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# A novel time-varying bullwhip effect metric: An application to promotional sales

Juan R. Trapero*, Diego J. Pedregal

*University of Castilla-La Mancha, Department of Business Administration, Ciudad Real 13071, Spain*

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ABSTRACT

Bullwhip effect is a problem of paramount importance that reduces competitiveness of supply chains around the world. A significant effort is being devoted by both practitioners and academics to understand its causes and to reduce its pernicious consequences. Nevertheless, limited research has been carried out to analyse potential metrics to measure it, that typically are summarized in the coefficient of variation ratio of different echelons demand. This work proposes a new metric based on a time-varying extension of the aforementioned bullwhip effect metric by employing recursive estimation algorithms expressed in the State Space framework to provide at each single time period a real-time bullwhip effect estimate. In order to illustrate the results, a case study based on a serially linked supply chain of two echelons from the chemical industry is analysed. Particularly, this metric is employed to analyse the effect of promotional campaigns on the bullwhip effect on a real-time fashion. The results show that, effectively, the bullwhip effect is not constant along time, but interestingly, it is reduced during the promotional periods and it is bigger before and after the promotion takes place.

## 1. Introduction

The bullwhip effect refers to increasing variability of demand from downstream to upstream in the supply chain (Forrester, 1961; Geary et al., 2006). This effect produces an increase in holding costs, lost sales, low service levels, and a reduced productivity among other effects (Cannella et al., 2013). Despite the fact that the bullwhip effect is considered one of the main problems in Supply Chain Management, the literature about how to measure such an effect has received very limited attention (Fransoo and Wouters, 2000; Cannella et al., 2013).

In general terms, the alternatives to quantify the bullwhip effect can be summarized in two research streams. On the one hand, a theoretical expression may be achieved by assuming: (i) a forecasting technique that usually is either an exponential smoothing algorithm (Chen et al., 2000; Zhang, 2004) or autoregressive and moving average models (Duc et al., 2008); and (ii) a replenishment policy (commonly an order-up to level stock control). Dejonckheere et al. (2003) also proposed a frequency domain point of view, where engineering tools as the frequency response plot and the periodogram can be employed to determine the bullwhip effect without relying on any assumption regarding the distribution of demand. In addition, they provide different metrics as the Amplitude Ratio; the peak Amplitude Ratio; and the noise bandwidth. Regarding the structure of supply chains, Sucky (2009) considered a three-stage supply network consisting of two retailers, a single wholesaler, and a single manufacturer. This work concluded that the bullwhip effect is overestimated if risk pooling effects are present. On the other hand, an empirical approach to measure the bullwhip effect may be calculated as the ratio between the demand coefficient of variation and orders coefficient of variation for a determined echelon in the supply chain (Fransoo and Wouters, 2000). This approach does not need to know what are either the forecasting or stock policies employed and it is based solely on measured data. In that sense, let the bullwhip ratio (*BWR*) be defined as:

$$BWR = \frac{\sigma_o/\mu_o}{\sigma_d/\mu_d} \tag{1}$$

where $\sigma_o$ is the standard deviation of the orders signal and $\mu_o$ is its mean. Likewise, $\sigma_d$ and $\mu_d$ are the standard deviation and mean of the market demand signal, respectively. Assuming that the orders mean and demand mean are the same, some authors compute the bullwhip effect as the ratio of either standard deviations or variances (Dejonckheere et al., 2003; Trapero et al., 2012). Note that, although in an idealistic situation, empirical and theoretical values of the bullwhip effect should be the same, there have been several studies that show a considerable gap between them (Zotteri, 2013; Trapero et al., 2014), where other exogenous factors as the potential incentives to the sales force can play an important role. In other words, it is expected a lot of ad hoc reactions of practitioners when running an

* Corresponding author.
*E-mail addresses:* juanramon.trapero@uclm.es (J.R. Trapero), diego.pedregal@uclm.es (D.J. Pedregal).

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ordering operation which makes a difficult task to identify a consistent ordering scheme (Nielsen, 2013). Additionally, theoretical bullwhip expressions do not consider the modification of baseline forecasts, such as Single Exponential Smoothing, by means of judgemental forecasting (Trapero et al., 2011).

In order to bridge the gap between theoretical and empirical bullwhip values, a dynamic bullwhip metric capable of estimating the bullwhip effect at each single time period can be helpful to distinguish the causes of such a discrepancy. An important direct application is, for instance, promotional sales. Let us assume that a promotional period takes place and thus, the demand (orders) mean and standard deviation are expected to be time-varying (Blattberg et al., 1995; Trapero et al., 2015; Kourentzes and Petropoulos, 2016). Expression in (1) is not adequate since the statistics (either standard deviation or mean) are not constant. In other words, when the promotion is active a change of mean and standard deviation can happen, and when the promotion has been exhausted another change may occur. In order to understand how those price variations affect at the bullwhip effect a new empirical time-varying bullwhip metric should be defined. Recall that price variations as well as demand signal processing, rationing gaming, and order batching are the main causes for the bullwhip effect (Lee et al., 1997). Furthermore, if we are able to define a time-varying (local) bullwhip ratio metric, it would facilitate to distinguish which of the potential causes of the bullwhip effect is more significant. It should be noted that this new metric follows the suggestion pointed out by Fransoo and Wouters (2000), where a bullwhip measure should be capable of analyzing which parts of the overall effect are the results of the different causes.

The aim of this paper is twofold. Firstly, a time-varying bullwhip effect metric is provided by means of recursive algorithms as the Kalman Filter and the Fixed Interval Smoothing. Secondly, a case study with promotional sales periods will be assessed in order to illustrate the advantages of adopting a time-varying bullwhip effect metric.

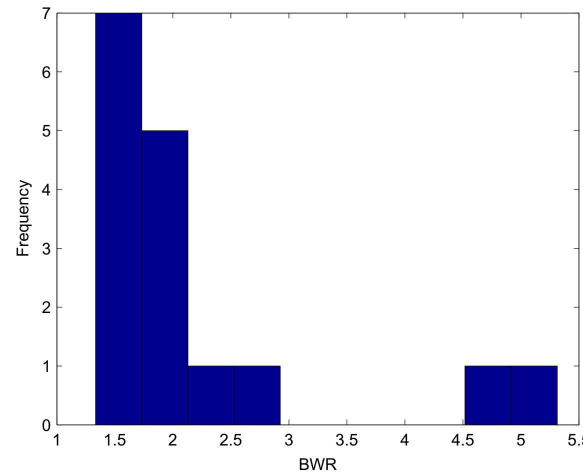


**Fig. 2.** Histogram of the bullwhip ratio.

This article is organized as follows: Section 2 introduces the case study and carries out an exploratory data analysis. Section 3 describes the new time-varying bullwhip metric. Section 4 verifies the usefulness of the proposed approach by comparing the results with the traditional metric for data at SKU level subject to promotional campaigns. Finally, main conclusions are drawn in Section 5.

## 2. Case study

The case study consists of a serially linked two-level supply chain. This supply chain comprises a flow of information from the market towards the manufacturer and a reverse one regarding materials.

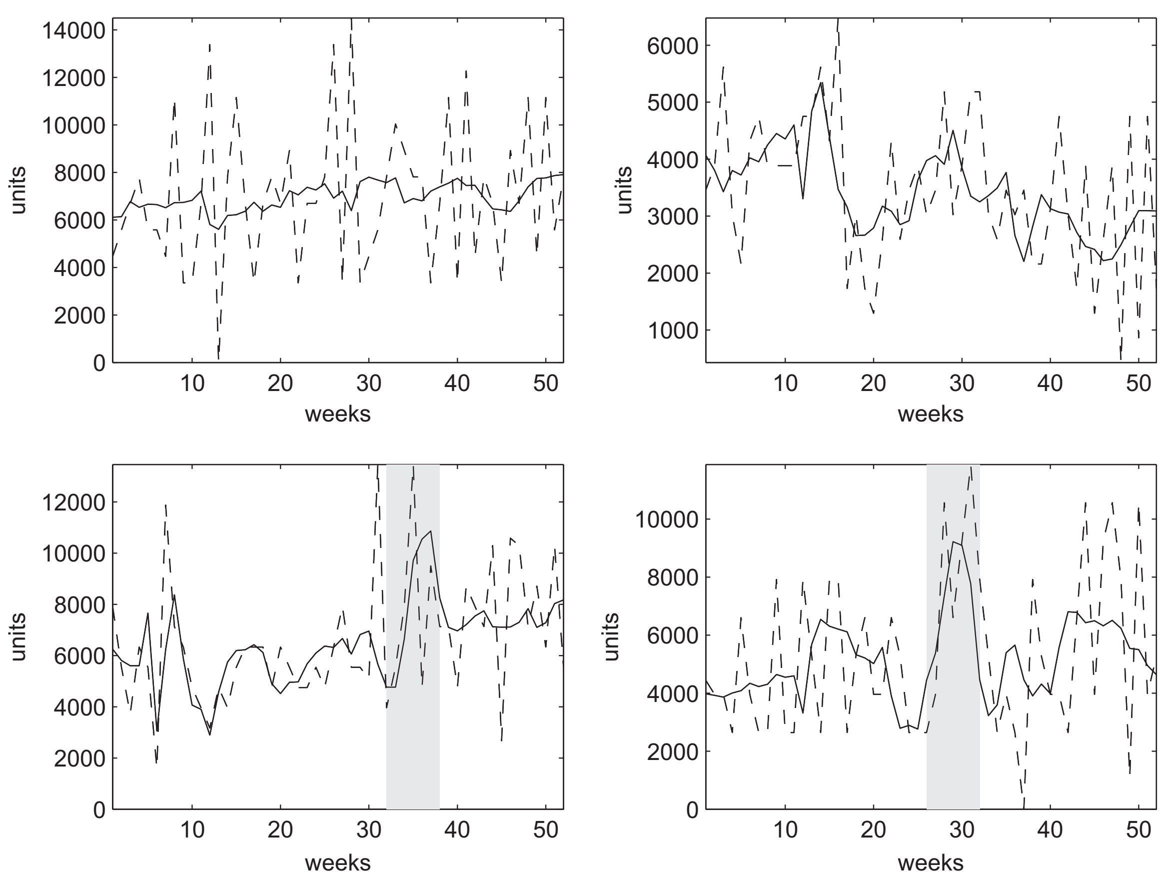


**Fig. 1.** Four SKU examples. Retailer sales are in a solid line and shipments in a dashed line. Promotional weeks are highlighted in a grey area.