



## EXTENDED RESEARCH NOTE

# Supply Chain Inventory Replenishment: The Debiasing Effect of Declarative Knowledge

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## ABSTRACT

Previous experimental research demonstrates that inefficient replenishment decision making in the supply chain can be caused by specific judgment and decision biases. Based on the literature we use controlled experiments involving both student subjects and supply chain managers to test debiasing interventions that provide declarative knowledge, which is theorized to enhance the acquisition of procedural knowledge. We first investigate the effects of three debiasing components in a single-echelon setting: knowledge of bullwhip, inventory position (IP), and use of a target order-up-to quantity. Experiment 1 ( $N = 1,608$  decisions by 67 student subjects) using a  $2 \times 2 \times 2$  factorial design for the three components finds that the conceptual understanding of IP is salient for efficient replenishment decisions. We next examine the effects of the components in a simulated, multi-echelon, serial supply chain, which introduces the additional complexity of coordination risk. Experiment 2 ( $N = 3,072$  decisions by 128 student subjects) using a  $2 \times 2 \times 2$  factorial design finds that although subjects benefit from training components, there is evidence of cognitive overload with an increased quantity of information. Finally we test whether these debiasing components may be an effective training program for practicing supply chain managers who can be expected to have higher levels of procedural knowledge through experience gained in the field. Experiment 3 ( $N = 864$  decisions by 36 supply chain managers) using a  $2 \times 1$  design investigates the effects of an instructional training intervention which includes all three debiasing components and finds the intervention to reduce costs by 14%. We provide avenues for future research and successful practice. [Submitted: February 2010. Revised: June 13, 2011; September 12, 2011. Accepted: October 10, 2011.]

***Subject Areas: Debiasing, Experiment, Inventory, Replenishment, and Training.***

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## INTRODUCTION

Cost efficiency in a supply chain depends on replenishment decisions within a dynamic, interactive system. The quality of these decisions constitutes a primary issue for supply chain managers. As Zipkin (2000) points out, sound and careful inventory management has been critical to the strategic viability of firms such as Wal-Mart, Toyota, and Dell. There is theoretical rationale to believe that improved individual level decision making may lead to more efficient aggregate outcomes. Experimental studies such as Bolton and Katok (2008) and Wu and Katok (2006), described in more detail in later sections, have used simulated inventory replenishment games to study the effects of “experiential training” on replenishment decisions, but the effects of “instructional training” are yet to be assessed in the literature. These two forms of learning are defined as follows: Experiential learning is a process through which a learner constructs knowledge, skill, and value from direct experiences (Luckmann, 1996). Instructional training is the communication of information to explain how an action, behavior, method, or task is to be initiated, completed, conducted, or executed (Anderson, 1982). Experiential training potentially involves the learner developing an understanding of best practices related to a certain task based on their experiences while completing that task untutored. In contrast, instructional training involves the transfer of declarative knowledge from a subject matter expert to the learner.

As we will discuss in our literature review, theories of learning suggest that instructional training may help decision makers overcome judgment biases for a specific decision task. We conduct an experimental study to investigate whether there are debiasing interventions that might improve supply chain decision making. The research questions addressed in this article are the following:

- (i) Which debiasing components of instructional training impact cost efficiency in replenishment decision making?
- (ii) Which debiasing components of instructional training impact cost efficiency in replenishment decision making in a multi-echelon setting when coordination risk is an issue?
- (iii) Can debiasing interventions be incorporated into a training program that is effective at improving the replenishment decision making of professional supply chain managers?

In pursuit of these objectives, the article is organized as follows: in the next section, a review of the literature involving experimental studies of replenishment decision making is presented, as well as research on debiasing decision makers. The following section reports on the results of Study 1, which investigates potential debiasing components of an instructional training intervention. Next, the results of Study 2 are reported, in which the effects of the individual training components are examined in a multi-echelon decision setting that introduces the additional complexity of coordination risk. The following section reports the results of Study 3, which investigates the effectiveness of an instructional training program that incorporates the three debiasing components with practicing supply chain managers.

Finally, we summarize our findings and discuss the implications and potential avenues for future research.

## **LITERATURE REVIEW**

### **Inventory Replenishment Decisions**

Experimental research investigating inventory replenishment decision behavior in a simulated supply chain has revealed that participants underweight the supply line (failing to take inventory that is on order into account), which increases the order variance and amplification of the variance in the upper echelons of the supply chain (Sterman, 1989). This order variance amplification, called the bullwhip (BW) effect, is a known, although not sole, cause of inefficiency in the supply chain. Sterman identifies demand signal processing where an echelon uses previous orders from a downstream customer to forecast future demand and to adjust the order-up-to level as an operational cause of BW. Subsequent experimental research uses a discrete uniform distribution on  $[0,8]$ , known by the participants in the experiment, to control for all four operational causes of BW, which makes the case that observed BW is due solely to behavioral causes (Croson & Donohue, 2003, 2006). Coordination risk, which arises when others in the chain do not behave optimally, provides another behavioral cause of the BW effect, in that decision makers place excess orders to mitigate the risk of their orders going unfilled (Croson, Donohue, Katok, & Sterman, 2011).

### **Training and Inventory Replenishment Decisions**

System-wide experiential training, in which participants play every role in a training period before playing a single role as a member of a team, as well as role-specific training, in which they play the role they will take during the evaluation period, improves performance in the beer distribution game, but only when the participants may communicate (Wu & Katok, 2006). Repeated play of the beer distribution game (i.e., 20 consecutive games, each lasting for 52 periods) improves performance, although the improvement reaches a plateau after around the ninth repetition (Martin, Gonzalez, & Lebiere, 2004). Repeated play of the newsvendor game coupled with feedback also results in improved realized profits, but participants appear slow to make adjustments in their order quantity (Bolton & Katok, 2008). Orders placed at the end of the 100 periods of this game remain significantly different from the optimal order quantity.

### **Improving Decision Making**

#### ***Experience and expertise***

It appears unlikely that experience alone can cure documented judgment and decision biases. Bazerman (2002) explains that experience is repeated feedback (the primary feature of experiential training), whereas expertise is a person's strategic conceptualization of what constitutes the rational decision-making process, along with recognition of the biases that limit such rationality. Shanteau, Weiss, Thomas, and Pounds (2003) note that though experts may have considerable experience, those with experience may not be experts. Their use of the term "expertise" thus

implies reliably superior performance on representative tasks (Ericsson, 2006), which represents a consequence in Bazerman's definition. As Shanteau et al. (2003, p. 622) state, at best, experience is an uncertain indicator of degree of expertise. At worst, experience may reflect years on the job and little more.

There may however be a remedy for this bleak state of affairs. Fischhoff's (1982) recommendation for debiasing involves warning decision makers about the possibility of a bias and describing the direction of the bias. In designing the training intervention to improve replenishment decision making used in this research, the following suggestion is adopted; that is, subjects in the training condition receive warnings about the BW phenomenon and its resulting increased costs, as well as a description of judgment and decision biases that contribute to increased costs, whether directly or through BW. Subjects are also provided with a description of how to avoid these judgment and decision biases.

### ***Procedural knowledge, declarative knowledge, and the acquisition of skill***

Declarative knowledge (Anderson, 1993) is factual knowledge that people can report or describe. Procedural knowledge is knowledge necessary to complete a task, which consists of rules or steps needed for skilled performance, as can be manifested only in performance. The operational basis for this definition suggests knowledge can only be inferred from a person's behavior. Camerer (1981) and Anderson (1982, 1983, 1993) argue that people who possess declarative knowledge, which consists of the learning and retention of facts and definitions, can acquire procedural knowledge more readily. In particular, it seems that active (but not necessarily long-term) declarative representations are essential for procedural learning (Anderson, 1993; p. 24), because when people have declarative knowledge of the task domain before practicing the task and receiving feedback, they can better interpret that feedback, develop explanations, and make better decisions.

### ***Why is learning difficult in a supply chain replenishment setting?***

There are several reasons why replenishment decision making in the context of a serial supply chain may require expertise beyond experience. Hogarth (2001) offers the concept of a learning structure that varies along two dimensions: the quality of feedback (deemed relevant if it is speedy and accurate or irrelevant if it is noisy, delayed, or characterized by uncertainty), and the consequence of errors (exacting or lenient). Accurate learning can be facilitated by relevant feedback and increases in precision, from lenient to exacting conditions (i.e., because with good feedback, the cost of errors is apparent and judgment can be adapted accordingly). Thus, Hogarth describes relevant-exacting conditions as creating a "kind" learning environment. The opposite of this environment, Hogarth observes, is the one in which errors occur and the feedback is misleading (e.g., a lag of unknown duration between the action and outcome), and outcomes cannot be linked to specific actions undertaken by the decision maker. This, he characterizes, as a "wicked" learning environment. Thus, despite the serious consequences of mistakes, this structure is not conducive to learning by the decision makers.

The specific decision-making scenario investigated in this research belongs to this insidious category of irrelevant-exacting learning structures. Suboptimal replenishment decision affects not only the decision maker but also other agents making decisions within the system. These other agents in turn likely make suboptimal decisions due to the additional complexity of incomplete information and increasing uncertainty, because they do not know what other effects might cascade upstream or downstream. The single suboptimal decision thus compounds due to interactive factors, and the result is the phenomenon of order variance amplification. Feedback received by the decision maker is temporally far removed from any specific poor decision (due to the lag). Furthermore, the nature of the mistake is difficult to comprehend because of the complexity of the interactions and decisions by others that are largely invisible to the decision maker. Thus, in a supply chain replenishment decision-making scenario, the conditions are not conducive for learning from repeated feedback (i.e., experience) alone. Therefore, we investigate the effect of providing decision makers with declarative knowledge that may enhance their ability to acquire procedural knowledge.

Providing warning about decision biases identified in the behavioral operations literature and direction about how to avoid these biases may be expected to improve decision making. As the prior literature gives no guidance, any attempt to predict the direction of interaction effects when multiple training components are combined can only be purely speculative. Therefore, we do not present formal hypotheses beyond the research questions we list in the previous section.

## **STUDY 1: DEBIASING EFFECT OF INDIVIDUAL TRAINING COMPONENTS**

Fischhoff (1982), in his discussion of ways to debias decision makers, suggests warning subjects of the possibility of a bias and describing the direction of that bias, as well as providing training on how to avoid it. We identify three training components that might serve to eliminate three known biases from the literature that are detrimental to optimal inventory replenishment decision making. Previous research shows that decision makers placing replenishment orders will typically have a target inventory level based on judgment and will give consideration to their on-hand inventory (Sternan, 1989). To minimize cost, one should calculate an order-up-to level based on expected demand, the protection interval, and the costs of excess inventory versus a shortage. Orders in a given period should be placed for the difference between this order-up-to level and one's current inventory position (IP), which is the sum of on-hand and on-order inventory, less any backlogs. The training intervention used in this study was designed to move decision makers away from biased decision behavior toward optimal decision behavior.

First, subjects were warned about a decision bias associated with holding too much versus too little inventory. Subjects were instructed to set a target IP and place orders based on the difference between that target and the actual IP. The optimal service level from the newsvendor model, uniformly distributed demand, and the protection period suggest an optimal order-up-to level (OO) of 22 units.

**Table 1:** Treatment condition details for Studies 1 and 2.

Treatment Condition	Training Components Received			Experiment 1 Subjects	Experiment 2 Subjects
	BW	IP	OO		
1	1	1	1	8	16
2	0	1	1	8	16
3	1	1	0	8	16
4	0	1	0	9	16
5	1	0	1	8	16
6	0	0	1	9	16
7	1	0	0	9	16
8	0	0	0	8	16

Second, subjects were warned about underweighting the supply line (out-standing orders) and were shown how to account for not just on-hand inventory, but on-order inventory and backlog. This requires monitoring IP (on-hand plus on-order inventory, less backlogs).

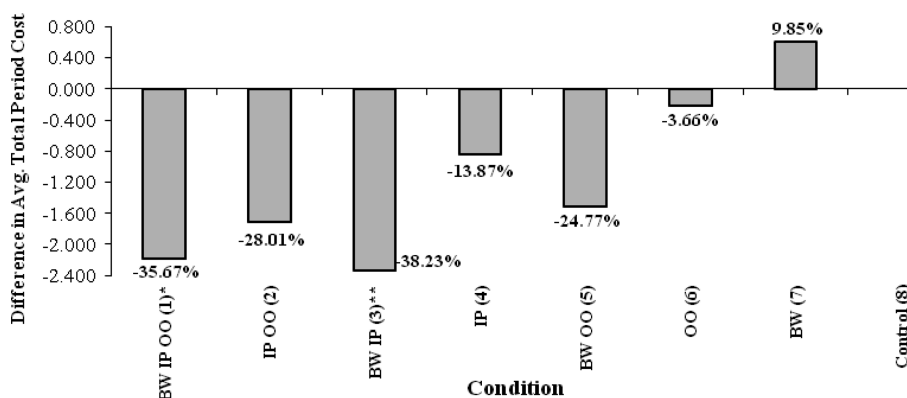
Third, subjects were warned about the BW effect, which commonly results from overreacting to period-to-period changes in demand. The range and distribution of demand at the consumer level are also highlighted so as to de-emphasize demand signal processing when demand is stationary. Armed with such knowledge, participants should be less likely to overreact to demand variation. Appendix A shows the instructions for the complete information condition.

**Method**

Study 1 involved the participation of 67 unique student subjects from two undergraduate business classes at a large university in the United States. The experiment was conducted in two sessions, which lasted approximately 90 minutes each. Subjects first watched a presentation about the mechanics of play of the beer distribution game (Forrester, 1958). A single echelon was used in conjunction with a U[0,8] demand distribution. Orders placed on a supplier offered unlimited and immediately available inventory, so subjects did not face supply shortages. The single-echelon experiment in Study 1 isolates the effects of the training interventions as in a multi-echelon setting; the performance of a given supply chain member depends on the performance of other members due to the interdependencies concerning supply and demand. By controlling for the effects of coordination (Croson et al., 2011) the impact of the various training interventions can be more clearly observed. Subjects received a handout containing two treatment-specific items: the training instructions and an accounting sheet on which to record their order decisions and records. Subjects were randomly assigned to one of eight debiasing treatment conditions as shown in Table 1 (coded 1/0 if training component is included/not included in condition).

Subjects received performance-based class points for participating in the study based on the formula  $b^i = 6[\max_i (c^i) - c^i]/[\max_i (c^i) - \min_i (c^i)]$ .

**Figure 1:** Study 1 difference in total period cost between treatment conditions and control condition.



\*Indicates difference from control significant at  $p < .10$ ; \*\*Indicates difference from control significant at  $p < .05$ .

## Analysis and Results

In Figure 1, the average difference in total period cost between each treatment condition and the control condition (Condition 8) is shown, using raw means for periods 13–36. Periods 1–12 were removed to allow for the sell through of the initial inventory settings. Pairwise comparisons obtained using a repeated measures general linear model (GLM) using SPSS statistical software with the condition as the between-subjects factor reveal a significant difference between the marginal means of the control condition and two of the treatment conditions, Condition 1 ( $p = .060$ ) and Condition 3 ( $p = .019$ ). These two conditions both include knowledge of BW and IP. The natural log of the dependent variable is used to mitigate heteroscedasticity. We also re-estimated the model (without the log transformation) using a Huber–White correction and found the same substantive results.

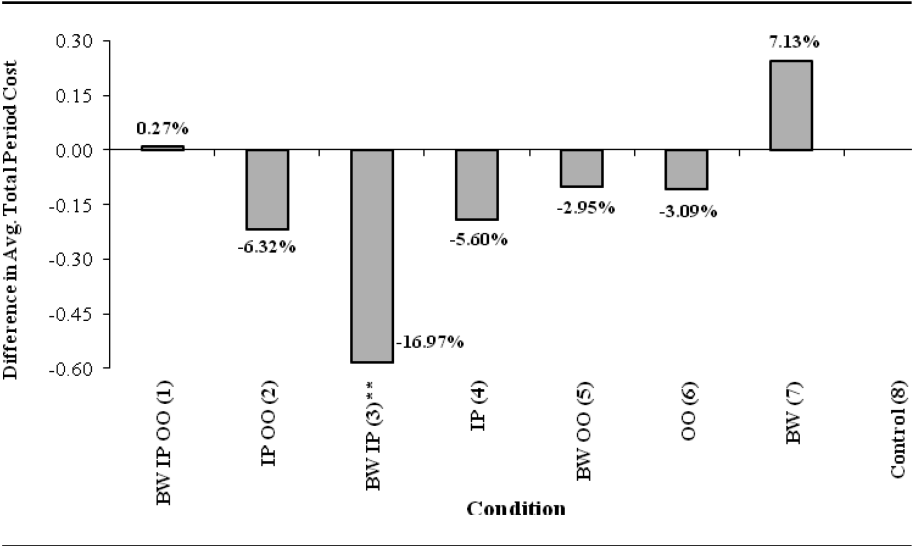
Another repeated-measures GLM, with BW, IP, and OO as between-subjects factors, indicates a significant main effect of IP ( $F(1, 59) = 6.249, p = .015$ ) and a marginally significant main effect of BW ( $F(1, 59) = 3.290, p = .075$ ). The main effect of OO and the interactions of the three training components are not significant.

Univariate tests of the within-subjects effects show no significant effect of the period of game play. After applying a Greenhouse–Geisser adjustment to account for nonsphericity, the  $F$ -test returned nonsignificant ( $F(7.54, 445.12) = 1.252, p = .190$ ). Similarly, the adjusted test for the interaction between period and condition was nonsignificant ( $F(52.81, 445.12) = .892, p = .688$ ). Based on these results, it is concluded that there was no learning over time in the game.

## STUDY 2: TRAINING COMPONENTS IN A MULTI-ECHELON SETTING

Study 2 examines the efficacy of the training intervention in a multi-echelon setting. In this setting even if a trained subject were to use information correctly, he or

**Figure 2:** Study 2 difference in total period cost between treatment conditions and control condition.



\*\*Indicates difference from control significant at  $p < .05$

she might still incur high costs if upstream and downstream partners make poor decisions. Study 2 included eight distinct conditions involving permutations of the three previously employed instructional training components (Table 1). Appendix B shows the instructions for the complete information condition.

**Method**

Subjects included 128 students recruited from undergraduate business classes at a large university in the United States. In total, five experiment sessions were conducted, each lasting approximately 2 hours. Each supply chain consisted of four serial echelons. Table 1 provides detail of the eight conditions in the experiment and the number of subjects in each.

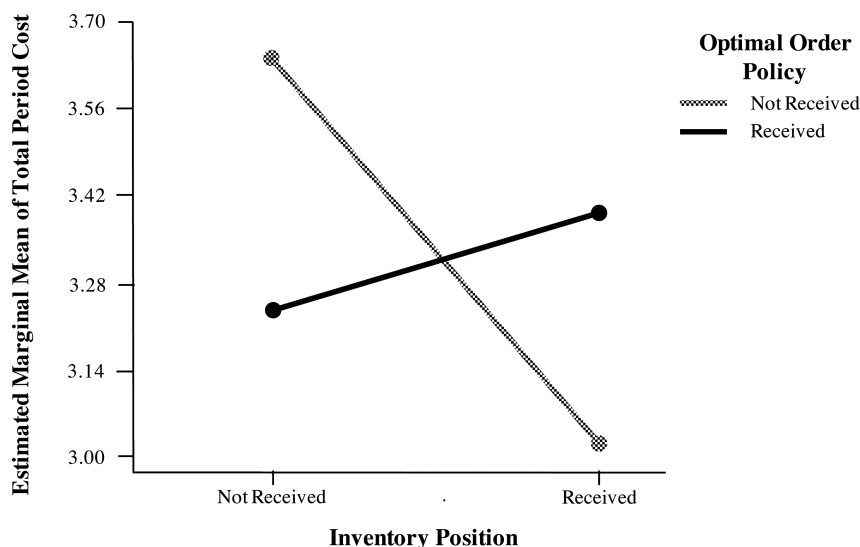
Subjects first saw a presentation on the mechanics of the beer distribution game following the game protocol employed by Croson and Donohue (2003, 2006), including the use of a  $U[0,8]$  pattern of consumer demand that is announced and explained to all subjects. They were then given a handout containing treatment-specific training instructions and a record sheet for their order decisions. Subjects were offered a base incentive of \$40 and the opportunity to earn a bonus of up to \$40 more based on the total cost incurred by their supply chain relative to other supply chains in the session. The bonus for each subject in supply chain  $i$  based on the total cost of the supply chain in the game  $c^i$ , was computed using the formula  $b^i = 40[\max_i (c^i) - c^i]/[\max_i (c^i) - \min_i (c^i)]$ . The average payment to each subject was \$64.39.

**Analysis and Results**

Figure 2 displays the average difference in total period cost between each treatment condition and the control condition (Condition 8) for periods 13–36 in the game.



**Figure 3:** Inventory position and optimal order policy interaction effect for Study 2.



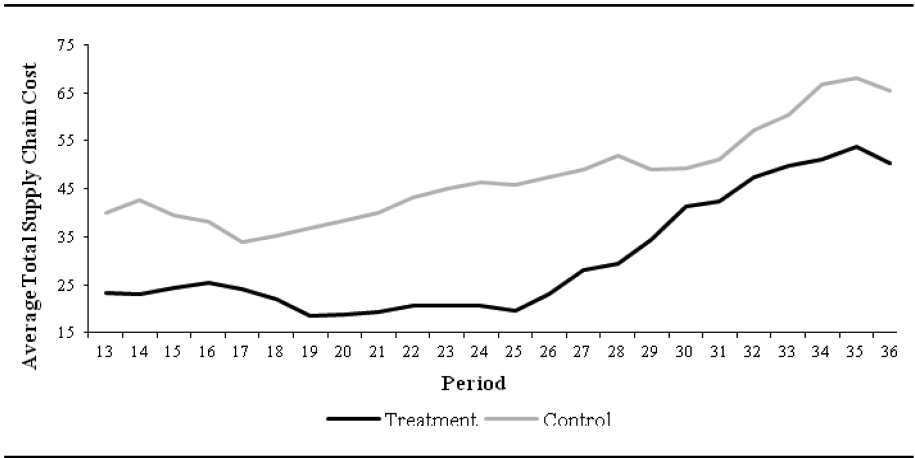
As in Study 1, periods 1–12 were removed to allow for the sell-through of the initial inventory settings. Pairwise comparisons were obtained using a repeated measures GLM with the treatment condition as the between-subjects factor. A natural logarithmic transformation of total cost was used as the dependent variable to account for the inequality of error variances across repeated measures. Results of the *post hoc* contrasts show a significant difference between Condition 3 and the control condition ( $p = .033$ ). Those who were trained concerning BW and IP incurred lower total cost each period than those who were not trained. One substantive difference from Study 1 is that those who received all three training components did not perform better than the control condition.

A second repeated measures GLM was used to investigate the impact of the three training interventions on total supply chain cost per period. BW, IP, and OO are used as between-subjects factors in a full factorial model. Results show a two-way interaction between  $IP \times OO$  ( $F(1, 24) = 4.037, p = .056$ ), which is illustrated in Figure 3. Those who did not know how to compute OO were better able to use knowledge of IP than those who knew how to compute OO—a seemingly surprising finding. We also reran the model with period as a within subjects factor and found that it was not significant, suggesting there was no learning over time.

### STUDY 3: DEBIASING EFFECT OF INSTRUCTIONAL TRAINING

Study 3 tests the efficacy of instructional training with practicing supply chain managers as opposed to undergraduate students. Although there is evidence that data collected from students is representative of practitioners (e.g., Remus, 1986;

**Figure 4:** Average total supply chain cost per period for Study 3.



Bolton, Ockenfels, & Thonemann, 2010), the evidence suggests that specific context can impact generalizability (Peterson, 2006).

**Method**

Study 3 was conducted with 36 supply chain managers from a large U.S. retail firm. The study was conducted at their corporate headquarters and used the beer distribution game. To begin the experiment, subjects watched a presentation describing the mechanics of the beer distribution game. The game protocol employed by Croson and Donohue (2003, 2006) was followed in the experiment, just as in Study 2. After receiving game play instructions, 20 subjects were randomly assigned to a treatment condition. These subjects were then taken to a separate room where they were given a second presentation incorporating the same three training components (BW, IP, and OO) described in the previous section (Appendix C).

It should be noted that a major difference between the method used in Studies 1 and 2, and the method used in Study 3, is that the first two provided the treatment information via written instructions and the third via a presentation. Although this diminishes the ability to make direct comparisons between the three studies, it does not impede the ability to assess the impact of the individual training components incorporated into a training program, ultimately the focus of this study. Play of the game lasted 36 periods for both treatment and control conditions, but subjects were told that it could go as long as 50 periods, to avoid end-of-game behavior.

**Analysis and Results**

A repeated measures GLM was used to test the effects of training on total costs incurred per period by the supply chain. The treatment condition served as the between-subjects factor and period of game play was used as a within-subjects factor. Periods 1–12 were removed to allow for the sell through of the initial inventory settings. Thus, the factor Period contained 24 levels as periods 13–36 were used to assess the effect of training on cost. Figure 4 presents the average cost per period by the treatment and control conditions.

Levene's test of equality of error variances of the dependent variable across repeated measures was significant ( $p < .05$ ) for several periods. After taking a natural logarithmic transformation of the dependent variable, the number of periods with a significant  $p$ -value was reduced to 1. Therefore the transformed dependent variable was used in the analysis.

The between-subjects effect of the training intervention was statistically significant ( $F(1, 7) = 6.693, p = .036$ ). The marginal means of the transformed dependent variable indicate that total period cost was lower for subjects in the trained condition (3.197) than for the control group (3.733), representing an average cost reduction of 14.36%. We conducted a univariate test for the within-subjects effect of period, applying the Huynh–Feldt correction for nonsphericity ( $F(2.49, 17.46) = 1.415, p = .272$ ). Similarly, a test of the interaction between period and treatment condition was not significant ( $F(2.49, 17.46) = .213, p = .854$ ); in conjunction these two analyses reveal no evidence of learning over time.

## GENERAL DISCUSSION AND CONCLUSIONS

Previous research has shown that experiential training alone has limited impact on performance in an inventory management task domain, which is consistent with general results from the judgment and decision-making literature. Insights from that literature suggest that the provision of declarative knowledge through instructional training before commencing a task will enhance the acquisition of procedural knowledge necessary for better performance. Overall, evidence was found of the effectiveness of instructional training in all three studies. In Study 1, knowledge of how to compute IP was isolated as the critical ingredient in the training. In Study 2, further support was found for this conclusion, although there was also evidence that too much information in a complex setting can be detrimental to performance. In Study 3, we confirmed that declarative knowledge incorporated into training programs can benefit even experienced supply chain managers.

### Single-Echelon Findings

Results from Study 1, the single-echelon experiment, seem to indicate that knowledge of computing IP is a key component of training—debiasing decision makers and resulting in efficient decision making. Although it was initially surprising to find that neither of the other training components nor any of their interactions was significant, there are explanations for this finding. If decision makers know how to compute the OO but not how to compute IP, then they will not truly know how to implement the optimal policy. The OO policy can only be implemented using IP, because the goal of the policy is to place orders such that IP is made equal to the order-up-to level each period.

For decision makers that only know about BW, poor performance may have been the result of attempts to maintain an even ordering pattern when really they should have been aiming to maintain an even IP. In effect, keeping orders constant will eventually result in overreaction, resulting in either the need to order nothing or to order a large amount. In addition, lack of significant findings with regard to training on BW may have resulted from the fact that when an order-up-to method

is employed, the amount ordered is equal to the amount taken from inventory each period. This leads to the variance of orders being equal to the variance in demand, resulting in no BW. Training on BW, however, may serve to alleviate behavioral tendencies to depart from the OO method.

### Multi-Echelon Findings

One limitation of the research is the use of student subjects for Studies 1 and 2 and industry professionals for Study 3, which hinders direct comparisons. Study 3 demonstrated stronger results than Study 2, and the training consisting of all three components was effective in Study 3 but not in Study 2. This may be the result of participants' *a priori* understanding of supply chain concepts. Although many of the undergraduate students had some exposure to supply chain topics, it is possible the professionals were better able to process and to use the instructional training because they possessed a greater degree of familiarity and exposure.

This discrepancy has other possible explanations. First, because subjects in Study 3 were all supply chain managers in the same company, it is possible that they were able to enjoy lower coordination risk (Croson et al., 2011) than those of Study 2 who were unacquainted students. Because these were managers from the same company in the same functional area, they were less uncertain about behavior of the other members of the supply chain. When subjects are professionals and are known to have some prior experience in the general task domain, the perception of coordination risk may be lower.

Further, the interaction plot from Study 2 suggests that subjects might have been unable to cognitively process the written information provided to them in the laboratory. That is, knowing about BW, IP, and OO may give the subject more information than they can effectively use. Anderson (1993) argues that only a limited number of components of declarative information can be combined in a single data structure that is represented in working memory. It is possible that the presentation is a more effective means of conveying information than the written instructions.

From a theoretical standpoint therefore, we hope that future researchers will be motivated to further investigate how and why instructional training impacts replenishment decision performance. It is possible to speculate that one benefit from training is that it provides a warning about the "wicked" learning environment (to use the terminology from Hogarth, 2001) so that decision makers are aware that they will *not* receive quick feedback that they may accurately associate with their recent actions. The IP and the BW training components may provide this warning by making salient the lags in the process and warning against coordination risk, respectively. Based on the prior literature, some of the primary causes for cost inefficiencies in inventory replenishment are behavioral. Therefore, it is necessary for future researchers to gain a deeper understanding of the precise psychological mechanisms that drive behavior (information cues, judgment biases, decision heuristics, motivations for compliance with known optimal recommendations, etc.). It is also hoped that they will take insights from these controlled laboratory studies into naturalistic decision settings, enabling the design of better real world training interventions.

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## APPENDIX A: TRAINING INTERVENTION FOR SUBJECTS IN STUDY 1, CONDITION 1

### Instructions

For a fun and efficient game, it is important that you understand the following directions thoroughly. If you have any questions, please raise your hand.

### Overview

- You are going to play the role of a retailer (and so is everyone else in the room).
- The chips on the board represent cases of beer (nonalcoholic, of course).
- The cards show consumer demand for each period. Do NOT browse through the cards. Only look at a card as directed.
- Assume that we will play the game for 40 periods.

### Process

- You will take chips out of your inventory (the big box on your left) each period based upon consumer demand.
- You can order as much as you want because the brewery has unlimited supply.
- There are two periods of order processing lead-time and two periods of transportation lead-time between you and the brewery.

- Because new inventory is not received until the end of a period, **orders placed in a given period (X) will not be available for use until period X + 5.** (Example: Orders placed in Period 1 will not be available to satisfy consumer demand until Period 6.)

### ***Objectives***

- The objective is to minimize the total cost your supply chain incurs.
- Inventory, backlogs, and orders are recorded at the end of each period.
- Inventory holding costs are \$0.50 per case per period based on ending inventory.
- Backlogs are \$1.00 per case per period.

### ***Bullwhip***

- This game is often used to illustrate a common problem in supply chains known as the bullwhip effect. The bullwhip effect is characterized by the amplification of order variance (changes in order size) from one supply chain partner to the next.
- The bullwhip effect is a serious problem because it leads to long periods of stock outs followed by a tremendous build-up of excessive inventory. In both cases, high costs are incurred.
- One of the causes of the bullwhip effect is the tendency of people to overreact to the period-to-period changes in the demand they experience. Try to keep this in mind while placing orders.

### ***Game play***

Each period of the game, the following five (5) steps will be repeated in sequence.

Step 1. Look at demand for the period and remove that amount from inventory.

- In this step, you look at consumer demand for the period (found on the cards) and remove that amount from your inventory. Those chips can be piled up somewhere off the board.
- If you do not have enough inventory to meet demand, you must try to make up for it in a future period. You will therefore need to record a backlog, which will be discussed in Step 3.

Step 2. Get the order ready at the Brewery.

- Pull up the post-it note in the box marked “Outstanding Order,” look at the amount written on it, and count out the appropriate number of chips from the Brewery’s stock (NOT from your inventory).
- Place these chips off to the side of the board. A good place would be directly behind the box marked “Inventory in Transit 1.”

Note: If an order for zero (0) units is received, crumple up an old post-it and use it to represent that shipment.

Step 3. Move post-it and place a new order.

- Move the post-it note in the box marked “New Order” to the empty “Out-standing Order” box.
- Write a new order on a fresh post-it note and place it in the empty “New Order” box.

### ***Inventory position***

- A common problem people have when making a replenishment (reorder) decision is that they do not adequately consider orders that have been placed, but not yet received (outstanding orders).
- One way to correct for this is to consider your inventory position, not just what you have on-hand, before placing an order. To calculate your inventory position (IP), add together your on-hand inventory and all outstanding orders, then subtract out any backlog you have.

$$IP = \text{On-hand} + \text{On-order} - \text{Backlog}$$

- Your on-order inventory can be quickly calculated by adding together the orders you placed in the previous four (4) periods.

### ***Optimal order***

- In the game you are about to play, there is a way to calculate the optimal order for any given period. To do so, simply subtract your current inventory position from 22 and order that amount.

$$\text{Optimal Order} = 22 - \text{Inventory Position}$$

- If you get a negative number (your inventory position is greater than 22) simply order 0 (zero) for that period.
- Please note that this formula will *not* prevent you from experiencing backlogs. However, it does achieve the optimal balance between inventory holding costs and backlog costs, thereby minimizing long-run total cost.

Note: When deciding on how much to order, please be aware of the following:

- Consumer demand (on the cards) will range between 0 and 8 and all values in that range are equally likely to occur.
  - *It's as if you were spinning a wheel with the numbers 0 through 8 on it.*
- You can order any amount you like. There is no minimum or maximum. However, you cannot order a negative amount (i.e., give inventory back).
- Should you wish to order nothing (zero) in a given period, simply write “0” on a post-it and place it in the new order box as you would a regular order.
  - Do NOT simply refrain from placing a post-it note in the New Order box for that period. Doing so will disrupt the flow of your game.

Step 4. Fill out your record sheet.

- Count up the number of chips you have left in your inventory box and record that amount under “Inventory.”



- Record the amount of the new order you just placed in the previous step.
- Record any backlogs you have (see backlog tutorial on next page).

***Be sure to ask if you have a question about filling out your record sheet***

Step 5. Move shipments from the brewery and receive new inventory.

- Take the chips in the box marked “Inventory in Transit 2” and move them in to your large, blue “Inventory” box.
- Take the chips in the box marked “Inventory in Transit 1” and move them in to the box marked “Inventory in Transit 2.”
- Take the chips from the Brewery (the ones placed off to the side of the board in Step 2) and move them in to the box marked “Inventory in Transit 1.”

***Starting quantities***

- Everyone begins the game with 12 units in inventory, two outstanding orders for 4 units each, and two incoming shipments of 4 units each.

**APPENDIX B: TRAINING INTERVENTION FOR STUDY 2,  
CONDITION 1**

Note: This intervention was given to retailers, wholesalers, and distributors in Condition 1. For those in the factory echelon, all references to lead-time were changed to 3 periods, protection interval to 4 periods, and optimal order-up-to level to 18 periods.

**Instructions**

***Bullwhip***

This game is often used to illustrate a common problem in supply chains known as the bullwhip effect. The bullwhip effect is characterized by the amplification of order variance (changes in order size) from one supply chain partner to the next. Consider the following illustration from a recent journal article (Lee, Padmanabhan, & Whang, 1997).

Not long ago, logistics executives at Procter & Gamble (P&G) examined the order patterns for one of their best-selling products, Pampers. Its sales at retail stores were fluctuating, but the variabilities were certainly not excessive. However, as they examined the distributors' orders, the executives were surprised by the degree of variability. When they looked at P&G's orders of materials to their suppliers, such as 3M, they discovered that the swings were even greater. At first glance, the variabilities did not make sense. Whereas the consumers, in this case, the babies, consumed diapers at a steady rate, the demand order variabilities in the supply chain were amplified as they moved up the supply chain. P&G called this phenomenon the “bullwhip” effect.

The bullwhip effect is a serious problem because it leads to long periods of stock outs followed by a build-up of excessive inventory. Each time there is a

stockout, firms incur backlog costs, and when there is excess inventory they incur holding costs—therefore, bullwhip is associated with increased costs.

One of the causes of the BW effect is the tendency of people to overreact to the period-to-period changes in the demand they experience. To illustrate, when one receives an increased order from their customer, they might take this as a signal that they will receive increased orders in the future, and then start placing increased orders themselves. This phenomenon is propagated up the supply chain, leading to a buildup in inventory. Later, when that customer has a large quantity of inventory on hand, they may stop placing orders to bring down their inventory levels. This in turn causes one to stop placing orders, and so on up the supply chain. This holds until eventually inventory is taken out of the system (consumed at the retail level), at which time the retailer begins placing orders again. Throughout the supply chain, this causes a period of numerous backlogs as all echelons begin to increase their order sizes. Thus the cycle repeats itself. Try to keep this in mind when making a replenishment (reorder) decision.

### ***Inventory position***

A common problem people have when making a replenishment (reorder) decision is a tendency not to factor in their outstanding orders, (i.e., orders that have been placed but not yet received).

One way to correct for this is to consider your *inventory position* before placing an order. Inventory position (IP) considers more than just current on-hand inventory. To calculate IP, use the following formula:  $IP = \text{On-hand} + \text{On-order} - \text{Backlog}$ .

- On-hand is the inventory you currently have in-stock.
- On-order inventory is the stock you have ordered but have not received yet. It can be quickly calculated by adding together the orders you placed in the previous four periods.
- Backlog is any past demand that you were unable to fulfill yet.

### ***Optimal order***

In the game you are about to play, calculating the optimal order for any given period requires the use of a specific *order-up-to amount*.

***What is an order-up-to amount?*** An order-up-to amount is the desired inventory position that one would like to maintain. When used for making a replenishment (reorder) decision, one orders the amount needed to bring current inventory position up to the desired inventory position (i.e., the order-up-to amount).

***How is the optimal order-up-to amount determined?*** The optimal order-up-to amount is set such that one maintains an IP that balances the cost of holding inventory with the cost of incurring a backlog. If one sets a very high order-up-to amount, backlog costs will rarely be incurred, but inventory-carrying costs will be excessively high. On the other hand, if the order up-to level is set very low, inventory-carrying costs will be very low as well, but backlogs will pile up and excessive backlog costs will be incurred. Use of the optimal order-up-to amount keeps one from holding too much inventory, but also from incurring too many backlogs.

### ***Balancing costs***

Given that we know inventory-carrying costs are \$0.50 per unit per period and backlog costs are \$1.00 per unit per period, we can find the *service level* that balances these costs. The service level is the percentage of time that all demand in a given period is met. Using these cost figures, the optimal service level is 67%. This means that to balance inventory holding costs and backlog costs, one should set an order-up-to level such that period demand is fully met 67% of the time.

To put it another way, one should set an order-up-to level such that in two of three periods, all of their demand is met and in one of three periods, they should expect to incur backlogs.

### ***Meeting demand***

Once the service level is determined, the question becomes one of finding the inventory position that is needed to provide that service level. This is answered by considering the average demand that one experiences during the *protection interval*. The average demand per period in this game is 4 units. The protection interval is the amount of time between when one places an order and when that order is received and available to help satisfy demand. Think of it this way: if one was to encounter a shortage of inventory and placed a large order to help address that issue, how long would it take before that “help” arrived? The answer is the length of one’s protection interval. The protection interval consists of the lead-time one faces plus the review interval.

- Lead-time: The number of periods of delay between when an order is placed and when it is received. In this game, the lead-time is four periods.
- Review interval: The number of periods between when two successive orders are placed. In this game, the review interval is one period.

As one can see, the protection interval in this game is  $4 + 1 = 5$  periods.

So the optimal order-up-to level must be set such that a sufficient inventory position is maintained to achieve the optimal service level while facing an average demand of 4 units per period during the protection interval. However, there is one last component that must be considered—the variance of demand.

The variance of demand is a measure of how spread out demand tends to be. The higher the variance, the more dispersed the demand, making it more difficult to accurately predict and plan.

Consider the following: if demand is exactly the same every period in this game (i.e., there is no variance), then planning to meet that demand will be very easy. One could hold no inventory yet never incur a backlog by simply ordering the amount of demand incurred each period. However, as demand is not the same for each period in this game, we must hold enough inventory to meet the best possible estimate of what it will be (the average), plus some extra to account for the uncertainty created by the variance.

***Using optimal order-up-to quantity.*** When the optimal order-up-to level is used to determine orders each period, one maintains an inventory position high enough to achieve the optimal service level over the protection interval. In doing

so, one minimizes long run total cost. In this game, the optimal order-up-to level is 22 units. Therefore, you should use the following formula to determine orders:

$$\text{Order} = 22 - (\text{Current inventory position})$$

Notes:

- In a situation where inventory position is greater than 22, order 0 (zero) units for that period.
- Remember that this formula will not prevent one from experiencing backlogs. However it does achieve the optimal balance between inventory holding costs and backlog costs, thereby minimizing long-run total cost.

## APPENDIX C: TRAINING INTERVENTION FOR STUDY 3

### Overview

- ◆ Production and distribution of beer on a game board
- ◆ Each team has four echelons: retailer, wholesaler, distributor and factory
- ◆ Small red chips represent cases of beer, poker chips represent 10 cases
- ◆ The cards show consumer demand for the period and only the retailer gets to see them

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### Process

- ◆ Retailer takes chips out of inventory based upon consumer demand
- ◆ Retailer orders from the wholesaler, who ships out of inventory based on the orders
- ◆ This continues at each echelon
- ◆ There are two periods of order delay and two periods of shipping delay
  - **Total lead time is at least four periods**

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### Objective

- ◆ The objective is to minimize the total cost your supply chain incurs
- ◆ Inventory, backlogs, and orders are recorded at the end of each period
- ◆ Inventory holding costs are \$0.50 per case per period based on ending inventory
- ◆ Backlogs are \$1.00 per case per period

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### The Bullwhip Effect

- ◆ The Beer Game is a tool often used to illustrate the bullwhip effect
- ◆ Bullwhip Effect – amplification of order variation as orders get passed up the supply chain

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### Key Problem

- ◆ Overreacting to Changes in Demand

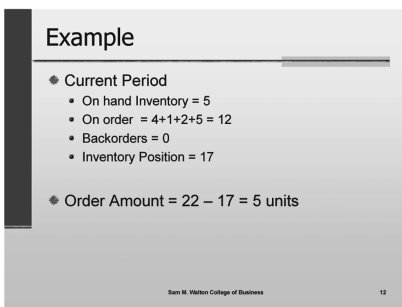
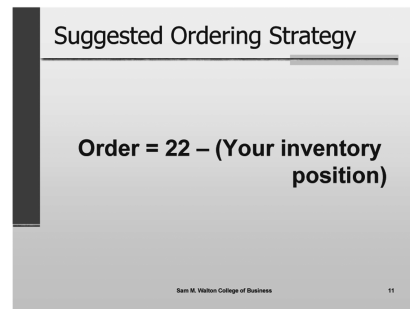
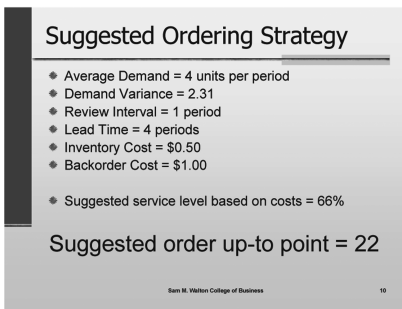
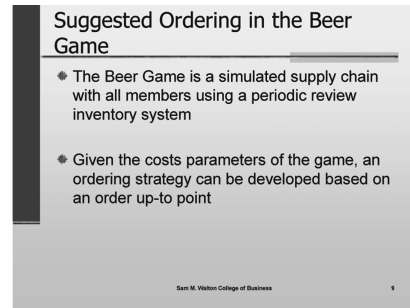
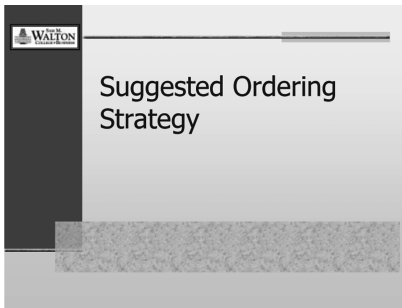
***Try not to overreact to changes in demand***

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### Other Issues Driving Bullwhip

- ◆ Long Lead Times
  - Remember that there is a lead time of at **least** four periods between when you place an order and when you receive it
- ◆ Underweighting of the Supply Line
  - When placing your order, think about the orders you have placed but have not received
  - Consider your Inventory Position, not just what you have on hand
    - $IP = \text{On Hand} + \text{On Order} - \text{Backorders}$

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