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An empirically-simulated investigation of the impact of demand forecasting on the bullwhip effect: Evidence from U.S. auto industry

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ABSTRACT

This study empirically examines the impacts of three major aspects of demand forecasting on the magnitude of the bullwhip effect. Three research questions are addressed to investigate the association between (1) forecast accuracy, (2) aggregate forecasting, and (3) responsive forecasting and the bullwhip effect. Using forecasted demand generated from popular time-series forecasting models and real-life demand data, the study investigates the relationship between the forecasted results and the consequential bullwhip effect. The findings show that the forecasting methods used lead to the variation of the bullwhip effect. Moreover, the lead time reduction and the stable demand forecast are beneficial to reduce the bullwhip effect. However, our empirical results differ from previous findings in two ways: (i) improving forecast accuracy does not necessarily reduce the bullwhip effect and (ii) aggregate forecasting does not always reduce the bullwhip effect.

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1. Introduction

The bullwhip effect (BWE) is described as the non-optimal solution adopted by supply chain participants to reach a global optimization for the whole system (Sterman, 1989) and defined as the increase of the variation of the order quantity from downstream members to upstream members in a supply chain (Lee et al., 1997b). Lee et al. (1997a) pointed out that the BWE is one major cause of the less-than-desired supply chain performance and has been observed in most manufacturing supply chains, such as Procter & Gamble's diaper products (Lee et al., 1997b), fast-moving consumer goods (Zotteri, 2013), and auto component in the assembly line (Klug, 2013). These cases among many others showed that the BWE is a long-lasting and still existing issue and can be observed in many different industries even after numerous efforts have been devoted to work on this problem for more than a decade. In addition, Lee et al. (1997a, b) showed that the BWE inflates supply chain operating cost by 12.5–25% and the elimination of the BWE would save the U.S. grocery industry for about $30 billion per year. In other words, the BWE is a serious problem across different industries and in different markets/countries. Summarizing the existing efforts, Geary et al. (2006) claimed ten major causes/principles of the BWE and demand forecasting is believed as a major contributor to the presence of the BWE (Barlas and Gunduz, 2011; Duc et al., 2008).

Forecasting-related factors were analytically/mathematically concluded to influence the magnitude of the BWE. With an assumed demand model, prior studies relied on a few forecasting methods to estimate the future demand which is further used to determine the inventory level and the order quantity for BWE estimation. The forecasting methods considered include simple moving average forecast (Chen et al., 2000b), simple exponential smoothing forecast (Chen et al., 2000a), double exponential smoothing forecast (Wright and Yuan, 2008), Holt-Winter's exponential smoothing forecast (Bayraktar et al., 2008), minimum mean-squared error forecast (Alwan et al., 2003; Zhang, 2004), autoregressive model (Chandra and Grabis, 2005), state-space approach (Gaalman and Disney, 2009), and damped trend exponential smoothing forecast (Li et al., 2014). Clearly, existing conclusions between forecasting and the BWE are drawn by a specific combination of the forecasting methods used and the demand pattern assumptions specified. As such, it would be interesting to investigate the forecasting-BWE problems by adopting new forecasting methods, by considering additional embedded forecasting properties, and by allowing different types of demand pattern.

The objective of this study is three-folds. The first is to provide a more insightful understanding between the BWE and selected aspects of the demand forecasting in response to the call for empirical verification of existing theories (Fisher, 2007) and offering managerial understandings between forecasting and operational

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performance (Fildes and Kingsman, 2010). Prior studies tested one or two aspects mentioned above at a time without taking a comprehensive view to demand forecasting. For example, some studies suggested a negative relationship between forecast accuracy and the BWE (Alwan et al., 2003; Bayraktar et al., 2008; Zhang, 2004). In other words, it showed that the smaller the forecast error, the smaller the BWE will be. Others (Barlas and Gunduz, 2011; Bayraktar et al., 2008; Chen et al., 2000a) have suggested that the responsiveness of the forecast which is influenced by the smoothing parameter is positively related to the strength of the BWE. Again, the conclusions are relied on an imposed demand assumption which may limit the reliability of the application in the real-world. Moreover, existing forecasting-oriented studies suggested that the relationship between forecast accuracy and the forecast utility is complex, especially in an inventory management setting which affects the order volume and inventory level at hand (Ali et al., 2012; Syntetos et al., 2010). These studies empirically explored the association between the forecast accuracy and the cost but little was made to study the relationship between the forecast accuracy and the BWE. Hence, we use the real-world demand to empirically verify the previous findings in a more comprehensive picture. Thus, this study provides additional findings to the accuracy-utility relationship.

The second objective is to investigate whether the aggregate forecasting leads to less BWE for the company. Current studies emphasized on testing whether or not the use of aggregate data to measure the BWE leads to stronger BWE. For example, Cachon et al. (2007) claimed that "whether data aggregation may preserve or mask the BWE is dependent on the correlation of the production and demand across the units being aggregate (firms, products, etc.)". Likewise, Chen and Lee (2012) argued that aggregating products with similar seasonality leads to less BWE. However, to the authors' best knowledge, no efforts were made to investigate the impact of aggregate forecasting on the BWE. In other words, it leaves an interesting question that remains to be answered, namely, can the BWE be managed by using data-aggregated forecasted demand. This study intends to fill this gap by considering demand at multiple levels and measuring the BWE from various groups.

The third objective is to re-examine the impact of lead time on the BWE when a new type of demand process is considered. The BWE was proposed to be a result of a joint effect from non-zero lead time and demand forecast (Forrester, 1958). Many existing efforts suggested that, regardless of the forecasting policy used, the longer the lead time, the stronger the magnitude of the BWE (Chen et al., 2000b; Zhang, 2004). However, Duc et al. (2008) have suggested "the magnitude of the BWE does not permanently increase when the lead time increases and claimed that the positive association between the length of the lead time and the magnitude of the BWE is greatly dependent on the attributes of the considered demand process". It implies that the claimed relationship between the length of lead time and the BWE should be retested when a new demand process is considered. Hence, since this study considers a less controlled demand processes presenting the complexity of the real world demand, it is interesting to re-evaluate the relationship between the length of the lead time and the magnitude of the BWE.

The remainder of the paper is organized as follows. Section 2 presents the research methods and models. In this section, we briefly introduce the forecasting methods, the replenishment policy, and the bullwhip measure. In Section 3, a description of the data and data source is provided. Section 4 presents the empirical results and describes the implications. Finally, the last section offers concluding remarks and extensions for future research.

2. Research methodology

In this section, we depict the business settings, provide the information concerning the inventory policy used and the estimation the order quantity, present the forecasting policies considered and other tested factors, and describe how to investigate the impact of aggregate forecasting upon the BWE.

2.1. The business settings and the BWE measure

Due to data availability, we conduct this study by emphasizing on the operations at the retailer (auto dealer) echelon in the automotive supply chain and use simulation to estimate the needed information. It is assumed that the retailer satisfies the consumer demand from its own on-hand inventory and refills the inventory by placing orders to the upstream party which is usually the auto maker. The upstream party is assumed to have no capacity restraint and is able to satisfy all order quantity from the retailer. Finally, it is also assumed that there is no negative order quantity placed by the retailer, meaning that the retailer cannot return the inventory to the manufacturer.

The timing of events in a period is described as follows. At the beginning of the period, the retailer receives the order placed l periods ago. The retailer satisfies the end customer's demand which is present as the actual monthly sales by the available inventory. The forecasted demand for the next period is generated based upon the actual sales information at the current period. Given the forecasted demand and the chosen inventory policy, the retailer places the order which will be received at the beginning of l periods after, where l is the lead time. To be clear, it is assumed that lead time is zero when l is one as used in Chen et al. (2000b). For example, if a retailer which places its order at the end of January receives this January order at the beginning of February, it is considered to have zero lead time. Yet, since there is one time period difference between the time the order is placed and the time the order is received, we consider that the order is delivered one time period late ($l=1$). Given the time frame for each move, we will use historical monthly demand at the auto type level to forecast future demand. Then, based on the forecasted demand, we can estimate the order quantity and the forecast error. In the end, when all forecasted demand and order quantity in 2008 are generated, the 2008 BWE is calculated.

The BWE measure is used to evaluate the influences of demand forecasting and replenishment lead time on the supply chain performance. In this work, the BWE at time t is evaluated using Lee et al. (1997b)'s bullwhip measurement which is the ratio of the variance of order (O_t) placed by the retailer at time t to the variance of demand (D_t) satisfied by the retailer at time t as described by

$$Bullwhip\ effect_t = var(O_t)/var(D_t), \tag{1}$$

where D_t is the monthly sales obtained from data while O_t is the order quantity estimated from the inventory policy considered.

2.2. The replenishment policy

In light of the popular application in previous BWE studies and the nature of the data used in this study, a periodic order-up-to (OUT) method is used to estimate the order quantity. Although the OUT policy is a likely cause to the presence of the BWE, the OUT policy is the standard ordering mechanism in many MRP systems (Gilbert, 2005), and is not restricted to specific demand types and can be used with the existence of trend (Li et al., 2014). Besides, the objective of this study is not to examine the existence of the BWE. Hence, the OUT policy is treated as the replenishment policy.