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The impact of bullwhip on supply chains: Performance pathways, control mechanisms, and managerial levers

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ABSTRACT

Even though few empirical studies have tried to actually explicate the relationship between the bullwhip effect and performance of the supplier firm, there exists a common perception for over 30 years among both practitioners and academics that the bullwhip effect naturally results in decreased firm profitability. Anecdotal evidence further suggests that this decline in profitability arises from a decline in operational performance. However, the results of our study, which empirically examines the bullwhip effect across supply chain partners through an analysis of 383 actual customer base-supplier dyads, challenge this commonly held position by suggesting that while traditional bullwhip often yields reduced ROA, it ultimately has no relationship with the firm's operating margin. Additionally, our results also call into question whether or not production coordination between customers and suppliers can minimize the need for inventory and capacity buffers, which are the two commonly utilized methods for battling the bullwhip effect. Thus the relationship between bullwhip and firm performance is far more nuanced and complicated than previously believed. We also show how the managerial bullwhip levers of coordinating production across supply chain partners, or deploying inventory and capacity buffer control mechanisms, can help maximize a firm's performance along different dimensions.

1. Introduction

It is commonly perceived that bullwhip reduces a firm's performance by wreaking operational havoc. We challenge this conventional wisdom by suggesting that while traditional bullwhip generally does result in lower return on assets (ROA), it has no relationship with the firm's operating margin, a primary indicator of operational performance. Such a finding suggests that how bullwhip actually impacts ROA is not as straightforward as previously thought.

This study dives deeply into the bullwhip–performance relationship by proposing and evaluating a new dimension of bullwhip, which captures the acceleration (or deceleration) of bullwhip between supply chain partners. Such an evaluation allows us to gain performance insights into not only the level of bullwhip a firm faces, but also the extent to which an acceleration (or deceleration) of the bullwhip impacts that firm's performance. Results from this analysis will also challenge the conventional wisdom that customers and suppliers in a supply chain that synchronize/coordinate their production can minimize the need for inventory and capacity buffers that represent traditional mechanisms utilized to combat bullwhip. As such, we will show that with respect to the bullwhip effect, leaning too heavily upon what many would consider to be "already known" or "well understood" information may not always yield contextually accurate insights.

At its most fundamental level, the bullwhip effect increasingly distorts the pattern of actual end customer demand to upstream supply chain partners (Lee et al., 1997a, 1997b; Zhang and Burke, 2011), who are then often forced into "boom or bust" production cycles. Such extreme production cycles resulting from bullwhip have been shown to significantly increase supply chain costs and lower performance (Sterman, 1989). Likewise, the Economic Theory of Production Smoothing (ETPS) suggests that firms have an economic incentive to avoid such extreme production cycles and instead should smooth production (Holt et al., 1960; Blanchard, 1983; Blinder, 1986; Miron and Zeldes, 1988). Numerous researchers over several decades have highlighted a number of countermeasures for combating the bullwhip.

Despite logical evidence that bullwhip behavior should be avoided and recommendations on how to minimize it, there

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remains significant evidence that bullwhip still continues to occur in about 67% of firms (Bray and Mendelson, 2012; Shan et al., 2014). If firms are incentivized to smooth production to avoid the "boom and bust" production cycles yet most do not do so, it suggests from a rational perspective that these firms must have a larger incentive not to smooth production, or from an irrational perspective, the majority of firms are subject to the same widespread behaviorally driven irrational actions. This apparent contradiction between theory and practice raises an interesting research question. Does the bullwhip effect actually result in reduced firm performance? If so, what are the specific pathways through which this decreased firm performance occurs? Finally, are there appropriate control mechanisms or managerial levers that can be applied to ameliorate the bullwhip effect?

2. Bullwhip definitions and assessment

Before developing the theoretical model, it is important to first establish definitions and foundational concepts underlying this research. We subscribe to the traditional conceptual definition of bullwhip as described by Lee et al. (1997a) as "the phenomenon where orders to the supplier tend to have larger variance than sales to the buyer (i.e., demand distortion), and the distortion propagates upstream in an amplified form (i.e., variance amplification)."

Building upon this conceptual definition of bullwhip, it is clear that bullwhip fundamentally consists of not only a level of demand distortion, but also the extent of variance amplification. In other words, while it is important to know if a firm is experiencing demand distortion, it is also important to know if such demand distortion is accelerating (or decelerating) along the supply chain. For the purpose of this study, we describe these two aspects of bullwhip simply as first and second order bullwhip effects. First order bullwhip effect is the absolute level of demand variation amplification for a given firm relative to the variance of actual demand for the furthest downstream partner (e.g. demand distortion); while second order bullwhip captures the *rate of change* (e.g. variance amplification) in demand distortion (first order bullwhip) between tiers in the supply chain. When evaluated together, first and second order bullwhip not only capture the level of demand distortion at a given node in the supply chain, but also the extent to which demand distortion is accelerating (or decelerating) between tiers in the supply chain. Thus, it is possible to capture all possible bullwhip supply chain configurations by simultaneously utilizing these two aspects of bullwhip.

We will first provide the mathematical equations we utilize to assess first and second order bullwhip effects, then we will provide a numerical example to further illustrate these calculations. First order bullwhip for supplier s in year y is calculated as shown in Eq. (1), where CV (P_{sy}) is the coefficient of variation of production of supplier firm s in the supply chain across the four quarters in year y, and CV (D_{cy}) is the coefficient of variation of demand for the supplier's customer c across the four quarters in year y.

$$\text{Supplier First Order Bullwhip} = \frac{\mathrm{CV}(P_{sy}) - \mathrm{CV}(D_{cy})}{\mathrm{CV}(D_{cy})} \quad (1)$$

It is important to point out that in line with extant literature (Bray and Mendelson, 2012; Shan et al., 2014), both demand and production are calculated at the quarterly level. As configured in Eq. (1), the first order bullwhip measure represents the percentage change in upstream production variation relative to downstream demand variation. As such, positive values indicate an increase in the absolute level of demand variation or amplification, while a negative number indicates a decrease in variation with respect to downstream demand variation or an absolute dampening. Given that first order bullwhip is consistent with how bullwhip has been examined in extant literature (Cachon et al., 2007; Bray and Mendelson, 2012), we will interchangeably use the terms bullwhip and first order bullwhip.

Table 1
Numerical illustration of bullwhip calculations using contrived data.

	Customer[a]	Supplier (Tier 1)[a]
Known information	Market Demand Variance = 5 Production Variance of Customer = 7	Production Variance of Supplier = 8
First order bullwhip[b]	0.4 = ((7 − 5)/5) (Production Variance of Customer is 40% higher than Market Demand Variance)	0.60 = ((8 − 5)/5) (Production Variance of Supplier is 60% higher than Market Demand Variance)
Second order bullwhip[c]	N/A	0.50 = ((8 − 5) − (7 − 5))/|7 − 5| (Supplier first order bullwhip is 50% higher than their Customer's First order Bullwhip indicating that bullwhip is accelerating between customer and supplier)

[a] Both customers and suppliers are manufacturers in our study.
[b] Positive values indicate amplifying, while negative values indicate dampening.
[c] Positive values indicate accelerating bullwhip, while negative values indicate decelerating bullwhip.

Whereas first order bullwhip captures the production variability of the supplier with respect to end customer demand variability, second order bullwhip captures the supplier's production variability as compared to the production variability of their customer. By doing so, it is possible to determine how the firm is behaving on both an absolute (first order) and relative (second order) basis regarding production variability. Second order bullwhip for supplier s and customer c in year y is calculated as shown in Eq. (2), where CV (P_{sy}) is the coefficient of variation of production for supplier firm s in the supply chain across the four quarters in year y, CV (D_{cy}) is the coefficient of variation of demand for the supplier's customer c across the four quarters in year y, and CV (P_{cy}) is the coefficient of variation in production for customer c across the four quarters in year y.

$$\text{Supplier Second Order Bullwhip} = \frac{(\mathrm{CV}(P_{sy}) - \mathrm{CV}(D_{cy})) - (\mathrm{CV}(P_{cy}) - \mathrm{CV}(D_{cy}))}{|\mathrm{CV}(P_{cy}) - \mathrm{CV}(D_{cy})|} \quad (2)$$

When this variable is positive, the supplier's first order bullwhip is larger than their customer's first order bullwhip, thus indicating that the supplier is accelerating variance amplification relative to their customer. When this measure is negative, the supplier is decelerating variance amplification with respect to their customer. Eqs. (1) and (2) make it possible to distinguish all combinations of first and second order bullwhip effects, such as firms that may be amplifying (first order) but at a decelerating rate (second order) and vice versa.

We use a numerical example with contrived data in Table 1 to illustrate the calculation of first and second order bullwhip using Eqs. (1) and (2). The first order bullwhip for the customer is 0.4 as shown in Table 1, or in other words the customer's production variance is 40% larger than market demand variance. First order bullwhip for the supplier is 0.6, or in other words their production variance is 60% larger than market demand variance. Second order bullwhip is 0.50, indicating that the supplier is amplifying at a 50% higher rate than which the customer is amplifying, thus confirming that the bullwhip is accelerating between the customer and the supplier.