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Returns and the bullwhip effect

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ABSTRACT

An almost universal assumption in the bullwhip effect modeling literature is that excess goods may be returned without restriction. We seek to determine if returns impact the level of bullwhip effect observed in a multi-stage supply chain. We build a hybrid agent/discrete-event simulation model of a supply chain and execute it under various conditions of demand variance, lead-time variance, information sharing, and return allowance. We find that permitting returns significantly increases the bullwhip effect. As a result, applying models that assume returns are permitted will systematically overestimate the bullwhip effect for supply chains that restrict returns.

1. Introduction

1.1. The bullwhip effect

We investigate the phenomenon of demand variance amplification, often referred to as the "Bullwhip Effect" (BWE). The bullwhip effect refers to a progressive increase in order (demand) variance as order information passes upstream in a supply chain, from the customer back to the supplier level. Essentially, orders placed by upstream supply chain nodes show increased variability as compared to orders placed by their downstream partners. The result is that orders from the customers may be relatively "flat" (exhibit low variation) but orders placed by nodes further upstream exhibit increasingly greater levels of variation such that at the furthest upstream nodes the orders may show significant variability. The increase in demand variance seen by the upper echelons has several negative implications including reduced service levels, large fluctuations in utilization levels, the need for greater safety stock to be held by stocking points, and greater production capacity needed by production points. The impacts of the bullwhip effect are not confined to production and inventory functions, as Haughton (2009) points out that the bullwhip effect increases capacity costs of transportation providers (carriers) and results in operational instability. Fig. 1 provides a graphic example of the bullwhip effect, showing the order quantities placed by five supply chain nodes over the same 20 time periods plotted side-by-side.

The work of Forrester (1958, 1961) is generally regarded as the first to explore demand variance amplification, although the term "bullwhip effect" was not used for another 20+ years. While Forrester's work may be thought of as the genesis of bullwhip effect research, some component ideas were discussed, but not as rigorously analyzed, over three decades beforehand with the recognition by Mitchell (1924) that "deception and illusion" due to "over-ordering" clouds the picture of what

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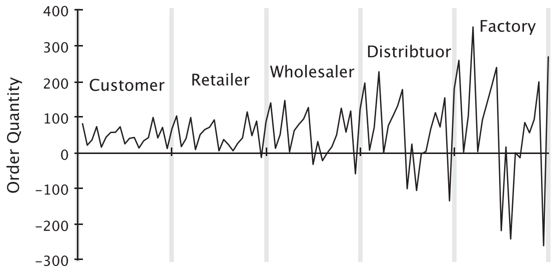

Fig. 1. Simple example of the bullwhip effect.

the real demand level is and results in boom and bust cycles. In the time since the work of Forrester there have been many studies of the bullwhip effect from a variety of perspectives utilizing several different methodologies.

1.2. Bullwhip effect modeling

There has been significant effort expended on modeling the BWE over the years, employing statistical, simulation, control engineering, and behavioral approaches, to name a few. In bullwhip effect studies it is common to refer to supply chain nodes with k, representing the level or echelon within the supply chain, starting with the far downstream node (customer) as $k = 0$ and incrementing to $k = 1$, $k = 2$, and so on upstream through the supply chain. These studies generally assess the bullwhip effect by comparing an upstream ($k > 0$) node's order variance with the customer ($k = 0$) demand variance, determining the total variance amplification defined as $TVAmp = s^2_{D,k}/s^2_{D,0}$. A significant increase in order variance ($TVAmp > 1.0$) indicates, by definition, the bullwhip effect.

Many bullwhip effect studies focus on developing two-stage models, representing a two-stage system sometimes referred to as a "node-pair" or a "single supply chain "link" (Kim and Springer (2008), p. 175). This system consists of a demand point (customer), a stocking point (retailer), and an outside supplier/manufacturer. The terms "two-stage" and "node-pair" are based on the fact that there are two nodes that place orders. The focus is on representing the interaction between the customer ($k = 0$) and the retailer ($k = 1$) and assessing the amplification of order variance, generally measured as $TVAmp = s^2_{D,1}/s^2_{D,0}$.

We point out the difference between a multi-stage model and modeling a multi-stage supply chain. We define a multi-stage model to be a supply chain model that represents multiple (more than two) stages of the supply chain simultaneously. This does not mean that a two-stage model cannot be used to analyze a multi-stage supply chain. Utilizing two-stage models to represent multi-stage supply chains generally involves breaking down (decomposing) the supply chain into a set of two-stage sub-systems (node-pairs) and serially reapplying the model to successive node-pairs, back through the supply chain. The advantage of a multi-stage model is that it is better positioned to represent and capture interactions that develop over multiple successive echelons, such as information passing several stages upstream in a supply chain. A recent study (Chatfield, forthcoming) suggests that decomposition of a multi-stage supply chain into a set of two-stage models systematically underestimates the bullwhip effect.

Several assumptions are commonly made to simplify analysis of the bullwhip effect. Modeling assumptions common in the bullwhip effect literature include the assumption that nodes may return goods, that the outside supplier will always have adequate stock and is capable of providing a 100% service level, that transportation providers will not experience capacity shortages or other delays, that the order lead-time is constant, and that decomposing a multi-stage supply chain into a set of two-stage sub-chains provides an adequate representation of the supply chain as a whole. Some work has been performed to explore the adequacy of a number of these assumptions, but the assumption of returnability has gone almost completely unquestioned.

1.3. Negative orders and returns

The assumption that orders may be negative in size is a modeling assumption that is essentially universal among the bullwhip effect literature. These negative orders are ostensibly equivalent to a return of excess goods and this assumption is often extended to cover unlimited and "costless" returns. We point out that our interest lies with this form of returns and not closed loop or reverse supply chains where a separate return path (ex. for recycling) is a defined part of the product life-cycle. We note that bullwhip effect research is underway in the context of closed-loop and reverse supply chains and direct the reader to works such as Zanoni et al. (2006), Zhou and Disney (2006), and Adenso-Diaz et al. (2012) for discussion of those situations. We point out that the allowance of negative orders does not match the inventory literature at large, but practically every available study of the bullwhip effect has made the assumption that such returns of excess stock are allowable and that these returns may occur without additional cost. An example is Lee et al. (1997a, p. 549), who state "to simplify analysis, we also assume excess inventory can be returned without cost". The allowance of returns has modeling advantages, particularly in that it improves tractability by eliminating truncated demand distributions, eliminates demand "lumpiness" that results from restricting returns.