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Layers and mechanisms: A new taxonomy for the Bullwhip Effect

Giovanni Miragliotta*

Politecnico di Milano, Department of Management, Economics and Industrial Engineering, Milano, Italy

Abstract

The Bullwhip Effect has a long research history: from the pioneering works of the 1960s to the most recent studies, many authors have tried to figure out the causes of this phenomenon and to propose management levers able to cope with it. It is quite interesting to observe that, even if analysed through an analytic approach, and therefore in a very objective way, there are heterogeneous interpretations of the causes, and also conflicting conclusions about the benefits of the recommended management levers.

The purpose of this paper is twofold. First, it aims at presenting an extensive literature review on the subject of the Bullwhip Effect, so as to consolidate present knowledge on the dynamics of a supply chain. Then, a new framework is presented to classify the causes of the Bullwhip Effect: this framework is innovative in that it introduces a twofold distinction between *layers* (physical, reconstructing and control levels) and *mechanisms* (determinants and triggers), whose interaction may lead to the Bullwhip Effect. Managers and researchers can benefit from this framework in order to classify, understand and explain the causes of this undesired behaviour, and to understand which interventions (on which mechanism and at which layer) could be more effective in reducing the variability amplification.
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1. Introduction

The Bullwhip Effect has become a well-acknowledged issue in Operations Management. Its roots can be traced back to the pioneering works of Simon (1952) and Forrester (1961), but its celebrity is certainly due to the Beer Distribution Game, or simply *Beer Game*, a role-playing simulation developed at MIT to illustrate the concepts of industrial dynamics. As described in Sterman (1984), the Beer Game concerns the material replenishment process of a stylised, 4-stage supply chain dealing with a step change in its finished product's demand. This game has been played by generations of managers and researchers worldwide and, from the early 1960s up to today (cf. Hieber and Hartel, 2003), it has never stopped to create excitement and to draw attention on this subject.

Many researchers have tried to measure and give evidence of the Bullwhip Effect (BE for brevity) in real life business environments, to find out what are the causes and to propose remedies. These three tasks have been quite successfully achieved, but

*Tel.: + 39 02 2399 2785; fax: + 39 02 2399 2700

E-mail address: giovanni.miragliotta@polimi.it.

there still are some aspects of this matter which are not properly defined and still lack a systematic appraisal.

Given this overview, the paper is arranged as follows. Section 2 will present a review of the literature about the BE, so as to depict the state-of-the-art knowledge about this subject. Section 3 will be devoted to highlight the weaknesses of the conceptual framework available to date; consequently, Sections 4 and 5 will try to overcome this by introducing and then applying a new taxonomy based on layers and mechanisms as new explaining factors for this phenomenon. Then, Section 6 will put forward some concluding remarks.

2. Literature review

The first academic description of the Bullwhip Effect is usually ascribed to Forrester (1961), whose pioneering work was later included in the classic production planning and control textbook by Buffa and Miller (1979). The same year, Burbidge (1961) presented a methodology for controlling production and inventory, which was inherently linked to the problem of demand amplification. Later, Burbidge (1984) was the first to provide a thorough definition of the BE: "if demand for products is transmitted along a series of inventories using stock control ordering, then demand variations will increase at each transfer". Actually, as emphasised by Towill (1997), the expression "demand variation" can be instanced in two distinct effects: the pure *demand variations amplification* effect, and the *rogue seasonality* effect, which refers to the absence of a stable seasonality pattern, with demand peaks and valleys alternating with no customer-driven periodicity.

Thus, in more general terms, the Bullwhip Effect can be defined as *a supply chain phenomenon revealed by a distortion (variability amplification and/or rogue seasonality) of the demand signal*[1] *as it is transmitted upstream, from retailers to suppliers.*

The literature concerning the BE can be divided into three streams: BE measurement and empirical assessment, causes of the BE and remedies for the BE. Over the last 40 years, many papers have been written using a wide range of research methodologies, as listed in Disney et al. (2004a). Although significant works of the past will be included, this review will be focused on papers published after

1990. These will be presented and discussed with the objective of depicting the research pattern of these years. By examining this review, the reader should be able to experience a "guided journey" through the available knowledge, so as to highlight which high-level evidences have been achieved, and to understand why a new taxonomy, as proposed in this paper, is needed.

2.1. Literature stream #1: measurement and empirical assessment of the Bullwhip Effect

The issue of measuring the Bullwhip Effect is of great importance, both for theoretical and empirical purposes. The *variance ratio* is by far the most widely used measure to detect the BE and is defined as the ratio between the demand variance at the downstream and at the upstream stages; when this ratio is greater than 1, then we have bullwhip at that stage. Some authors resort to the standard deviation ratio, but the differences are negligible, at least from a conceptual point of view. With respect to which data to observe to detect the BE, Taylor (1999) suggested analysis at both demand data (passed from company to company) and activity data (e.g. production orders registered within the company), in order to gain more insight on what is really happening.

These ratios, as can be argued by considering the reference section of this paper, are used by the vast majority of researchers and practitioners dealing with the issue of measuring the BE. Nevertheless, it is interesting to see which alternative metrics have been proposed, and with which purposes.

Edghill et al. (1988) proposed a model of the ordering process, later quoted by Towill (1992), which is useful to isolate the Forrester and the Burbidge effects. Similarly, El-Beheiry et al. (2004) introduced a modified variance ratio to isolate the batching effect from the observed amplification. These are among the few measurement procedures able to separate the effect of multiple factors causing a BE.

Intensive measures are sometimes used: for instance the seasonality coefficient in Metters (1997) or the coefficient of variation in Fransoo and Wouters (2000) and Dejonckheere et al. (2003). Nevertheless, extensive measures like the variance or the standard deviation are largely preferred because of their ability to monitor the scale of the phenomenon. Warburton (2004), for instance, used the ratio between the quantities ordered from

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[1]The demand signal is represented by the sequence of orders issued among the actors at the various stages of the supply chain.