Measure of bullwhip effect in supply chains with first-order bivariate vector autoregression time-series demand model

Abstract

With supply chains becoming increasingly global, the issue of bullwhip effect, a phenomenon attributable to demand fluctuation in the upstream section of the supply chains, has received greater attention from many researchers. However, most existing research studies on quantifying the bullwhip effect were conducted under the first-order autoregressive [AR(1)] incoming demand process or its variants as the fundamental demand process. This research work thus examines the bullwhip effect for a first-order bivariate vector autoregression [VAR(1)] demand process in a two-stage supply chain consisting of one supplier and two retailers. The impacts of the correlation parameters of the demand process, the correlation coefficient between the two error terms, and the variances of error terms on the bullwhip effect were investigated. As such, the measure of the bullwhip effect was established using an analytical approach in which the minimum mean square error (MMSE) forecasting method and the base stock policy were applied to all members of the supply chain. The number of scenarios was studied to determine the conditions in which the bullwhip effect would be present.

Keywords: Supply chain; Bullwhip effect; Bivariate VAR(1) model; Base stock policy

1. Introduction

Supply chain management takes into consideration all tasks that could impact costs and customer requirements so as to maximize the overall value (Chopra and Meindl, 2001). Besides, the management of supply chain becomes increasingly challenging as a result of fluctuating demand and complex interactions among various organizations in the supply chain (Simchi-Levi et al., 2008). Many suppliers have discovered that order quantities tend to exhibit greater fluctuation than do customer demands across the supply chain, the phenomenon of which is referred to as the bullwhip effect and invariably leads to inefficiencies in the supply chain.

The work of Forrester (1958) seemed to be the earliest paper describing the system dynamics phenomenon (now called the bullwhip effect) with recognition of integrated nature of organizational relationships. Another study by Sterman (1989) presented the well-known beer game from which participating players could observe the bullwhip effect. Two papers by Lee et al. (1997a, b) indicated that the bullwhip effect was the result of strategic interactions among rational supply-chain members and proposed possible remedies based on the underlying coordination mechanism.
These research studies on the bullwhip effect are still referred to by researchers in the field of supply chain management today.

The impacts of demand forecast on the bullwhip effect in a simple two-stage supply chain with one supplier and one retailer were investigated by a number of researchers. For example, Chen et al. (2000a, b) examined the effect of the simple moving average (MA) and the simple exponentially weighted moving average (EWMA) forecasting methods through an analytical approach, while Dejonckheere et al. (2003) studied this effect through a control systems engineering approach. It was found that the bullwhip effect was unavoidable under the MA and EWMA forecasting methods. A number of researchers, such as Alwan et al. (2003), Liu and Wang (2007), and Luong (2007), measured and examined the behavior of the bullwhip effect using the minimum mean square error (MMSE) forecasting method for a stationary first-order autoregressive, AR(1), demand process. It was found that the MMSE forecasting technique, which could prevent the occurrence of the stratification error, tended to lessen the bullwhip effect, and the bullwhip effect did not exist if the first-order autocorrelation coefficient was negative or zero. Comparative studies of the bullwhip effects among three forecasting techniques were undertaken by Liu and Wang (2007) and Zhang (2004). Liu and Wang (2007) then proposed the rule for selection of the forecasting method to reduce the bullwhip effect, while Zhang (2004) demonstrated that the MMSE forecasting method was the best among the three methods in case of a stable process in which inventory costs were taken into account.

The AR(1) demand process was still used by several researchers in their works, examples of whom were Duc et al. (2010), who investigated the influence of a third-party warehouse on the bullwhip effect in the case of a three-stage supply chain with one supplier, one third-party warehouse, and two retailers; Pati et al. (2010), who studied the bullwhip effect in a closed loop supply chain; and Hussain et al. (2012), who examined the effect of the forecasting schemes on inventory variance. In addition, under the non-stationary AR(1) demand process, Nepal et al. (2012) analyzed the bullwhip effect with consideration for a product's life-cycle demand.

There were research studies on the bullwhip effect in which the incoming demand processes were not the AR(1) process. Instead, they were, for example, a high order autoregressive, AR(p), demand process by Luong and Phien (2007) and a mixed autoregressive-moving average, ARMA(1,1), demand process by Duc et al. (2008). In addition, the AR(1) and ARMA(1,1) models were referred to by Alwan et al. (2003) in a study on the behavior of upstream echelons in a supply chain. Wang et al. (2010) studied the behavior of the bullwhip effect for the first-order moving average, MA(1), demand process including the AR(1) and ARMA(1,1) demand processes under the three forecasting methods as previously mentioned. Besides, ARIMA(0,1,1) demand process was used by Graves (1999) to study the impact of inventory model on the bullwhip effect for a non-stationary demand process. Recently, Cho and Lee (2011)