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In search of intra-industry bullwhips☆

Ming Jin[a,*], Nicole DeHoratius[b], Glen Schmidt[a]

[a] David Eccles School of Business, University of Utah, United States
[b] University of Chicago, United States

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A B S T R A C T

Previous research (e.g., Cachon et al., 2007) has examined the prevalence and magnitude of the bullwhip effect across industries, measuring the bullwhip as the ratio of the variance in the stream of orders placed relative to the variance in orders received (in some cases surrogates are used for the order measures). Our contribution is to use the decomposition framework of Jin et al. (2016a) to look intra-industry, examining whether the bullwhip is created in shipping, manufacturing, or ordering – and exploring whether this varies across industries. Our analysis is based on monthly, industry-level U.S. Census Bureau data. We find (and begin to explain) significant differences across industries regarding the source of the bullwhip – be it in shipping, manufacturing, and/or ordering. We also examine how the bullwhip is impacted by the duration and end-point of the time aggregation interval; our results suggest that some managers may want to shift their reporting period.

1. Introduction

The seminal paper of Lee et al. (1997) defines the bullwhip effect as "the phenomenon where orders to the supplier tend to have larger variance than sales to the buyer (i.e., orders distortion), and the distortion propagates upstream in an amplified form (i.e., variance amplification)" (p. 546). A number of researchers have explored the cause of the bullwhip phenomenon and proposed a variety of remedies (e.g., Lee et al., 1997; Chen et al., 2000; Chen and Lee, 2012). Other scholars have measured the bullwhip in practice, empirically testing for possible drivers of its magnitude (e.g., Bray and Mendelson, 2012; Cachon et al., 2007; Chiang et al., 2016; Dooley et al., 2010; Duan et al., 2015; Fransoo and Wouters, 2000; Isaksson and Seifert, 2016; Lai, 2005; Jin et al., 2016a; Mackelprang and Malhotra, 2015; Shan et al., 2014; Zotteri, 2013).

The bullwhip definition noted above – and the preponderance of the research to date – views a firm or an industry as one 'echelon' in the supply chain and looks across the echelon. It is an inter-echelon bullwhip measure as it effectively looks across the echelon by comparing the variability in the orders an echelon places with its suppliers to the variability in the orders the echelon receives from its customers. If the measure is greater than one, the bullwhip effect is said to exist. On the other hand, smoothing is present if this measure is less than one. That is, the echelon dampens rather than amplifies its order variability.

While the conventional bullwhip measure is informative and useful for determining what happens across an echelon in the supply chain (i.e., inter-firm or inter-industry), numerous actions inside the echelon contribute to this conventional bullwhip measure. One of our contributions is to use the decomposition framework of Jin et al. (2016a) to look intra-industry, examining whether the bullwhip is created in shipping, manufacturing, or ordering. We explore whether this varies across industries, and offer some possible explanations as to why we observe these differences.

Our analysis is based on monthly, industry-level U.S. Census Bureau data. Our data set is the same as that used by Cachon et al. (2007), who argue that studying volatility and measuring the bullwhip at the industry-level can ultimately help inform an individual firm's operational decisions with respect to procurement of materials, and with regard to acquiring labor and capacity. By studying the three 'intra' bullwhips at an industry level we also offer an individual firm an aggregate view of its broader industry, which enables that firm to benchmark itself against the industry at large.

As previously suggested, our work proceeds 'in search of' intra-industry bullwhips. The first of the 'intra' bullwhip component is the shipment bullwhip – it describes the variability in the industry's shipment (i.e., sales) stream relative to the stream of demand (i.e., orders received). Moving upstream within the industry, the second component is referred to as the manufacturing bullwhip – it measures

☆ Department of Operations and Information Systems, 1645 East Campus Center Drive, KDGB 107, Salt Lake City, UT 84112, United States.

* Corresponding author.
E-mail addresses: ming.jin@eccles.utah.edu (M. Jin), nicole.dehoratius@chicagobooth.edu (N. DeHoratius), glen.schmidt@eccles.utah.edu (G. Schmidt).

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the variability in the industry's manufacturing stream relative to its shipment stream. Next is the order bullwhip, defined as the variability in the stream of orders the industry places relative to the industry's manufacturing stream. Mathematically, the multiplication[1] of these three component bullwhips results in the conventional bullwhip measure. That is, the conventional bullwhip measure is the product of the industry's shipment, manufacturing, and order bullwhips.

Our results highlight differences between, and within industries regarding the three intra-industry bullwhip measures. For example, we find some industries exhibit a strong shipment smoothing effect (the shipment bullwhip measure is well below one, meaning shipments are much smoother than demands) whereas others exhibit a strong shipment bullwhip (shipments are substantially more variable than demands). While our data are neither extensive nor informative enough to definitively assign cause and effect, we make several observations regarding the differences in the industry characteristics. We find, for example, that industries who smooth in shipping often incur bullwhips upstream in manufacturing and/or ordering. However, industries that smooth in manufacturing tend to also smooth in ordering (i.e., orders occur in a smoother stream than manufacturing output). Our exploratory results can motivate future research seeking to formally tests plausible drivers of the observed difference in intra-industry bullwhips across industries. While we focus on the industry-level unit of analysis, other scholars can build off the results presented herein by attempting to replicate our analysis at less-aggregate levels (e.g., using a firm's division, a factory, a product category, or a product as the unit of analysis).

We also provide mangers with insight into the impact of their decisions regarding the bullwhip measurement time interval (here we focus on the conventional bullwhip measure). Our results are consistent with Chen and Lee (2012) who propose that time aggregation tends to dampen the bullwhip (i.e., when the bullwhip ratio is above one, time aggregation reduces it). Moreover, a new empirical finding is that time aggregation tends to amplify the bullwhip ratio in the presence of smoothing (pushing the bullwhip ratio upward, toward one). A related contribution of our work is to demonstrate the importance of properly setting the ending point for the time aggregation interval. For example, while many retailers use a January 31 quarterly end date, we show that an end date of December 31 may be more appropriate (we are not suggesting a change in the reporting period used for accounting purposes; rather we are suggesting a possible modification to the 'bullwhip reporting period').

In sum, our empirical observations provide further insight into the factors managers should take into account when determining their shipment schedules (which impact their shipment bullwhip), when setting their manufacturing plans (which impact their manufacturing bullwhip), and when establishing their order quantities (which impact their order bullwhip). While other researchers have studied some of the internal factors that might influence the inter-firm bullwhip, such as inventory stocking levels (e.g., Svensson, 2003) and manufacturing activities (e.g., Taylor, 1999), we demonstrate how the intra-industry bullwhips contribute to the inter-industry bullwhip.

The paper proceeds as follows. In §2 we explicitly show how the shipment, manufacturing, and order bullwhips contribute to the inter-industry (undecomposed) bullwhip measure. Next, in §3, as motivated by previous literature, we develop hypotheses regarding whether we expect each of the intra-industry bullwhips to be greater than or less than one (i.e., whether the bullwhip or smoothing predominates). We also hypothesize as to the effect of time aggregation and aggregation interval end point. We describe our dataset in §4, proceed to test our hypotheses in §5, and summarize the results in §6.

[1] We calculate bullwhips using the variance ratio method, which results in the multiplicative relationship. If bullwhips are instead calculated using the variance difference method (see for example Cachon et al., 2007 for further discussion), then the relationship is additive instead of multiplicative.

2. Bullwhip decomposition

To better understand the bullwhip effect in an industry and along the supply chain, we follow the framework of Jin et al. (2016a) in order to break down an industry's conventional inter-industry bullwhip measure into three intra-industry bullwhips. Fig. 1 characterizes how the variability in various information and material flow streams is either amplified or dampened.

Starting at the upper left of Fig. 1, an industry at any point in the supply chain (referred to as the focal industry) receives a demand stream that has variance denoted by V_D^F (the superscript F refers to the focal industry, while the subscript D denotes that this parameter is the variance in the demand stream). Industry F may choose not to (or may be unable to) fulfill demands immediately, so its shipment stream may not exactly match its demand stream ('demand stream' refers to the stream of orders received). The discrete order quantities from customers may differ from industry F's actual shipment quantities (an order may not be filled with exactly one shipment of exactly that quantity, and furthermore, the time between order and shipment may also vary). For example, the economy may suddenly strengthen, creating a surge in demand that industry F cannot immediately fill via manufacturing output and/or inventory. Thus the variance in industry F's shipment stream, denoted by V_S^F (the superscript again denoting industry F and the subscript S referring to the shipment stream), may differ from the variance in its demand stream, V_D^F. The variance ratio $\frac{V_S^F}{V_D^F}$ is the industry's *shipment bullwhip,* denoted by B_S^F. Note that the shipment bullwhip might indicate an amplification of the demand stream ($B_S^F = \frac{V_S^F}{V_D^F} > 1$) or a smoothing ($B_S^F < 1$). The shipment bullwhip (B_S^F) may be identically equal to one, but this exact outcome is virtually never observed so we focus on the two possible outcomes of amplification (i.e., a bullwhip) or smoothing.

If industry F holds finished goods (FG) inventory at any point in time, then its manufacturing output stream will not necessarily match its shipment stream. For example, demand may be seasonal, and even if demand is fully known in advance, industry F may find it optimal to smooth its output (overproduce and build up finished goods inventory in periods of slack demand and under-produce and ship from inventory in periods of high demand). If demand is uncertain, this further complicates industry F's decision making with regard to its manufacturing stream. Factors such as batch manufacturing may result in the manufacturing stream being further decoupled from the shipment stream. In other words, there may be a *manufacturing bullwhip* within the industry, defined as $B_M^F = \frac{V_M^F}{V_S^F}$, where V_M^F denotes the variance in the manufacturing stream. The manufacturing bullwhip recognizes the fact that the manufacturing stream may differ from the shipment stream. Again, the manufacturing bullwhip may indicate an amplification ($B_M^F > 1$) or smoothing ($B_M^F < 1$).

Similarly, it may not be optimal for industry F to order raw materials to exactly match its manufacturing stream (i.e., for its order stream to match its manufacturing stream). For example, an upstream industry's supply may be uncertain or it may offer end-of-quarter discounts or have other promotions due to a surplus in inventory. Factors such as these may make it optimal for industry F to alter its order stream as compared to the manufacturing stream. That is, it may be optimal for an industry to plan to hold raw materials inventory. The variance in the stream of orders that industry F places is denoted by V_O^F, and the *order bullwhip* is defined as $B_O^F = \frac{V_O^F}{V_M^F}$, where V_O^F denotes the variance in the order stream. Similar to the above discussion, the order bullwhip may indicate an amplification ($B_O^F > 1$) or a smoothing ($B_O^F < 1$).

As previously noted, Lee et al. (1997) effectively define the bullwhip as "order distortion." Accordingly, industry F's inter-industry, or "undecomposed", bullwhip ratio (denoted by B^F) is defined to be the variance in the orders industry F places with its suppliers (V_O^F) divided by the variance in the orders received by industry F from its customers