Definition

To evaluate demand fluctuations, usually bullwhip effect is used. In this paper, a three stage supply chain with one retailer, one manufacturer and one supplier is considered. (figure1)

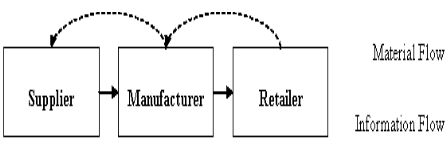

Figure1. Supply chain model

In this serial supply chain, in each period t, the retailer faced to demand D_t and places order D_t' to the manufacturer, and thereby the manufacturer places order D_t'' to supplier. The demand in market place that is retailer's demand, has mean μ and standard deviation σ .We are about to evaluate the impact of forecasting on demand variations denoted by bullwhip effect.

We assume four forecasting techniques: last period, last period with trend correction, moving average and exponential smoothing. In each case, the manufacturer predicts future demand base on retailer orders, and in a like manner the supplier forecasts base on manufacture orders.

3. Last Period Demand

In this method, and in easiest case, each stage of supply chain use only the latest period demand and ignore any trend of variations. The retailer and manufacturer forecast their demands as:

$$D'_t = D_{t-1} \quad (1)$$

And

$$D''_t = D'_{t-1} \quad (2)$$

And then:

$$Var(D) = Var(D'_t) = Var(D''_t) = \sigma^2 \quad (3)$$

In this method, there is no amplifying in demand variance.

4. Last period demand with trend correct

In Last period method, there is no motivation in prediction. An intelligent method is using latest trend in prediction process. We consider a coefficient, γ of last trend, to minimize bullwhip effect.

$$D'_t = D_{t-1} + \gamma(D_{t-1} - D_{t-2}) = (\gamma+1)D_{t-1} - \gamma D_{t-2} \quad (4)$$

And:

$$D''_t = D'_{t-1} + \gamma(D'_{t-1} - D'_{t-2}) = (\gamma+1)^2 D_{t-2} - 2\gamma(\gamma+1)D_{t-3} + \gamma^2 D_{t-4} \quad (5)$$

$$B.E. = Var(D''_t)/Var(D) = 6\gamma^4 + 12\gamma^3 + 10\gamma^2 + 4\gamma + 1 \quad (6)$$

The minimum of bullwhip effect occurs when $\gamma = -0.5$. So, the bullwhip effect is 3/8 and the forecast function is:

$$D'_t = (D_{t-1} + D_{t-2})/2 \quad (7)$$

A moving average of last two demands, that reduce demand variations. We extend the moving average to more previous data in next section.

5. Moving Average Method

In this method, we extend previous data to last n demands and use moving average method stage. The retailer estimates future demand by:

$$D'_t = \frac{D_{t-1} + D_{t-2} + \dots + D_{t-n}}{n} \quad (8)$$

The manufacturer estimates its future demand by:

$$D''_t = \frac{D'_{t-1} + D'_{t-2} + \dots + D'_{t-n}}{n} \quad (9)$$

Because of D'_t s correlations, we rewrite it in terms of D_t that are independent. Then we have:

$$D''_t = \frac{D_{t-2} + 2D_{t-3} + \dots + (n-1)D_{t-n-2} + nD_{t-n-1} + \dots + D_t}{n^2} \quad (10)$$

The variance of this relation is:

$$Var(D''_t) = \frac{(2n^2+1)}{3n^3}\sigma^2 \quad (11)$$

In case of *n=2* it became like last method and when *n>2* the variations will decreased. Increasing *n* leads to lower fluctuations.

6. Exponential Smoothing Method

In this section, exponential smoothing method is used to forecast demand.

$$D'_t = \sum_{k=1}^{n} \alpha(1-\alpha)^{k-1} D_{t-k} \qquad (12)$$

And then:

$$E(D'_t) = [1-(1-\alpha)^n]\mu \qquad (13)$$

$$Var(D'_t) = \alpha[1-(1-\alpha)^{2n}]/(2-\alpha)\sigma^2 \qquad (14)$$

(6)

The supplier demands forecasted as:

$$D''_t = \sum_{k=1}^{n} \alpha(1-\alpha)^{k-1} D'_{t-k} \qquad \textbf{(15)}$$

(9)

Because of correlation between D'_t s, for deriving its mean and variance we develop it in terms of D_t .

$$D''_t = \alpha\sum_{k=1}^{n}\alpha(1-\alpha)^{k-1}D_{t-k-1} + \alpha(1-\alpha)\sum_{k=1}^{n}\alpha(1-\alpha)^{k-1}D_{t-k-2} + \ldots + \alpha(1-\alpha)^{n-1}D_{t-n-2} \qquad (16)$$

$$= \alpha^2 D_{t-2} + 2\alpha^2(1-\alpha)D_{t-3} + 3\alpha^2(1-\alpha)^2 D_{t-4} + \ldots + n\alpha^2(1-\alpha)^{n-1}D_{t-n-1} + \ldots + \alpha^2(1-\alpha)^n D_{t-2n}$$

Then it can be written as:

$$Var(D''_t)/\sigma^2 = \alpha\left[1-2n(1-\alpha)^{2n-1} + (2n-1)(1-\alpha)^{2n} - n^2\alpha^2\right]/(2-\alpha)$$
$$+\alpha^3(1-\alpha)^{2n}\left[(n-1)^2 - n^2(1-\alpha)^2 - (1-\alpha)^{2n} - (1-\alpha)^{2n+2} + (2n+1)(1-\alpha)^4\right]/(2-\alpha) \qquad (17)$$

(24)

7. RESULTS

Forecasting the future demands is important in a supply chain. In this paper, we investigate the demand variations denoted as bullwhip effect measure. The bullwhip effect calculated as ratio of the Supplier demand variance to the retailer demand variance. We evaluate four measure of bullwhip effect.

In moving average method, when *n* last demands are used in prediction process, this ratio is:

$$(2n^2+1)/3n^3 \qquad (18)$$

The bullwhip effect can be reduced by increasing of n. The demand variation is demonstrated in figure2.

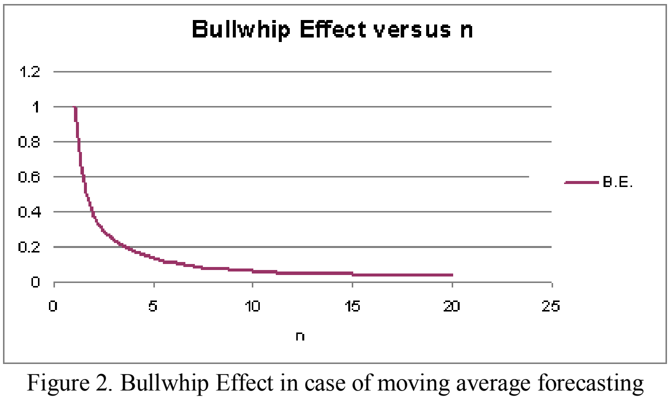

Figure 2. Bullwhip Effect in case of moving average forecasting

As n increases, i.e s.

The bullwhip effect in case of exponential smoothing method is:

$$\alpha^2\left[\frac{(1-\alpha)^2+(2t-3)(1-\alpha)^{2t}-(2t-1)(1-\alpha)^{2t-2}+1}{(\alpha-2)^2}\right] \quad (19)$$

The demand variations showed in figure3.

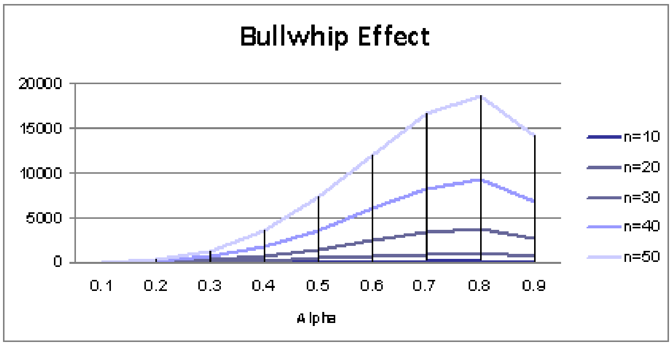

Figure 3. Bullwhip effect when exponential smoothing is used

As *n* increases, demand variation increases and decreasing α lead to decreasing the demand variations. When $\alpha = 0.8$ demand variations has maximum level.

8. Conclusion

The purpose of the current study was to measure the demand variability in a simple three- stage supply chain. We used last demand, last demand with trend correction, moving average and exponential smoothing method for forecasting the future demand in a serial supply chain. We use analytical method to extend the model to third stage.

The most obvious finding to emerge from this study is amplifying demand variability as one move up the supply chain. It was also shown that the more demand information used to forecasting the demand, the smaller the increase in variability. The demand variation is an increasing function of the smoothing parameter. Moreover variability for moving average method is decreasing function of number of used data. In any case, supply chain stages must use more demand information to reduce demand variability.

However, this paper does not capture of some complexities involved in real world. Multiple retailers and manufacturers, in form of network, can be considered. Furthermore, it can extend to multiple stages and using various forecasting methods in various stages.

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