THE BULLWHIP EFFECT IN SUPPLY CHAIN

Reflections after a Decade

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Abstract — ***A decade has passed since the publication of the two seminal papers by Lee, Padmanabhan and Whang (1997) that describes the "bullwhip effect" in supply chains and characterizes its underlying causes. The bullwhip phenomenon is observed in supply chains where the decisions at the subsequent stages of the supply chain are made greedily based on local information, rather than through coordination based on global information on the state of the whole chain. The first consequence of this information distortion is higher variance in purchasing***

quantities compared to sales quantities at a particular supply chain stage. The second consequence is increasingly higher variance in order quantities and inventory levels in the upstream stages compared to their downstream stages (buyers). In this paper, we survey a decade of literature on the bullwhip effect and present the key insights reported by researchers and practitioners. We also present our reflections and share our vision of possible future.

Keywords: **Bullwhip Effect, Information Distortion, Information Flow, Production and Inventory Management.**

Introduction

The general opinion of a supply chain is that it is a channel that finished goods are produced from raw materials and then transported to customers (Vollmann *et al.,* 2000). Mentzer et al. (2001) describes upstream and downstream flow of products, information and finances from supplier to customer that occurs between three or more echelons. "According to a Georgia Technical University study, because of supply chain problems, a firm loses its value between 9 and 20 percent in a six-month period" (Reddy, 2001). Due to the high competition of business environment in the global world, most firms try to increase productivity and eliminate problems of their supply chain systems. Some of the problems that firms face are excessive inventory, shortage of the products, information distortion and insufficient transportation. One of the main reasons of these problems is the "bullwhip effect". The Bullwhip effect is the demand variance amplification while moving through to upstream echelons from downstream echelons (Lee *et al*, 1997).

The concept of the bullwhip effect was first mentioned by Procter & Gamble to explain increasing order behavior of Pamper diapers between customer and supplier (Lee et al., 1997). Although customer demand is almost stable, Procter & Gamble realized that there is a significant variance at wholesale orders. They also realized that the variance of orders placed to the raw material suppliers is greater than the variance of orders placed to wholesalers. There are also other firms that realized the "bullwhip effect" with respect to their companies' order fluctuations such as Hewlett-Packard, 3M, Eli-Lilly, DRAM market. The bullwhip effect causes inefficiency and this returns as costs to firms. For example, "among various members of the $300 billion (annual) grocery industry, there is $75 billion to $100 billion worth of inventory caught due to the inefficiencies" (Fuller *et al*, 1993).

The "bullwhip effect" phenomenon is also known in different names such as "whiplash effect", "whipsaw effect" and "acceleration principle" but the "bullwhip effect" term is the most preferred one. In this tutorial, we searched "bullwhip effect" in "ABI/INFORM Global (ProQuest)" database system and we used only full text resources.

The Bullwhip Effect and the Beer Game

First studies on the bullwhip effect belong to Jay Forrester. He developed a computer simulation model using the DYNAMO simulator that represents traditional supply chain. The supply chain consists of three echelons, namely factory, distributor and retailer. He demonstrated the amplification of demand in his model but did not call the phenomenon as "bullwhip effect". Forrester believed that irrational decision making is the main cause of the bullwhip effect which he proved through his model. He also showed that time delays, random fluctuation of demand and limited capacity can lead to the bullwhip effect.

Emergence of the Beer Game

Beer Distribution Game is one of the exercises that illustrate the dynamics of a supply chain (Jacobs, 2000). The game was developed at the Massachusetts Institute of Technology's Sloan School of Management by System Dynamics Group (Sterman, 1989). The Beer Distribution Game consists of four echelons which are customer, retailer, distributor and factory. Each echelon is managed by a single player and communication between echelons is not allowed. In the game, the customer requests beer from the retailer and, in turn, the retailer orders to the distributor. Similarly, the distributor gives orders to the factory and then the beer is produced. Only the retailer knows the actual customer demand and the other players base their decisions according to the ordering patterns of their immediate downstream echelon. The time that is required for ordering, process and delivering the beer are represented by ordering and shipping delays. The main objective of the game is minimizing total cost, which is the combination of inventory holding and backlogging costs. Sterman (1989) inferred three consequences from the game:

1) Large oscillations appear in orders and inventories.

2) Demand amplification increases as one goes to upstream.

3) Order rate tends to peak from retailer to factory.

The following figures show the results of a beer game played by a diverse population of industrial engineering and management science undergraduate students in Istanbul, Turkey. The figures I and II in appendix part display the ordering patterns of 2 teams representing the supply chain of Brand 1 and Brand 2.

Having observed outcomes of the beer game, Sterman (1989) claims that the bullwhip effect occurs due to the irrational behavior of managers or feedback misperception.

Lee et al. (1997) identify the underlying causes of the bullwhip effect by developing a mathematical model of serial supply chain. In contrast to Forrester (1961) and Sterman (1989), they model the manager of each echelon as being rational and optimizing. In the follow-up paper, Lee et al. (2004) demonstrate that the bullwhip effect is a result of strategic interactions among rational supply chain members. Lee et al. (1997) demonstrate four reasons of the bullwhip effect:

1) Demand Signal Processing

2) Order Batching

3) Price Fluctuations

4) Shortage Gaming

We will shortly point out these four reasons because this model constitutes the backbone of the bullwhip effect studies.

Demand Signal Processing: Most companies use forecasting to determine capacity planning, production scheduling, material requirement and inventory control. Forecasts are often based on historical data gathered from sales information of the company. When a downstream echelon places an order, its immediate upstream firm considers this order as a signal about expected future product demand. Subsequently, upstream firm adjusts its forecasts based on this signal. For instance, if a retailer places an order to a distributor, the distributor adjusts its forecasts and places an order to wholesaler. Similar relation occurs between the wholesaler and the factory. In this case, orders have larger variance due to the updated forecasts. Moreover, safety stock is required as a result of forecasted demand and the longer lead time results in the need of more safety stock. This situation causes higher order variance than the actual demand, therefore the bullwhip effect occurs.

Order Batching: Some inventory monitoring and control are used by each echelon in order to place orders to its immediate upstream echelon in a supply chain (Lee et al., 1997). Generally, companies do not immediately place orders to their suppliers. They often batch demands and use periodic ordering or push ordering strategies. In periodic ordering, companies place orders once in a week or in another period. For example, if a company places order monthly, supplier will face erratic downstream orders, since there will be a spike in a month and no demand orders in the rest of the month. "Obviously, the supplier faces higher demand variability than the company" (Lee et al., 1997). This increased variability attests to the fact that periodical ordering causes the bullwhip effect. In push ordering, salespeople regularly measures quarterly or yearly. As a result, most of the companies have orders at the end of a quarter or a year. In this situation, the bullwhip effect appears due to companies' order patterns that indicate higher variance than customers' consumption patterns.

Price Fluctuations: Price fluctuations are generally resulted by "forward buy" arrangements between a company and its supplier. Lee et al. (1997) indicated that 80 percent of transaction between manufacturer and distributor is forward buying in the grocery industry. Coupons, price discounts, quantity discounts and rebates are frequently used in marketplace and these special promotions also cause price fluctuations. This situation triggers customers to buy more than their immediate needs and they stock products for their future needs. If prices return to its previous level, customers do not buy products until their entire stock will be consumed. Because of the fact that the buying pattern has higher variances than the normal pattern, it does not reflect actual consumption pattern. Hence, the bullwhip effect occurs.

Shortage Gaming: If the demand of a product exceeds its supply, shortage gaming occurs. Because there is insufficient amount of the product, supplier rations the product between downstream members. After that, downstream members place demand orders more than their needs to finally reach their actual needs. After shortage time passes, placed demand orders will be canceled since they were inflated. Shortage gaming causes the bullwhip effect because the actual demand variance is amplified as we moved from the customer to the supplier.

Literature on the Bullwhip Effect

There are numerous researches about the bullwhip effect. Most of the researches demonstrate that the bullwhip effect exists and some others investigate how the bullwhip effect reacts according to different conditions.

Impact of Forecasting on the Bullwhip Effect

The relationship between forecasting and the bullwhip effect is considered by many authors. Hanssens (1998) empirically connects the bullwhip effect and forecasting. He illustrates that the bullwhip effect exists as a result of forecasting and measures the impact of the effect. Graves (1999) also shows that the bullwhip effect exists in consequence of forecasting under integrated demand method. Chen et al. (1999) measure the magnitude of the bullwhip effect under different forecasting techniques such as exponential smoothing and moving average. Also Chen et al. (2000) quantify the impact of demand forecasting on the bullwhip effect in a two stage supply chain and extend this study to a multistage supply chain. They demonstrated that the variance of orders placed by the downstream echelons will be higher than the variance of demand if a downstream echelon periodically updates the mean and the variance of demand that based on observed customer demand data. They assume that exact demand value is not known. Dejonckheere et al. (2004) have gained similar results with Chen.

Metters (1997) investigates the bullwhip effect in monetary terms. He proves that forecasting is one of the main reasons of the bullwhip effect. Results of his research indicate that eliminating forecast error may increase profitability between 5 – 10 percent. Miyooka and Hausman (2004) deploy “stale” or old forecasts to determine base stock levels and use current forecasts to communicate upstream and downstream stages. Their strategy can decrease expected inventory level, shortage cost and production fluctuations in the decentralized strategy. In contrast to benchmarking, their strategy results in higher shortage costs and inventory level but lower variability at period to period production

Impact of Information on the Bullwhip Effect

Chen (1998) studies the importance of centralized demand information in a serial inventory system. He compares the echelon stock and installation stock policies and shows that the value of information is related to the system parameters namely lead times, batch sizes, number of stages, demand variability and customer service level. Towill and McCullen (2001) study on the efficiency of a supply chain and they used *information transparency system* as one of the methods that reduce the bullwhip effect which consists of high information integrity between supply chain members. Yu et al. (2001) discuss information sharing between supply chain members and investigate its benefits to the each member of the chain. In their model, a retailer and a manufacturer can both gain benefit by information sharing.

Disney and Towill (2003) examine the relation between the vendor-managed inventory and the bullwhip effect in a traditional “serially-linked” supply chain. They demonstrate that some causes of the bullwhip effect can be eliminated and the influence of other causes can be reduced by applying VMI policy. Croson and Donohue (2003) focus on how point of sale (POS) data can help to reduce the bullwhip effect in a multi-echelon supply chain. They found that POS information across the supply chain can reduce the magnitude of the order oscillations and decrease the magnitude of the order amplification between the wholesaler and the distributor. However, they do not come to same conclusion in a retailer - wholesaler and a distributor – manufacturer relation. Moreover, they prove that order oscillations of sharing POS information provide less benefit to retailers and wholesalers than to manufacturers and distributors (Donahue et al., 2003).

Chen et al. (2000) study the impact of sharing centralized customer demand information on the bullwhip effect in a multistage supply chain. They prove that by information sharing, it is possible to reduce the bullwhip effect but they could not eliminate the bullwhip effect. Hayya et al. (2004) use a simulation model to examine the effects of information quality and information sharing on bullwhip effect and illustrate that information quality is also important besides information sharing. They use the results of Chen (2000) and Dejonckheere et al. (2004) to verify the accuracy of the simulation. Kulp et al. (2004) conclude that supply chain performance is better when information sharing and collaborations occur.

Clark and Hammond (1997) make an empirical analysis which illustrates that investing in Electronic Data Interchange (EDI) for information sharing provides less benefit than investing for business process reengineering. Cachon et al. (2000) show that using information technology to expand the flow of information provides less benefit than using information technology to accelerate and smooth physical flow of goods in a supply chain. Lee et al. (2000) state that information sharing of retail demand data decreases the cost of the manufacturer.

Impact of Seasonality and Order Batching on the Bullwhip Effect

Firms use production smoothing technique due to the increasing marginal cost or high cost of changing the rate of production. Blinder (1981) claims that batching occurs due to the setup and ordering costs. Jung et al. (1999) analyze order batching in terms of customer's effect and claim that infrequent orders in large lot sizes are preferred by firms even they are flexible supplier. Cachon (1999) shows that if a retailer order is periodically in fixed lots, the order cycles and the batch size influence the bullwhip effect proportionally. Moinzadeh and Nahmias (2000) observe that the bullwhip effect can be reduced as a result of correlated ordering instead of order batching. Gilbert and Chatpattananan (2006) study on ARIMA model and show how to optimally distribute the bullwhip effect over smoothing periods. Lee et al. (1999) illustrate that batching contributes to the bullwhip effect.

Cachon et al. (2006) have searched the bullwhip effect according to monthly data of U.S. Census Bureau between January 1992 and February 2006 that consists of 6 retailers, 18 wholesalers and 50 manufacturing industries. They claim that the bullwhip effect is more dominant than production smoothing if an industry's production is more volatile than its demand. "An industry's incentive to production smooth should increase as its demand becomes more seasonal" (Cachon et al., 2006). Most of the researchers observe the bullwhip effect in various examples and conclude that it is consistent with the variance of sales is lower than variance of production. However, Cachon et al. (2006) find that manufacturing demand is less volatile than downstream echelons. Only wholesalers reflect amplified demand characteristics. Moreover, they find some verification that retails demand is the most volatile in the supply chain which contradicts with the bullwhip effect. They believe that they come to different conclusions because "seasonality in combination with increasing marginal costs provides a strong motivation to smooth production relative to demand, so it is not surprising that eliminating a primary reason to production smooth leads to incorrect conclusion that most firms amplify" (Cachon et al. 2006). Also, they consider that seasonality is one of the major causes of the bullwhip effect that should be analyzed. Similarly, Metters (1997) depicts that seasonality is a major factor of the bullwhip effect.

Strategies for Dealing with the Bullwhip Effect

Lee et al. (1997) suggest that making demand data available at downstream site to an upstream site is a remedy to mitigate demand signal processing. Thus, upstream site and downstream site can use same data while updating their forecasts. Their strategy can be achieved by using electronic data interchange (EDI) and point of sale systems (POS). They prove EDI can also help to break order batching. Against price variations they recommend reducing price discount and using strategies like everyday low pricing system. They add that sharing sales capacity and inventory data can be helpful to eliminate shortage gaming.

Hayya et al. (2004) find out that information sharing decreases total and stage to stage variance amplification. They also illustrate that information sharing decelerates variance amplification as going to upstream site from downstream site. Additionally, the authors show that information quality is an important factor to reduce the bullwhip effect. Chen et al. (2000) demonstrate that smoother demand forecasts provide smaller variation increase. They also illustrate that the retailer should use more demand data to reduce the bullwhip effect if longer lead times is in process. They also have similar conclusion about using centralized information but they demonstrate that the bullwhip effect is not completely eliminated by using information sharing policies. Croson and Donohue (2003) confirm that behavioral impact of adding POS data sharing improves performance of supply chains.

Ruggles (2005) suggests that using collaboration tools like vendor managed inventory (VMI) can help to reduce the bullwhip effect because these systems make available the demand data and inventory position information to members of the supply chain. Disney and Towill (2003) recommend VMI as a remedy against the bullwhip effect. They argue that shortage gaming can be completely eliminated because responsibilities in relation change. Also, they claim order batching effect can be eliminated by the structure of the information flow. Moreover, VMI can reduce the bullwhip effect that is caused by price variations. Finally, they claim that VMI supply chain causes less variation than traditional supply chain.

Yu et al. (2001) investigate the benefits of information sharing to members of the chain. They found that in "decentralized control" and "coordinated control", retailer will obtain nothing but in "centralized control" retailer can gain performance improvement. However, manufacturer can gain inventory level reduction if information sharing occurs. Manufacturer gains more than retailer but it is possible to provide *pareto improvement* (benefit of the two stages) by information sharing. Towill (1999) demonstrates that removal of one or more intermediate echelons, encouraging collaboration among supply chain members and reducing time delays can significantly reduce the bullwhip effect. McCullen and Towill (2001) categorize various supply chain strategies into four principles:

1) **Control System Principle:** Strengths dynamic stability of the supply chain.

2) **Time Compression Principle:** Aims reduction in material and information flow lead times

3) **Information Transparency Principle:** Information sharing between members

4) **Echelon Elimination Principle:** Removal of echelons.

Authors embedded these principles in a company's strategy and achieved 36 per cent reduction in the bullwhip effect (Mc Cullen et al., 2001).

Kaipia et al. (2006) state that reducing "nervousness" can reduce the bullwhip effect. They have three strategies.

1) Stabilize and simplify planning process.

2) Develop communication practices with suppliers

3) Implementing VMI system

Donavan (2003) makes some managerial suggestions to minimize the bullwhip effect and increase business performance. He suggests minimizing cycle time, monitoring actual demand for products, increasing quality and frequency of collaboration, minimizing or eliminating information queues, minimizing incentive promotions to customers and providing vendor-managed inventory.

Conclusion

Although the bullwhip effect phenomenon has been heavily considered in the last two decades, nowadays it is a well known issue that is being investigated in various aspects. There are a lot of research that demonstrate the bullwhip effect exists and that try to find reasons which cause the bullwhip effect. Moreover, some researches seek remedies to eliminate or reduce the bullwhip effect and some firms like Cisco and P&G explain the reasons of the inefficiencies they faced in their supply chain by referring to the bullwhip effect (Lee et al. 2004).

The researches about the bullwhip effect come to a point but there is a long way that to go through to clearly understand the effect because there are still contradictions. For example, Cachon et al. (2006) find out significant contradictions to the definition of the effect that was discussed in part 3. The fact that they come up with different results could not be fully explained. We do not know if it is a special case or researches before Cachon's have similar characteristics. Moreover, there are possibly different choices that can be made regarding the way data was aggregated and neither current literature nor business practice is clear about this matter. In addition, different choices can be used while separating the data (Fransoo, 2000). Since different choices can be considered we are not able to find the exact reflections of the bullwhip effect but it can be said that similar databases and applied methods can be used as an initiative to eliminate the bullwhip effect and to increase the efficiency of the supply chain systems.

Appendix

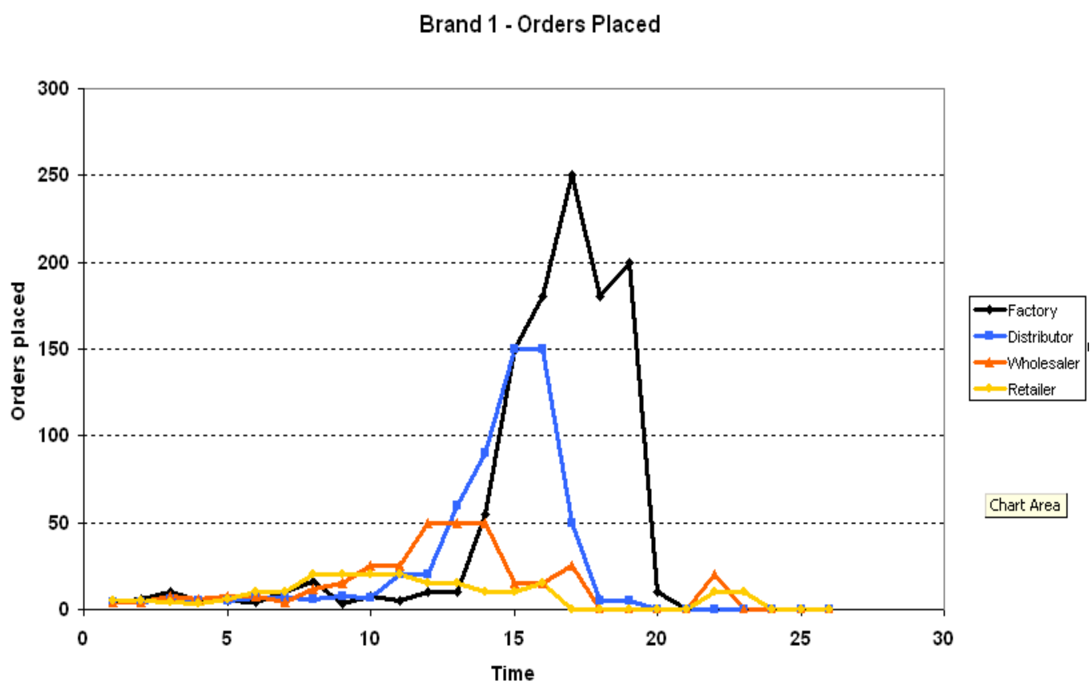

Figure 1

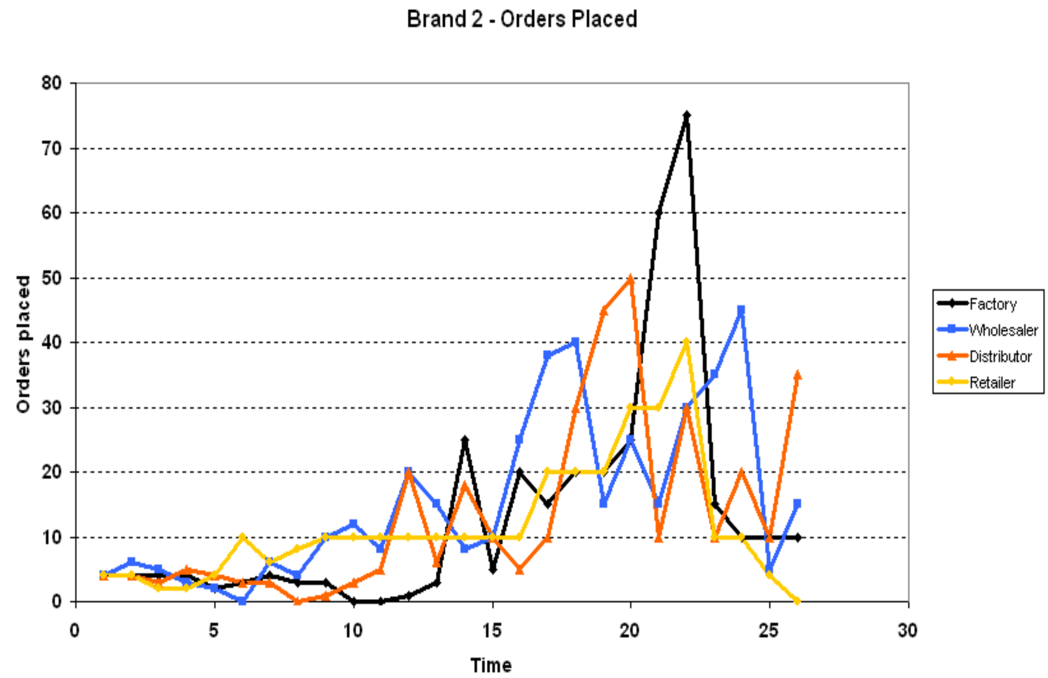

Figure 2

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