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Comments on "Information Distortion in a Supply Chain: The Bullwhip Effect"

The Bullwhip Effect: Reflections

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In this commentary, we trace back how we pursued research on the bullwhip effect, which resulted in the article published in *Management Science*. We reflect on the evolution of this concept, the impact that our work has had on industry, the way our work has been used in the teaching of supply chain management, and the key directions of research that have taken place since then.

Key words: supply chain management; information distortion; coordination

Discovering and Rediscovering the Bullwhip

The bullwhip phenomenon, i.e., the amplification of demand variability from a downstream site to an upstream site, has been observed or identified in industry for a long time. The first recorded documentation of this phenomenon was probably by Forrester (1958), who did not coin the term bullwhip, but used industrial dynamic approaches to show such amplification. The beer game, constructed by Forrester's colleagues at MIT, was another means through which students and industry executives have been exposed to such a phenomenon. The game is still one of the most successful and widely played games in academia and industry. This is why some people in industry call demand variability amplification the "beer-game" phenomenon.

Historically, the bullwhip effect had been accepted as a normal occurrence and rationalized as an inevitable outcome of the order-to-delivery system that characterized the production and distribution systems of the past. Forrester (1958) identified that the action/reaction and interaction of the flows of information, materials, and money among the self-interested parties in the supply chain would lead to delays, oscillation, and amplification in the flows of information and physical goods through the channel. Sterman (1989) offered a more nuanced rationalization of this phenomenon. His view was that the decision makers/managers made systematic errors in perceiving the dynamic environments in which they operated, which featured, amongst other things, multiple feedback loops, time delays, and nonlinearities. These misperceptions coupled with the tendency to view business events as consequences of forces outside their control would lead them to believe that the bullwhip effect was a fact of life that they had to live with.

For a long time, industry had debated why such a phenomenon exists. We were intrigued by the phenomenon and were trying to understand better the sources of demand variability amplification. We were first exposed to the term "bullwhip" when the three of us visited Procter and Gamble (P&G) in the early nineties. As part of our research on improving the coordination of manufacturing and retailing, we interviewed P&G executives, and one of them described how P&G was paralyzed by this "bullwhip" effect. It was through P&G that we learned of the now-famous example of the bullwhip effect—although the end consumption of P&G diapers by babies (Pampers) was very stable, the demand as generated by customers of P&G on diapers was so variable that one might think that some babies were using no diapers in one week, and doubling their normal usage the next week to make up for it. We then engaged in animated discussions with our P&G friends about what the causes of the bullwhip effect could be. We were excited by the possibilities of research and the development of teaching materials around the illumination, explanation, and remedies of the bullwhip effect. We are very grateful to our P&G friends for introducing us to this term and for inspiring us to pursue this line of research.

As we discussed the bullwhip effect with executives in other industries, we began to realize that the bullwhip effect was everywhere. Companies like Hewlett Packard (HP), Xilinx, Canon, 3Com, Raychem, and Intel showed us data that clearly indicated the existence of the bullwhip effect. Interestingly, some companies had no terms to describe the phenomenon, and others used different terms to describe this effect. We have heard terms like "whipsaw effect," "whiplash effect," and "acceleration principle," etc., but the bullwhip term seems to be the most popular now. Besides the amplification of demand variability as you move from downstream to upstream sites along a supply chain, the bullwhip effect was also used to describe the distortion of information from one part of the chain to another; the distortion of consumption pattern from the ordering pattern at a firm, or simply put, "what you see is not what they (your customer) face."

The bullwhip effect has been viewed as one of the forces that paralyze supply chains. Several industry studies, including ECR (Efficient Consumer Response) and EFR (Efficient Foodservice Response), have identified the bullwhip effect as most harmful to the efficiency of a supply chain. Consequently, these industry reports focused on ways to mitigate the bullwhip, such as common data definitions, information sharing, electronic data exchanges, collaborative forecasting and planning, and reducing the number of intermediaries in a supply chain.

We are very gratified to see that our research (Lee, Padmanabhan, and Whang 1997a, or LPWa) to understand the causes and develop counterstrategies of the bullwhip effect has contributed to the industry's awareness and responses to address this problem, as well as to the teaching and research of supply chain management at large. We will describe some of these impacts in the rest of this commentary.

Bullwhip Effect and Industry Practice

Our view in LPWa is that the bullwhip effect is not a consequence of exogenous shocks, but an endogenous outcome of a firm's policies as well as the business processes and industry characteristics that shape and drive behaviors of the different institutions in the supply chain. Of great relevance to the bullwhip effect are, therefore, supply chain practices such as the price schedule offered by the vendor, ordering frequency, returns policy, frequency and depth of price promotion, the degree of information sharing, demand forecasting methods, allocation rules in case of shortage, and so forth. We are not unique in making this point. As we indicated in the previous section, many academics, consultants, and practitioners have also identified this as being the driver of the bullwhip effect.

The consequence of this view is that efficiency in supply chain management, and the potential competitive advantages generated through these efficiencies, can only be obtained by carefully identifying the forces and factors that shape individual institutions behaviors and their interactions with related supply chain participants. The need for such an understanding is even more imperative in the modern-day context of supply chains characterized by dispersed production, functional outsourcing, and global customers. This realization is the driving power behind much of the recent activities and initiatives in supply chain management in both the academic and industrial domains.

In our paper we identified four forces that contributed to the bullwhip effect—demand forecast updating, order batching, price fluctuations, and rationing. These causes have provided a framework for industry to address the supply chain problems created by information distortion.

For example, consider Cisco's 2001 write-off of $2.1 billion in inventory. In the heat of rapid market growth in 2000, Cisco committed to large orders of scarce components well in advance, based on optimistic projections from the company's salesforce. But facing chronic shortage and long lead times in the previous several years, salespeople had inserted some "cushion" in their forecasts of their customers' forecasts. Further, Cisco customers also allowed themselves some form of cushion in their orders: Knowing that the equipment is hard to get on time, they would place duplicate and triplicate orders with Cisco's competitors. Similar shortage gaming was played among its contract manufacturers (CMs), too. This way the actual order was exaggerated multiple times, and Cisco was dragged into an inventory fiasco. Learning from the mistake, Cisco is now completing the e-Hub, an information platform through which Cisco can track the inventory and order status at its top three tiers of suppliers. Such visibility would hopefully prevent overcommitment of procurement by the CMs and Cisco itself.

From this example and others, we find that roughly two approaches—information systems and collaboration—are widely used to counter the bullwhip effect. The visibility of inventory, demand, and supply in the supply chain has been at the forefront of supply chain initiatives in recent times, and new information technologies have been used to foster such sharing. Similarly, the collaboration among supply chain participants and the integration of their activities and processes into a holistic chain have also been at the core of the industry efforts to counter the bullwhip phenomenon. Since the mid-1980s, there have been many initiatives launched across a variety of industries to improve the coordination of the overall supply chain. These include, for example, VMI (vendor managed inventory), CMI (co-managed inventory), JMI (jointly-managed inventory), CPFR (collaborative planning, forecasting, and replenishment), collaborative commerce, and CTM (collaborative transport management).

We increasingly find companies taking preemptive actions and measures to mitigate the bullwhip effect. The Laserjet group at HP, for example, has measured the degree of the bullwhip effect by comparing the standard deviations of the orders from their customers (resellers) with those of the sell-through quantities from their customers to the stores. Such measures helped to identify customers with large bullwhip factors so that HP could target their efforts to collaborate with customers to see how the bullwhip effect could be reduced.

Teaching Supply Chain Management

As mentioned before, the beer game has continued to be an important part of the operations management or supply chain management curriculum of most academic institutions. Sterman's 1992 article clearly shows the power of the beer game. In a comprehensive survey of teaching materials on supply chain management, Johnson and Pyke (2000a) also cited the beer game as one that almost every course in supply chain management or operations management uses. We are also gratified that our research on the bullwhip effect has reinforced the interest and importance of supply chain coordination and communication and, consequently, contributed to the continual and renewed popularity of the beer game. Our companion paper (Lee, Padmanabhan, and Whang 1997b, or LPWb) has been used by many of our colleagues as either readings or discussion materials following the beer game.

Beyond the beer game, we have found that many other games are used as teaching tools to, among other things, introduce and address the bullwhip effect. Many of these games were conducted with the LPWb paper as handouts. The Johnson and Pyke book (Johnson and Pyke 2000b) contains several excellent examples of other games, such as the PC-versions of the beer game (Kaminsky and Simchi-Levi 1998, Chen and Samroengraja 2000), the Web-based beer game (Jacobs 2000), the Otogel simulation exercise (McKone 2000), the Siemen's brief case game (Mehring 2000), and the mortgage service game (Anderson and Morrice 2000).

One of the most extensively used teaching cases in supply chain management is Barilla (Hammond 1994). The case focuses on how Barilla was "bullwhipped" by its customers and the initiatives that Barilla undertook to counter the bullwhip. This case was also one of the first published that documented empirically the existence of the bullwhip effect. More recent teaching cases that address the bullwhip effect include Hoyt (2001) and Peleg (2003).

In a similar way, the topic of information distortion and coordination is also increasingly a basic element of industrial training and executive education. Naturally, we do not have an exhaustive list, but at a minimum, we are aware of companies such as Accenture and HP, where such a topic is at the core of their training programs for supply chain professionals. Kuper and Branvold (2000) is one documented source that describes the HP experience.

Further Research on the Bullwhip Effect

The LPWa paper lists four causes of the bullwhip effect: demand signal processing, order batching, price fluctuations, and shortage gaming. These four causes have stimulated multiple streams of research, with richer modeling assumptions, to gain deeper understanding of the behaviors that lead to, as well as counter, the bullwhip. Here, we will not be able to give a comprehensive and exhaustive literature survey, but will give some examples of research that are based on one or more of the four causes of the bullwhip effect.

Demand Signal Processing

LPWa identified the bullwhip effect as a natural consequence of the use of statistical forecasting methods by multiple stages in a supply chain. Formal models have been used to build explicit relationships between key drivers, such as lead times and the number of forecasting stages, and supply chain performance, quantify the value of information sharing or supply chain integration, propose ways to mitigate the effect, and examine the mechanisms with which information can be shared.

Hanssens (1998) is one of the early papers that empirically link forecasting method with the bullwhip effect. Using retail data on high-technology consumer durables, he demonstrates the existence of the bullwhip effect, quantifies the impact of the effect, and shows how the use of retail sales information can significantly improve the accuracy of order forecasting. Graves (1999) also shows how standard forecast methods could lead to the bullwhip under the integrated moving average demand model. Chen et al. (1999) also quantify the magnitudes of the bullwhip effect resulting from moving averages, exponential smoothing, and other forecasting methods.

Chen (1998) studies the *value of centralized demand information* in a serial inventory system. By comparing two inventory policies—one based on echelon stock and the other installation stock—the value of centralized demand information can be shown to depend on key system parameters such as the number of stages, lead times, batch sizes, demand variability, and the desired level of customer service. Along the same line, Chen et al. (2000) compare the supply chain performance of multiple-stage supply chains with and without centralized customer demand information and demonstrate that the bullwhip effect can be reduced, but not completely eliminated, by centralizing demand information.

Lee et al. (2000) study the impact of *information sharing* in a two-level supply chain where the retailers face serially correlated demand. They show that sharing retail demand data can significantly reduce the costs for the manufacturer, particularly when the serial correlation is quite high. Kim and Ryan (2003) develop a variant of this model where the retailer or the manufacturer does not know the true nature of the demand process. Cachon and Fisher (2000) analyze the value of information sharing in a supply chain with multiple retailers. In this case, the supplier can take advantage of full information to better allocate inventory among retailers. They conclude that implementing information technology to accelerate and smooth the physical flow of goods through a supply chain is significantly more valuable than using information technology to expand the flow of information. Raghunathan and Yeh (2001) show that continuous replenishment benefits both manufacturers and retailers while the improved forecasting through information sharing via EDI benefits manufacturers.

More recently, Aviv (2001, 2002) has quantified the value of collaborative forecasting in a supply chain and provided support for the CPFR movement.

Besides analytical modeling approaches, there is also emerging research on *empirical analysis* of the value of information sharing and coordination. Clark and Hammond (1997) make use of empirical data from major manufacturers and retailers to show that investing in EDI for information sharing alone yields much less benefit than if such investment is accompanied by business process reengineering like continuous replenishment. Based on sample data from food and consumer packaged goods manufacturers, Kulp et al. (2004) find that supply chain performance improvement is greater when both information sharing and collaborative initiatives, such as joint planning and new product introduction, are pursued.

Lee and Whang (2000) study the *types and modes of information* that are shared in a supply chain and the resulting value. Swaminathan and Tayur (2003) offer a review of information sharing models that can be implemented through the Internet. See also a recent survey of the information systems literature by Banker and Kauffman (2004), where the *value of information* research is listed as one of five main research streams. They review a set of work on information sharing in supply chains, including several papers related to bullwhip effect.

Order Batching

The LPWa paper identifies order frequency and the evenness of order arrivals over time as key parameters that drive the bullwhip phenomenon. This has stimulated research on the value of synchronized ordering and the trade-off of various factors in the choice of order batch sizes.

Cachon (1999) investigates the performance of balanced ordering policies in a supply chain model with multiple retailers. When retailers have to order on fixed periodic cycles and in multiples of fixed batch sizes, it is natural that the bullwhip effect would depend on the order cycle and the batch size. The author recommends balanced ordering with small batch size and a long order interval to reduce the supplier's demand variance.

Jung et al. (1999) analyze the impacts of buyers' order batching on the supplier's demand correlation and capacity utilization in a simple branching supply chain with two buyers whose demands are correlated. In this case, an increase in order lot size mitigates the correlation of purchase orders; and that a supplier whose facilities are flexible would prefer frequent, smaller orders only when market demands are highly negatively correlated. This means that even flexible suppliers would prefer infrequent orders in larger lot size in the presence of positively correlated demands. This provides another reason why large batch size is common in practice and, as a result, a supply chain frequently suffers from the bullwhip effect.

Moinzadeh and Nahmias (2000) examine correlated ordering as a means to reduce the bullwhip effect. They observe that correlated ordering is only one form of "controlling order variance," and consider a broader class of long-term contractual agreements between the buyer and the seller. For example, a fixed quantity is delivered to the buyer at regular time intervals, but the buyer also has the option of adjusting the delivery quantity upward just prior to a delivery, at some premium cost. Using a diffusion approximation, they prove that the fixed delivery contract results in lower variance of orders to the seller.

Price Fluctuations

As pointed out in LPWa, fluctuations in the wholesale prices of a manufacturer will cause the bullwhip effect. The marketing literature uses the term "trade promotions" to refer to the practice of short-term changes in the wholesale price of a manufacturer. The early literature on trade promotions highlighted the rationales for this practice of short-term price fluctuations (e.g., Blattberg and Neslin 1990, Lal 1990, Gerstner and Hess 1995). However, the growing share of trade promotions in the total marketing budget of manufacturers (from less than 35% in the early 1980s to 53% in the late 1990s) accompanied by trade practices such as forward-buying and diverting, which reduced the profitability of trade promotions, led many to call for a reexamination of this promotional practice. Consequently, many researchers suggest that strategies such as EDLP (everyday low prices) should be preferred to trade promotion (e.g., Buzzell et al. 1990; and Kristofferson and Lal 1996a, b).

LPWa contributed to this literature by (i) linking trade promotions to information distortion and the bullwhip effect, and (ii) highlighting the fact that trade promotions, when combined with appropriate changes in promotional design and interactions of channel institutions, could still be beneficial from an overall channel perspective.

This view is also reflected in the more recent literature in marketing and operations. Ailawadi et al. (1999) show that trade promotions that link the manufacturer's wholesale price to retail channel output measures such as retail sales or retail price improves the manufacturer's performance. Dreze and Bell (2003) show that scan-backs, which tie promotional allowances to point of sales (POS), are better than off-invoice promotional sales for both the manufacturer and the overall channel. Interestingly, they show that this mechanism also results in lower forward buying, higher retail pass-through, and higher sales during the promotional period. In other words, better promotional design as well as collaboration between channel partners in information sharing can improve the overall channel performance. Achabal et al. (2000) develop a decision support system featuring the collaboration between a manufacturer and retailers on a series of channel throughput metrics. The system was implemented by a major apparel manufacturer with a subset of their major retail vendors, and the participants in this collaborative exercise did systematically better than the rest. Steckel et al. (2004) examine how changes in order and delivery cycles, shared POS data, and patterns of consumer demand impact the dynamics in a channel and thereby the severity of the bullwhip effect.

Shortage Gaming

The last cause of the bullwhip effect is rationing and shortage gaming. Key control variables regarding this cause are order cancellation policy, rationing rules in case of shortage, and the sharing of capacity information.

Cachon and Lariviere (1999a, c) examine how the *choice of allocation mechanism* impacts retailer actions and supply chain performance. Examples of such mechanisms are the turn-and-earn allocation, linear, proportional, and uniform allocations. Both the proportional and linear allocation rules are shown to produce bullwhip effects. Cachon and Lariviere (1999b) expand the search for "better" allocation rules and find that a broad class of allocation mechanisms is prone to manipulation. They also characterize the set of truth-revealing mechanisms.

Cheung and Zhang (1999) study the impact of *order cancellations policies* on the supply chain and as a driver of the bullwhip effect. In particular, they show that the probability and the timing of a cancellation matter in the overall performance.

Epilogue

Today, the bullwhip effect is a standard industry term and reference to it in industry publications has become commonplace. Evidence of the bullwhip effect and its devastating consequences on the performance of suppliers, manufacturers, distributors, and retailers routinely makes the headlines of the business press. We are also finding the reference to the effect in companies' annual reports. A Google search on the "bullwhip effect" returned more than 10,000 references. Terms like "taming the bullwhip," "cracking the bullwhip," "dampening the bullwhip," or "controlling the bullwhip" could be found extensively.

When companies overstated their orders in preparation of 2000—the Y2K syndrome—the press referred to this phenomenon as the bullwhip effect. In disaster relief operations, when relief agencies like the International Federation of Red Cross and others duplicated their independent estimates for demands of blankets and food, leading to an oversupply by suppliers, the press also referred to it as the bullwhip effect. When the market went south in 2001, companies like Cisco and Solectron (see discussion earlier) had huge excess inventory, and these companies blamed the problem on the bullwhip effect. We have seen lawsuits about companies being accused of distorting their sales pictures, and the term bullwhip had also been used. An example of business press using the bullwhip effect to explain some of the above supply chain inefficiencies and disruption is *The Economist* (2002).

The bullwhip effect has also been used to describe the impact of technology innovations. Industry experts and analysts have cited extensively how two recent innovations can help improve supply chain performance through their ability to help companies "dampen" the bullwhip effect. The first technological innovation was the Internet. One of the often-cited potential benefits of e-business was facilitation of information sharing, which was a key ingredient to counter the bullwhip. The second, more recent, technological innovation was radio-frequency identification (RFID). More ambitious are new technologies for tagging based on monitoring and communications using low-earth orbiting satellites (LEOS) systems. Again, in reports after reports, companies recognized that the potential value of RFID was more real-time, accurate, and extensive information sharing. The use of the term "bullwhip" was also extensive in these reports.

Although the bullwhip effect seems well known among practitioners, it is not clear if companies have completely succeeded in taming the bullwhip. The incentive barriers are still huge for companies to take action. We are sure that some companies (such as Barilla, P&G, and Wal-Mart) have made major inroads in this respect. The evidence of the bullwhip seems to be overwhelming, including many examples with hard data that illustrate its existence. But of course one cannot infer that the bullwhip is everywhere. It would certainly be worthwhile for our community to conduct empirical research to estimate the magnitudes of the bullwhip effect in different industry segments, identify practices of companies that have been successful in containing the bullwhip, and understand why bullwhip containment is possible in some companies and not in others.

We believe that there is still a lot to be done in the research of the bullwhip effect, as well as in continuing to disseminate our research results to practitioners, influencing their actions, and helping them to create new structures and processes that would dampen the bullwhip. We are happy to see that our 1997 *Management Science* article has contributed a small step in this direction.

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