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Learning, communication, and the bullwhip effect

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Abstract

We investigate the effect of learning and communication on the bullwhip effect in supply chains. Using the *beer distribution game* in a controlled laboratory setting, we test four behavioral hypotheses – bounded rationality, experiential learning, systems learning, and organizational learning – by systematically manipulating training and communication protocols. We find that order variability decreases significantly in a setting in which participants start with hands-on experience, and are then allowed to formulate team strategies collaboratively. This result indicates that while training may improve individuals' knowledge and understanding of the system, it does not improve supply chain performance unless supply chain partners are allowed to communicate and share this knowledge. Our results indicate that the bullwhip effect is, at least in part, caused by insufficient coordination between supply chain partners.

Keywords: Bullwhip effect; Supply chain management; Experiential learning; Systems learning; Organizational learning; Communication; Experimental economics

1. Introduction

Supply chain management is an example of a dynamic decision task that involves lagged feedbacks and multiple dependent decision makers. This task is known to be difficult for several reasons. According to Sterman (1989a), when decisions have indirect and delayed feedback effects decision makers find it difficult to control the dynamics. Moreover, multiple agents are involved in the process, whose performance depends on the quality of other supply chain members' decisions, and therefore is subject to coordination risk that may trigger instabilities in the system (Croson et al., 2005). One well-known inefficient outcome produced is the much studied *bullwhip effect*.

The bullwhip effect refers to the observation that the variability of orders in supply chains increases as one moves closer to the source of production. The effect is costly because it causes excessive inventories, unsatisfactory customer service, and uncertain production planning. According to Lee et al. (2004), several industry studies such as efficient consumer response (ECR) and efficient foodservice response (EFR), report the bullwhip effect as most harmful to the efficiency of a supply chain. The bullwhip phenomenon was first noted by Forrester (1958), and has since been observed in many diverse settings. For example, Hewlett-Packard found that orders placed to the printer division by resellers have much bigger fluctuations than customer demands, and the orders to the company's integrated circuit division have even worse swings (Lee et al., 1997). A wide range of industries, including computer memory chips (Fisher, 1994), grocery (Fuller et al., 1993), and gasoline (Sterman, 2000), has experienced similar symptoms.

Previous research on the bullwhip effect thus focuses on understanding of its causes and ways to alleviate it.

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Two categories of explanations have been advanced. Lee et al. (1997) identify four *operational* causes of the problem, including errors in demand signal processing, inventory rationing, order batching, and price variations, and recommend a number of operational strategies for dampening the effect.

The second category focuses on the *behavioral* causes of the effect. Behavioral causes are usually studied in the laboratory because it provides ways to eliminate operational causes, which is impossible to do in the field. The existence of the behavioral causes of the bullwhip effect has been demonstrated in a variety of laboratory settings and by many different researchers (see for example, Sterman, 1989a,b; Croson and Donohue, 2003, 2004; Croson et al., 2005). These studies consistently show that participants do not adequately account for the time delays in making ordering decisions, and specifically, they tend to underweight their *supply line*, orders placed but not yet received. Hence, the first behavioral explanation emphasizes the individuals' bounded rationality to control systems with lagged, indirect and nonlinear feedbacks (Sterman, 1989a). More recently, Croson et al. (2005) identifies another behavioral cause based on *coordination risk*, the uncertainty about the actions of other decision makers, and show that it often triggers instability.

The controlled environment of laboratory also enables us to explore and isolate the impact of *institutional or structural* changes to the supply chain on mitigating the bullwhip behavior. Innovations such as reducing ordering and shipping delays (Steckel et al., 2004), providing additional inventory information (Croson and Donohue, 2004), sharing point-of-sale information (Steckel et al., 2004; Croson and Donohue, 2003), and adding excess inventory to the system (Croson et al., 2005), all improve performance in the laboratory.

In this paper, we further delve into the causes of supply chain instability, and look at the problem of the bullwhip effect from an *organizational learning* (OL) perspective. The concept of OL was first introduced by Cangelosi and Dill (1965) and has dominated the management literature in the 80 and 90 s. The general consensus on theories developed in this area is that learning occurs at multiple levels (Crossan et al., 1995): *information* is processed and transformed into *insights* and innovative ideas by individuals first (Simon, 1991); then knowledge is shared and mutual understanding is developed among groups (Huber, 1991; Lant, 1992; Stata, 1989); and some individual or group learning further become institutionalized as organization artifacts (Crossan et al., 1999; Shrivastava, 1983).

Some recent research efforts have been made to apply the OL paradigm to supply chain management, recognizing its competitive advantage on improving supply chain relationships (Bessant et al., 2003; Hult et al., 2003; Preiss and Murray, 2005). In this study, we view the supply chain as an integrated organization and investigate the effect of learning on alleviating the bullwhip symptoms. More specifically, as the unifying framework by Boudreau et al. (2003) proposed to bring human resource management considerations into operations management context, we examine to what extent *training* and *communication* impact the local ordering decision-making process and the global learning and behavior of supply chain as an organization. To study this question we take advantage of the controlled laboratory setting.

We conduct the study within the context of the *beer distribution game*, a simulated serial supply chain with four links (see the next section for details). This game is popular in supply chain management classes and has also been used extensively in the experimental research we cite above. In order to increase control and provide the most rigorous test of the behavioral theories of the bullwhip effect, we modify the standard design in two ways for all of our experiments: (1) we use a stationary distribution for customer demand which eliminates all operational causes of the bullwhip effect, and (2) to facilitate individual decision-making, we *directly* display for each participant information about his own supply line (or *outstanding orders*), which has not been made visible in prior studies.

So as to examine the role of human activities on one's judgment in the simulated environment, we relax some traditional game protocols. First, instead of using participants with little or no experience, in some of the sessions we provide participants experiential training with the beer game to promote individual learning and counteract possible decision biases. One of our manipulations is how this extra hands-on experience is structured: in some of the treatments participants practise in a specific role assigned to them, which we call *role-specific training* since it allows participants role-constrained learning experience (March and Olsen, 1975). In other treatments participants practise in the role of central planners making decisions for all members in the supply chain, and we call this condition *system-wide training* since it permits *systems thinking* that directs attention to underlying systemic interrelationships (Checkland, 1981; Senge, 1990; Senge and Sterman, 1992; Jackson, 1995). We also include treatment without any training, as a benchmark. The second manipulation involves communication. In some