DECISION-MAKING AND THE NEWSVENDOR PROBLEM – AN EXPERIMENTAL STUDY

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Abstract

This paper investigates repetitive purchase decisions of perishable items in the face of uncertain demand (the newsvendor problem). The experimental design includes: high, or low profit levels; and uniform, or normal demand distributions. The results show that in all cases both learning and convergence occur and are effected by: (1) the mean demand; (2) th order-size of the maximal expected profit; and (3) the demand level of the immediately preceding round. In all cases of the experimental design, the purchase order converges to a value between the mean demand and the quantity for maximizing the expected profit.

Keywords: Inventory, Learning, Behavior, Management, Optimization.

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1. INTRODUCTION

In the newsvendor problem, the decision-maker, facing uncertain demand distribution, has decide how many units to buy each day. Since Whitin (1955) first presented the newsvenc problem, it has become one of the classic models in inventory management. Interest in t newsvendor problem and its various versions remains unabated and many extensions to have been proposed in the last decade (Khouja 1999, Laua and Lau 1997, Shore 2004).
The newsvendor problem focuses on the purchase of perishable products. The mathematic model maximizes the expected profit by determining the optimal order-size. For the sake convenience, the order-size of the maximal expected profit is abbreviated as "Optimal orde Optimal order and expected profit are functions of: (1) the item cost and the marginal prof and (2) the demand distribution (Nahmias 1994).

In this paper we present an experiment in which participants play the role of newspap storeowners and decide on how many papers to order, given known demand distribution. V use the results in order to answer the following questions:

1. Do decision-makers act according to the theoretical prediction?
2. Do the orders of the decision-makers converge throughout the experiment?
3. What is the effect of alternative parameters on the participants' orders? (Different deman distributions and costs, marginal profit levels etc.).

We used computerized learning experiments and each individual was assigned a single combination of different conditions (uniform or normal demand distribution, and low or hig marginal profit). The participants were asked to decide on their order quantity in the course

100 periods. While other experimental studies focused on uniform distribution demand, we used also the normal distribution demand.

The paper is organized as follows. First we present a short review of the literature. Second we define the hypotheses of our study and in the third section we describe the experimental procedure. Next, we present the primary results and provide some possible explanations. Finally, we summarize the conclusions.

2. LITERATURE REVIEW

The classical newsvendor problem (Whitin, 1955) deals with a single-period invento
Unless it is sold, it will lose part or all of its value. The newsvendor (the decision-make
facing uncertain demand *D* from a known distribution function *F*(*D*) with a probabil
density function f(D), has to decide on the order quantity *Q*. The newsvendor problem
extremely popular and it has been extensively reviewed by Gallego and Moon 1993, Silver
al. 1998, Khouja 1999, Petruzzi and Dada 1999 to mention a few.

Since the cost of each unit is *C* and the selling price for the customer is *P*, the marginal pro
C_u equals P-C. The marginal loss C_0 equals *C* (or if a salvage value *s* is returned C_0 =*C*-
The newsvendor model finds the optimal order quantity *(Q*)* by maximizing the expect
profit $\pi(Q)$.

To compute the expected profit of a given order *Q*, the profit is divided into two cases:

(a) for demand exceeding the order quantity - $Q<D$: $\pi(Q) = (P-C)Q = C_uQ$

(b) for demand lower than order quantity - $Q>D$: $\pi(Q) = (P-C)D - C_0\,(Q-D)$

$= C_u D - C_0(Q-D)$

In the mathematical development below, (b) is divided into (b1)=$C_u D$ and (b2)=$C_0(Q-D)$.

Computing the expected profit of an order of Q items, based on (a) and (b) yields,

$$E\left[\pi(Q)\right] = \overbrace{C_u \int_Q^{\infty} Q \cdot f(D)dD}^{(a)} + \overbrace{C_u \int_0^{Q} D \cdot f(D)dD}^{(b1)} - \overbrace{C_0 \int_0^{Q} (Q-D) \cdot f(D)dD}^{(b2)} \quad ($$

The well-known formula for optimality conditions of (1) is:

$$F\left(Q^*\right) = \frac{C_u}{C_u + C_o} \quad ($$

Carlson and O'Keefe (1969) were the first to report an experiment with the newsvend problem. In this instance, the newsvendor problem was part of a much larger experiment scheduling decision-making. The authors reported participants as making erratic decisions that no conclusion could be made except that "participants made almost every kind mistake". Fisher and Raman (1996) provided evidence from a firm engaged in manufacturi fashion apparel to indicate that order-purchase decisions do not correspond to the optim order. In other studies, Sterman (1989) and Diehl and Sterman (1995) discussed t anchoring phenomenon and insufficient adjustment bias in an inventory distribution syste experiment with multiple actors, time periods, feedback and time delay. However, the studies were not designed to disentangle biases in the newsvendor context.

Schweitzer and Cachon (2000) conducted an important experimental test of the newsvend problem model. In their study, they analyzed 15 decision periods of ordering for each subje with known uniform distribution. They show that participants systematically deviate from t optimal order and that when marginal profit is larger (smaller) than the cost, participants te to order less (more) than the optimal order. Bolton and Katok (2004) extended their wo using 100 decision rounds. They found that enhanced experience improves newsvend performance, although this improvement is, on average, rather slow.

Both Fisher and Raman (1996) and Schweitzer and Cachon (2000) claim that there a behavioral factors that lead to deviation from the optimal order, such as risk and lo aversion, underestimation of opportunity cost or waste aversion.

3. HYPOTHESES

This study examines three hypotheses. One is based on theoretical model but the other two refer to behavior-based learning theories.

First, we assume that the participant, who follows the optimal order calculated by t newsvendor problem model, is also biased towards the demand distribution mean. We ba this assumption on the "central tendency bias" as discussed, for example, by Hollingwor (1910), Helson (1964) and Elizabeth, Huttenlocher1 and Engebretson (2000).

Formally, we assume that the participants order (Q) is a weighted average of the optimal order Q^*, and the distribution mean, E(D).

$$Q = \alpha_t * E(D) + (1-\alpha_t)*(Q^*) \qquad for \quad 0 \le \alpha_t \le 1 \qquad \textbf{(3)}$$

The mean coefficient, α_t, is the strength of the "central tendency bias" for each subject.

Hypotheses

H1: **Participants' order quantity**.

The participants' order quantity is a weighted average of the optimal order and the demand distribution mean. For initial stages $\alpha_t \approx 1$ (that is, the order is close to the mean demand). In a classic learning process, the effect of recent outcomes declines with experience, and the average marginal increase in profit declines with experience. As a result, the decision-make order converges to a subjective level.

H2: **Learning**

Individuals learn during 100 periods, and as a result:

(a) The coefficient of the mean declines over time and so $\alpha_t < 1$ in late periods

(b) The average profit increases.

(c) The mean and the optimal order weights converge to a subjective level.

We assume that participants are affected by recent outcomes (see Erev & Barron, 2001). Johnson et al. (2005) found that in the context of trading stocks, consumers strongly prefer t buy winning stocks and sell losing stocks. We use the same effect for the consumer of newspapers. If the difference between previous round demand and previous round order is positive (negative), the subjects increase (decrease) the order as they would with a winning (losing) stock. The effect of feedback on inventory decision-making and the learning proce was tested in different tasks (Atkins et al (2002), Diehl and Sterman (1995).

H3: **Effect of previous round results**.

The current order is higher/lower than the previous order if the difference between previous demand and previous order is positive/negative. Over time (i.e; in later stages) the influence of the previous round declines.

4. THE EXPERIMENTS

The experiments included 60 management students, sophomores and juniors, who had taken basic course in statistics. The experiments took place at a computer laboratory[1], and last approximately one hour. Each subject was free to progress at his or her own pa independently of the other participants in the experiment.

The participants were divided into four groups before the experiment to examine t combinations of two profit levels and the two, variance levels (using different distributions) Two of the groups (one for each cost level) were assigned the same cost, selling price, a demand distribution as described by Schweitzer and Cachon (2000): a uniform demand ran of 1-300 products. The other two groups (one for each cost level) were assigned a norm demand distribution with the same mean (μ=150) and a SD (σ=50) that ensures that 99.7% the demand distribution is within the range of 1-300.

For the low profit level, the values of the optimal order, for the uniform and norm distributions respectively, are: 75 and 116. For the high profit levels, the values of the optim order are 225 and 184 for the uniform and normal distributions respectively.

We tested the normal distribution since the demand in real life situations may have normal distribution. We also wanted to prevent distribution effect by using two different distributio to test whether the results depended on the distribution.

extend :Deleted

By using the normal distribution we extend the previous analysis by comparing the different distributions separately.

Throughout the experiment, the participants made 100 inventory purchase decision rounds, following ten rounds of practice. In each round, participants were informed of the cost and price of the product. Each round was followed by: a presentation of the actual demand; the total cost of the order; the total revenue; the demand /supply surplus; the forfeited profits du to inventory shortage; and the profit. The data was presented in a table format[2].

Before the experiment, participants were handed written instructions (see appendix A), including examples. The demand's distribution was given to the participants as follows:

(1) for uniform distribution, participants were told that each value from 1 to 300 has the san likelihood of being chosen.

(2) for normal distribution, participants were given a table with demand results of 1 simulated days. This represented the normal distribution in a palpable manner.

To provide concrete incentives, at the end of the experiment, one of the rounds was random selected and the participants were paid proportionally[3] to the profit in the selected round (in cash).

5. RESULTS

Table 1 presents the average weight (a_t) of the mean in the first and last 20 periods accordi to equation (3). To validate the effect of learning on the order decisions, we used a pair t-test to compare the average weight in the first 20 periods and in the last 20 periods. T average order in the 5 blocks of 20 periods each is presented in figures 1 and 2 in appendix

Insert table 1 about here

First we see that the average coefficient (α_t) declines over time, meaning that the tendency t move towards the distribution's mean declines while the subjects move closer towards the optimal solution of the newsboy problem. This is also shown in figures 1 and 2.

76.6% of the subjects move toward the direction of the optimum; 1.6% stay at the mean; a the rest, 21.6% of the subjects move away from the optimum. This indicates that participa change their quantity toward the optimal order

Next, we used t-tests to examine the hypothesis that the average coefficient is not differe from one, meaning that the order is equal to the mean. The results show that in most of t treatments the average weight is not significantly different from one in the first 20 perio while in the last 20 periods, the average order is significantly different from one.

The results are consistent with hypotheses (H1) and (H2a). Participants' order quantity is a weighted average of the optimal order and the demand distribution. In the initial rounds, α_t= 1.

Next, we calculated for each subject the absolute change in the order (in percentage) from one period to the next period. The absolute change is used as a measure of convergence. Next, we calculated the average change for each block of 20 periods.

67% of the subjects show a decline in the average change between the first 20-period block and the last 20-period block.

In Table 2 we show the percent of subjects that show an average absolute change in each range in the last 20-period block.

Insert table 2 about here

Table 2 shows that only 24.6% of the subjects show an average change higher than 10% in the last 20 periods compared to 62.5% in the first 20 periods. This shows significant convergence into a stable order over the experiment. Note, however, that this stable order is not the optimal order from the mathematical model.

54.1% of the subjects show an average change lower than 5% in the last 20 periods, compared to 19.5% in the first 20 periods.

Table 3 shows the average profit in the first and last blocks of 20 rounds.

For each case we present the optimal order's average profit (in brackets). This profit was calculated by using the optimal order in each period instead of the subject's order.

Insert table 3 about here

Table 3 shows that the average profit in the last 20 rounds is higher than the average profit i the first 20 rounds, meaning that the profit is increasing between the first rounds and the las rounds, consistent with hypothesis (H2b).

Table 4 presents the average rate between the actual profit and the profit calculated by usin

the optimal order as follows:

$$100 \times \frac{\text{actual profit - profit using mean}}{\text{optimal profit - profit using mean}} \qquad (4)$$

Insert table 4 about here

Table 4 shows that the rate between the actual profit and the profit calculated by using the optimal order is improving between the first rounds and the last rounds. The results are consistent with the finding that subjects move towards the optimum and away from the mea

The negative rate at the first 20 rounds in the low profit groups is a result of an average loss since participants order above the optimal order, and the cost of an unsold product (9 NIS) i three times more than the profit from a sold product (3 NIS).

In table 5 we present the number of times each subject changed his or her order quantity fro one round to another in the first and last 20 rounds. We distinguish between changes towar previous demand[4] and away from previous demand.

Insert table 5 about here

Table 5 shows that participants change their order towards the demand of the previo periods more frequently than away from this demand in all the treatments. This indicates t participants are affected by the prior round demand. This is consistent with hypothesis (

The effect of prior rounds becomes weaker in the last 20 periods indicating that the subje learns throughout the experiment that past information is not relevant to current decisic making.

Overall, the number of changes towards and away from prior demand in the first 20 periods higher than in the last 20 periods, indicating that participants converge to a subjective orc level and a subjective mean weight. This is consistent with hypothesis (2c).

6. CONCLUSIONS

In general, there is a convergence to a stationary order quantity and stationary me coefficient throughout the experiments. This convergence is reflected by a declining numb of changes throughout the 100 rounds and an increase in the participants' profits. Howev we also demonstrated that subjects converge away from the level of stocking that optimiz expected profit.

We found that in the first purchase decision rounds, participants tend to be more bias toward the mean demand than in the last rounds. This bias persists, since, despite the gene convergence to a stationary order, we found a significantly positive mean coefficient in t last rounds too. While we can't explain why subjects do not converge to the expected val of optimal order in the newsvendor problem, the existence of bias towards the mean, whi we found can partly explain the way subjects move from the optimal order

The results are also consistent with the hypothesis that subjects are affected from previo experience. If past demand is higher than past order (demand surplus), participants tend increase their order. Participants are affected by the demand or supply surplus. If pa demand is lower than past orders (supply surplus), participants tend to reduce their orde However, participants learn throughout the experiment to reduce this effect.

Clearly, one should be very careful in generalizing from simple experiments to behavior a prices in real inventory problems. The experiment was conducted in a laboratory w students and a virtual product. However, in real life situations the inventory managers m deal with many different products. Moreover, inventory managers may use their experien and not theoretical results when deciding on the order quantity. We hope, however, that t intriguing results of this study will motivate further research of the interaction betwe individual behavior biases and the inventory problems.

Notes

[1] The experiment was programmed using Visual Basic and Excel.

[2] For discussion on the effects of feedback format, see Atkins et al (2002).

[3] The average payment was 20 N.I.S, or about $5.

[4] Change toward last demand is: (1) if the immediate previous demand is larger than t immediate previous order - an order increase from the previous order and (2) if the immedia previous demand is lower than the immediate previous order - an order decrease fro previous order.

APPENDIX A: EXPERIMENT INSTRUCTIONS

- This is a computerized experiment in decision-making. You will function as a retai of a single product

- The experiment is composed of a large number of rounds in which you will be ask to make inventory decisions.
- In each round you are able to order the product from your supplier at a wholesale co You will then sell the product to consumers at a higher price.
- Consumer demand in each round is randomly selected from known distribution.
- The prices and profits in every round will be in experiment tokens.

Possible scenarios:

- Overage – If fewer products are demanded than the quantity you ordered, you w have to dispose of some inventory (i.e. you cannot keep unused inventory for futu periods).
- Shortage - If more products are demanded than the quantity you ordered, you w have to forgo some sales.

Data after each round

After ordering the quantity from the supplier in each round, the realized demand and t profit will be presented to you.

Theoretical Example

The decision screen:

The decision screen will not change during the experiment.

Data

Round:	1	Your order quantity: __________	
Price:	15		**Confirm**
Cost:	5		

You then decide your order quantity. And then press the confirm button.

Assume that your order decision is: 380 units and the realized demand was: 136

The results screen:

In product units:		In experiment tokens:	
Your order quantity:	380	The order cost:	1400
The realized demand:	136		
The quantity purchased:	136	The total revenue:	2040
Overage of product:	244		
Shortage of product:	---	The forgone sales value:	---

Total profit: 640

Payment for experiment:

Part of your payment will be fixed (10 NIS) and the other part depends on your profit/lc level.

Following the completion of the experiment, one of the rounds will be randomly picked a will determine the payment for the experiment. This means that the payment is dependent the quality of your decision. The profit/loss of the picked round will be divided by 50 a added to a fixed sum of 10 NIS.

Assume that the profit in the chosen round was: 704

Your payment for the experiment will be: 10 + (704)/50 = 24.08

APPENDIX B: AVERAGE ORDER IN 20-ROUND BLOCKS

Figure 1. Average Orders Along 100 Rounds for **Uniform Distribution** Low/Hig
Profit

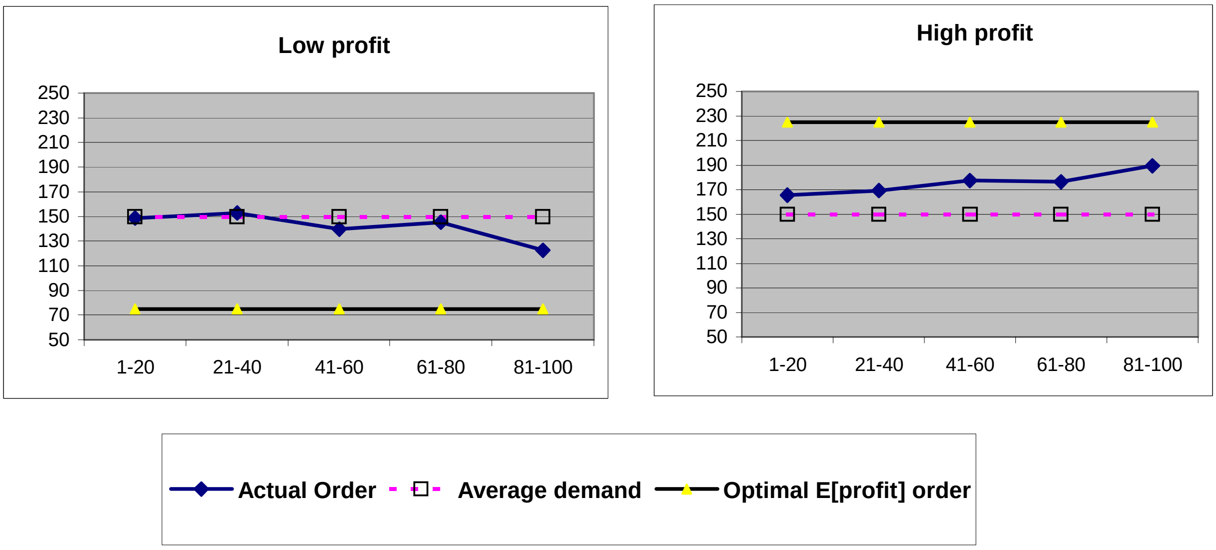
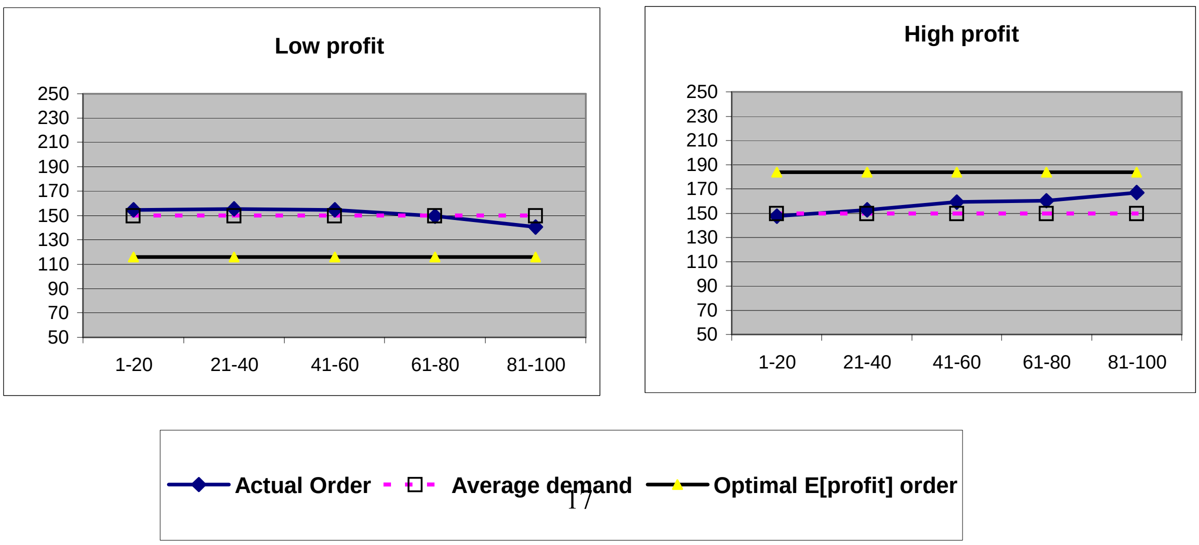


Figure 2. Average Orders Along 100 Rounds for **Normal Distribution** Low/High



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Tables

TABLE 1. AVERAGE "MEAN COEFFICIENT" IN THE FIRST AND LAST 20 PERIODS – NORMA AND UNIFORM.

Distribution	Margin Profit	Average coefficient of mean (α) First 20 periods	Last 20 periods	First to Last 20 periods T-value (paired t-test), p- value
Uniform	Low	**0.98**	**0.63**++	t=3.22, p<.01
	High	**0.79**++	**0.47**++	t=-3.96 ,p<.01
Normal*	Low	**1.14**	**0.7**+	t=2.6, p=.01
	High	**1.07**	**0.5**++	t=-4.3, p<.01

* α>1 signifies average order on the side of the mean that is opposite to the optimal level.

** $Q = \alpha_t{*}E(D) + (1-\alpha_t){*}(Q^*)$ [(Q) is a weighted average of the optimal order Q^*, and the distribution mean, E(D)].

++ Indicates significance of 5% level for the hypothesis that the average weight ≠ 1.

+ Indicates significance of 10% level for the hypothesis that the average weight ≠ 1.

Table 2: Percentage of subjects in different ranges of absolute change in the first and last 20 periods.

Average absolute change	First 20 periods	Last 20 periods
Exactly 0%	3.2%	16.4%
0% < change <5%	16.3%	37.7%
5% < change <10%	18%	21.3%
10% < change	62.5%	24.6%

Table 3. Average Profit in the First and Last 20 Periods - Normal and Uniform.

Distribution	Margin Profit	Average profit in the first and last 20 periods First 20 periods	Last 20 periods	First to Last 20 periods T-value (paired t-test), p- value
Uniform	Low	-225 (1)	-124 (32)	t=1.9, p=.04
	High	621 (640)	705 (754)	t=9.16 ,p<.01
Normal	Low	-24 (147)	99 (183)	t=3.96, p<.01
	High	919 (931)	994 (1006)	t=5.73, p<.01

* In brackets we present the optimal order average profit. This profit was calculated by usin the optimal order in each period instead of the subject's order.

Table 4. Average Rate, Between the Actual Profit and the Profit Calculated by Using the Optimal Order in the First and Last 20 Periods - Normal and Uniform.

Distribution	Margin Profit	Average profit in the first and last 20 periods: First 20 periods	Average profit in the first and last 20 periods: Last 20 periods	First to Last 20 periods T-value (paired t-test), p- value
Uniform	Low	-16%	40%	t=5.571, p < 0.01
	High	36%	71%	t=2.48, p=0.01
Normal	Low	-48%	43%	t=3.68, p<0.01
	High	13%	80%	t=3.5, p<0.01

* We calculated the rate as follows: $100 \times \frac{\text{actual profit - profit using mean}}{\text{optimal profit - profit using mean}}$

TABLE 5. NUMBER OF CHANGES TOWARDS AND AWAY FROM LAST DEMAND.

Distribution	Margin Profit		Average changes towards and away from previous demand: First 20 rounds	Average changes towards and away from previous demand: Last 20 rounds	First to Last 20 rounds T-value (paired t-test), p- value	C
Uniform	Low	Towards Prior Demand	6.7	3.3	t=3.14, p<.01	
		Away from Prior Demand	2.6	0.9	t=3.16, p<.01	
		Paired t-test	t=3.69, p<.01	t=3.32, p<.01		t=5.
	High	Towards Prior Demand	10.1	5.2	t=4.9, p<.01	
		Away from Prior Demand	2.1	1.4	t=2.9, p<.01	
		Paired t-test	t=7.15, p<.01	t=3.4, p<.01		t=6
Normal	Low	Towards Prior Demand	7.5	5	t=2.8, p<.01	
		Away from Prior Demand	2.6	0.8	t=3.5, p<.01	
		Paired t-test	t=5.3, p<.01	t=4.1, p<.01		t=6
	High	Towards Prior Demand	7.3	3.3	t=5.6, p<.01	
		Away from Prior Demand	2.6	1.2	t=1.7, p=.05	
		Paired t-test	t=4.8, p<.01	t=4.3, p<.01		t=7