Int. J. Production Economics 118 (2009) 311–322

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

The bullwhip effect in supply chains—An overestimated problem?

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ARTICLE INFO

Available online 23 August 2008

Keywords:
Bullwhip effect
Risk pooling
Supply network
Order-up-to policy
Square root law

ABSTRACT

A phenomenon that is now well known as the bullwhip effect suggests that the variability of orders increases as they move up the supply chain from retailers to wholesalers to manufacturers to suppliers. In this paper, we will focus mainly on measuring the bullwhip effect. Existing approaches that aim at quantifying the bullwhip effect neglect the network structure of supply chains. By only assuming a simple two-stage supply chain consisting of a single retailer and a single manufacturer, some of the relevant risk pooling effects associated with the network structure of supply chains are disregarded. Risk pooling effects arise when the orders, which a retailer receives from its customers, are statistically correlated with a coefficient of correlation less than one. When analyzing the bullwhip effect in supply chains, however, the influence of risk pooling has to be considered. The fact that these influences have not yet been analyzed motivates the research presented in this paper. We will show that the bullwhip effect is overestimated if just a simple supply chain is assumed and risk pooling effects are present.

1. Introduction

A phenomenon that is now well known as the bullwhip effect suggests that the variability of orders increases as we move upstream in the supply chain from retail to manufacturing. In a supply chain, although consumer sales do not seem to vary much, there is pronounced variability in the retailer's orders to the wholesaler. Furthermore, the wholesaler's order quantities to the manufacturer as well as the manufacturer's orders to the supplier vary even more in time. For a detailed elaboration of the bullwhip effect, see Kahn (1987), Lee et al. (1997a, b), and Metters (1997).

Numerous studies find the bullwhip effect in some industries and in numerous examples from individual products and companies. In the supply chain for diapers, *Procter and Gamble* (P&G) noticed that the volatility of the diaper orders issued by the distributors was quite high even though end consumer demand was reasonably stable (Lee et al., 1997b). In another paper, the same authors, Lee et al. (1997a), observe the bullwhip effect in a soup supply chain as well as in the supply chain for printers of *Hewlett–Packard* (HP). *Barilla* also finds that phenomenon in the supply chain for pasta (Hammond, 1994). Furthermore, Terwiesch et al. (2005) have found that the semiconductor equipment industry is more volatile than the personal computer industry, and Anderson et al. (2000) assign the volatility in the machine tool industry to the bullwhip effect. Additionally, the bullwhip effect has been experienced by many subjects playing *The Beer Game* (Sterman, 1989).

Regarding the large number of studies, which observed an increase in demand variability as one moves up a supply chain, Lee et al. (2004) conclude that nowadays "the bullwhip effect is a standard industry term and reference to it in industry publications has become commonplace" (p. 1891). In a seminal paper, these same authors identify four major causes of the bullwhip effect—(i) the updating of demand forecasts, (ii) order batching, (iii) price fluctuation, and (iv) rationing and shortage gaming—and suggest several managerial

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doi:10.1016/j.ijpe.2008.08.035

practices to mitigate its consequences. In addition, Dejonckheere et al. (2003) find that an important factor to the bullwhip effect is the replenishment rule used by the supply chain members. The authors conclude that whatever forecasting method is used (e.g. exponential smoothing or moving averages), order-up-to systems will always result in the bullwhip effect.

However, in a recent study of US industry level data, Cachon et al. (2005) find that demand volatility does not increase as one moves up the supply chain. In contrast to the natural consequences of the bullwhip effect, the authors observe that—in general—manufacturers do not have substantially greater demand volatility than retailers and may have even lower demand volatility. These results are explained mainly by production smoothing: predictable seasonality in combination with increasing marginal costs provides a strong motivation to smooth production relative to demand. Therefore, "the majority of retail and manufacturing industries smooth their production relative to their demand, i.e., they impose less volatility on their suppliers than they face from their customers" (Cachon et al., 2005, pp. 18–19). Cachon et al. (2005) conclude that the bullwhip effect is not widespread in the US economy and, moreover, the bullwhip effect is not commonplace.

In this paper, we analyze another strong force that mitigates the bullwhip effect. We focus on analyzing and measuring the bullwhip effect analytically. Because "supply chains" are more like "supply networks", our analysis accounts for supply chains that possess a network structure. In practice, supply chains can be considered as networks of geographically dispersed facilities—where raw materials, intermediate and finished products are produced, tested, modified, and stored—and the transportation links that connect the facilities. The different operations (e.g. raw materials procurement, finished goods manufacturing, and distribution) are performed on different stages of the supply chain. The term supply chain implies that only one player is involved at each stage of the supply chain. In reality, however, a manufacturer supplies several wholesalers and may receive material from several suppliers. Therefore, in the following, we use the term supply chain if only one player is involved at each stage, i.e. if the supply chain has a linear structure. If two or more players are involved at one stage, we will consequently use the term supply network.

Existing approaches that aim at quantifying the bullwhip effect neglect the network structure of supply chains. By assuming only a three-stage supply chain consisting of a single customer, a single retailer, and a single manufacturer, some relevant risk pooling effects associated with the network structure of supply chains are disregarded. Risk pooling effects arise for example when the orders a retailer receives from its customers are statistically correlated with a coefficient of correlation less than one. Note that the risk pooling effect is a special case of the well-known portfolio effect (Ronen, 1990). When analyzing the bullwhip effect in supply chains, however, the influence of risk pooling cannot be neglected. The fact that these influences have not been analyzed yet motivates the research presented in this paper.

We extend the analysis of Chen et al. (1999, 2000) to a supply chain with a network structure in which risk pooling can reduce the bullwhip effect on every individual stage. We first describe the supply chain setting, the forecasting technique, and the inventory policy used by the individual actors. To measure the bullwhip effect, the variances of the orders placed by the wholesalers to the manufacturers relative to the variance of the demand faced by the wholesalers will be determined. We will show that the bullwhip effect may be overestimated if just a simple supply chain is assumed and risk pooling effects are present. Therefore, in a supply network, using a simple forecasting method (e.g. moving averages), order-up-to systems will not always result in the bullwhip effect. The analytical results will be illustrated and affirmed by a simulation study.

2. Related literature

Since the first analysis of this phenomenon by Forrester (1958, 1961), the bullwhip effect has been addressed in a large number of publications. Recent research on the bullwhip effect can be divided into six general categories: (i) papers aiming at a quantification of the bullwhip effect (e.g. Carlsson and Fullér, 2000; Chen et al., 2000; Dejonckheere et al., 2003; Kahn, 1987; Lee et al., 1997a, b; Metters, 1997; Zhou and Disney, 2006), (ii) works focusing on analyzing and identifying the causes of the bullwhip effect (e.g. Geary et al., 2006; Lee et al., 1997a, b; Metters, 1997; Nienhaus et al., 2006), (iii) studies observing the bullwhip effect in some industries or in numerous examples from individual products and companies (e.g. Cachon et al., 2005; Lee et al., 1997a), (iv) papers addressing methods for reducing the bullwhip effect (e.g. Carlsson and Fullér, 2001; Chen et al., 1999; Dejonckheere et al., 2003; Disney and Towill, 2003; Ingalls et al., 2005; Mason-Jones and Towill, 2000; Moyaux et al., 2007), (v) works focusing on simulating the system behavior (e.g. Disney and Towill, 2003; Ingalls et al., 2005; Makajic-Nikolic et al., 2004; Nienhaus et al., 2006), and (vi) papers focusing on experimental validation of the bullwhip effect (e.g. Moyaux et al., 2003).

A great part of previous research has focused on demonstrating the existence and identifying the possible causes of the bullwhip effect (category (ii) of the relevant literature). Particularly, Lee et al. (1997a, b) identify four major causes of the considered phenomenon: (a) the updating of demand forecasts, (b) order batching, (c) price fluctuation, and (d) rationing and shortage gaming. The first cause occurs when the parties involved in the supply chain base their forecasts on the historical demand behavior of their immediate customers. Every supply chain member then adjusts to fluctuations of their order entry. Moreover, if every member reacts to fluctuations with smoothing techniques, the fluctuations will amplify throughout the supply chain. The effect of order batching—which is a rational order policy if the costs for frequent order processing are high—is an amplification of the order variability; the connection between the order policy and the actual demand patterns of the customers is