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ANALYSIS ON THE ORDER BEHAVIOR OF RETAILER WITH CONSIDERATION OF BOUNDED RATIONALITY

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Abstract. *Behavioral experimental researches have shown that human subjects do not order according to newsvendor model. In this paper, "Anchoring" effect is reexamined; the effect of parameters on human subjects' order behavior is explored from purchase cost to demand scale, retail price and salvaged cost through experimental researches. Then the trend of human subjects' order quantities with the parameters rise and fall when the decision-maker is in a state of profit or loss is compared. The experimental results show that retail price and salvaged cost have an "Anchoring" effect similar to purchase cost, and when the optimal order quantity is lower or higher, there is a gap between the subjects' actual mean order quantities and the optimal order quantities; the higher (the lower) the optimal order quantity is, the greater the difference between the two is. It is also found that the effect of demand scale is different from that of retail price, purchase cost and salvaged cost, and the decision environment (profit or loss) has no significant effect on the subjects' actual mean order quantities.*
Keywords: Supply chain, Bounded rationality, Newsvendor decisions, Order behavior

1. **Introduction.** The newsvendor problem is one of the classic models in supply chain inventory management focused on the purchase of perishable products. In choosing the optimal order quantity the decision-maker must balance the costs of ordering too little against the costs of ordering too much. The mathematical model maximizes the expected profit by determining the 'optimal order' with a common assumption that decision-maker is perfectly rational. However, behavioral experimental researches have shown that the assumption of perfectly rational does not accord with actual decisions; the order quantities placed by the decision-makers are inconsistent with the expected profit maximizing behavior [1-3]. Since Tversky and Kahneman [4] put forward Prospect Theory, the concept of bounded rationality from behavioral economics has brought revolutionary changes in multiple areas of traditional economic theory. Behavioral supply chain management is emerged under the background that whether the assumption in this field should be consistent with reality. So far, the research on bounded rationality in supply chain inventory management mainly includes: anchoring (also known as pull-to-center), demand chasing and fairness concerning. The anchoring effect refers to the observation that the order quantity in the newsvendor problem placed by human subject is between the mean demand and the expected profit maximizing quantity in experimental researches [2,3,5]. The demand chasing effect refers to the observation that people adjust their order quantities based on previous demand realization [2,3]. Behavioral experimental studies have also confirmed the existence of fairness concerning tendency. The fairness concerning effect refers to the observation that although people prefer a higher payoff, what matters is not only the absolute size of the payoff, but also its relative size when compared in a peer group; people care about the fairness of the process or procedure through which the decision is made and the outcome is reached [6]. Researches on supply chain inventory

management in behavioral experiments also show that experienced procurement managers broadly exhibit the same kind of pull-to-center bias as students do, and the managers use information and task training no better than the students [7].

Although previous behavioral experimental researches have achieved fruitful results, from the perspective of bounded rationality, there are still some problems need to be studied. In this paper, we first reexamine the conclusion that previous behavioral experimental researches have proved that human subjects do not order according to the newsvendor model. Then we extend the previous researches from the relationship between human subjects' order behavior and low or high marginal profit levels to the trend relationship between the order quantities of human subjects and alternative parameters such as demand scale, retail price and salvaged cost; especially we explore the trend of human subjects' order quantities with the increase or decrease in the quantity of demand scale, retail price, purchase cost and salvaged cost. Finally, we compare the trend of human subjects' order quantities with the parameters rise and fall when the decision-maker is in a state of profit or loss.

2. **Newsvendor Experiments.**

2.1. **The descriptions of the models.**

In the newsvendor problem, the retailer chooses an order quantity q, which arrives before the start of a selling period. Let D be stochastic demand during this period. Let $F(D)$ be the distribution function of demand and $f(D)$ the density function. For simplicity, assume $F(D)$ is continuous, differentiable and strictly increasing. The retailer purchases each unit for cost c and sells each unit at price $p > c$. When $q > D$, each unit remaining at the end of the period can be salvaged for $s < c$. Let $\pi(q, D)$ be realized profit, the newsvendor model finds the optimal order quantity q_n by maximizing the expected profit $E[\pi(q, D)]$. To compute the expected profit of a given order quantity q, the profit is divided into two cases:

(a) For demand D lower than the order quantity q, where

$$E[\pi(q, D)] = \int_0^q [px - cq + s(q - x)] f(x)\, dx \tag{1}$$

(b) For demand D exceeding the order quantity q, where

$$E[\pi(q, D)] = \int_q^\infty (pq - cq) f(x)\, dx \tag{2}$$

Then

$$\begin{aligned} E[\pi(q, D)] &= \int_0^q [px - cq + s(q - x)] f(x)\, dx + \int_q^\infty (pq - cq) f(x)\, dx \\ &= (p - s) \int_0^q x f(x)\, dx - (p - s) \int_0^q q f(x)\, dx + (p - c) q \end{aligned} \tag{3}$$

Let $q_n = \arg\max E[\pi(q, D)]$, and

$$\frac{dE[\pi(q, D)]}{dq} = (p - c) - (p - s) \int_0^q f(x)\, dx = 0 \tag{4}$$

Then, the order quantity that maximizes the expected profit is

$$q_n = F^{-1}\left(\frac{p - c}{p - s}\right) \tag{5}$$

The ratio $(p - c)/(p - s)$ is called the critical fractile (CF).

2.2. **Hypotheses.** The mathematical model can provide the well-known 'optimal order' for the newsvendor problem, but the observations of anchoring, demand chasing and fairness concerning from behavioral experimental researches have proved that there is an antinomy between the theoretical model and the practical decision. To explore and measure the gap between the theoretical model and the experimental observations is a valuable research work. In this paper, we first reexamine the conclusions that previous behavioral experimental researches have proved that human subjects do not order according to the theoretical newsvendor model [1-3].

Hypothesis 1: The order quantity of retailers is q_n.

Then we extend the previous behavioral experimental researches from the relationship between the newsvendors' order behavior and low or high marginal profit levels to the relationship between the order quantities of human subjects and alternative parameters such as demand scale, retail price and salvaged cost; especially we explore the trend of human subjects' order quantities with the increase or decrease in the quantity of the parameters

Hypothesis 2: The order quantity of retailers depends on q_n only, not on the demand scale, retail price, purchase cost and salvaged cost.

Finally, we compare the trend of human subjects' order quantities with the parameters rise and fall when the decision-maker is in a state of profit or loss. According to the explanation from Prospect Theory, when the decision maker is in a profitable environment, he or she will be more sensitive of excess ordering, and then he or she will tend to reduce the order quantity. When the decision maker is in a loss environment, he or she will be more sensitive of stock out, and then he or she will exhibit risk chasing, and tend to increase the order quantity.

Hypothesis 3: The order quantity of retailers does not depend on whether the decision-maker is in a state of profit or loss.

2.3. **The experiments.** The experiments included 83 college students, majored in logistics management. They have studied some basic courses in economics, management, statistics supply chain and logistics management, and have been familiar with newsvendor problem, but they do not grasp the optimization knowledge to the problem. The experiments were carried out in the computer laboratory of the college, and lasted approximately 4 hours each time. The experiment was programmed using Visual Basic and Excel. Each subject was free to fulfill the experimental task at his or her own pace independently of the other participants. The experiment can provide feedback of the previous actual demand (randomly generated by the software) and the previous and accumulated profit.

Before the experiments, we spent 2 hours in explaining and demonstrating the experimental procedure and the use of the software, answering their questions to help the subjects to fully understand the experiment, especially to understand the actual significance of related parameters, in order to deepen their philosophy that the right amount of order may bring profit, and too much or too little of the order quantity may cause a loss. After the explanations we gave them two exercises to check up whether the subjects understood the experiment, and we declare that we shall only accept the data from the subjects who have presented the correct solutions to the two exercises. In order to obtain high quality of experimental data, two disciplines have been taken in the experiments. One is the strict emphasizing that the participants should not talk to each other, and not peep at other experimental data. The other is the combination incentive method of cash and the course scores. The cash and the course scores are calculated according to a certain proportion of the subjects' actual accumulated profit.

In the experiments, each subject was informed a series of newsvendor order problems, and the demand distribution was uniform throughout the experiment. In order to explore

whether the order quantities depend on the decision environment (where the decision-maker was in a state of profit or loss), the subject was informed that the previous 30 rounds of purchase decision had been made out; as a result, he or she could see from the software that he or she was in a profitable state or a loss state, and then was asked to finish the remaining 30 rounds of the decision. It was emphasizing that the previous accumulated profit or loss would be added to the profit or loss resulted in the remaining 30 rounds. In order to explore the trend of the order quantities with the increase or decrease of demand scale, retail price purchase cost and salvaged cost, three of the four parameters were fixed in each experiment, remaining one of them in turn increased or decreased by 10%, 16.7%, 20% and 30% to examine the trend of the order quantities from the subjects. The experimental contents are detailed in Table 1. Experiments 105, 107, 109, 111 were referred to the case where the decision-maker was in a state of profit, and experiments 106, 108, 110, 112 were the corresponding case where the decision-maker was in a loss state.

Table 1. The experimental contents and parameters

The relationship between mean order quantities and retail price			*The relationship between mean order quantities and demand scale*			*The relationship between mean order quantities and purchase cost*			*The relationship between mean order quantities and salvaged cost*		
Exp. No.	*Exp. No.*	*Retail Price*	*Exp. No.*	*Exp. No.*	*Demand scale*	*Exp. No.*	*Exp. No.*	*Purchase Cost*	*Exp. No.*	*Exp. No.*	*Salvaged cost*
105-1	*106-1*	$P = 90$	*107-1*	*108-1*	$(0, 90)$	*109-1*	*110-1*	$C = 50$	*111-1*	*112-1*	$S = 10$
105-2	*106-2*	$P = 80$	*107-2*	*108-2*	$(0, 80)$	*109-2*	*110-2*	$C = 40$	*111-2*	*112-2*	$S = 20$
105-3	*106-3*	$P = 70$	*107-3*	*108-3*	$(0, 70)$	*109-3*	*110-3*	$C = 30$	*111-3*	*112-3*	$S = 30$
105-4	*106-4*	$P = 110$	*107-4*	*108-4*	$(0, 110)$	*109-4*		$C = 70$			
105-5	*106-5*	$P = 120$	*107-5*	*108-5*	$(0, 120)$	*109-5*		$C = 80$			
105-6	*106-6*	$P = 130$	*107-6*	*108-6*	$(0, 130)$	*109-6*		$C = 90$			
Uniform demand $(0, 100)$ *Purchase cost* $C = 60$ *Salvaged cost* $S = 0$ $N = 30$			*Retail price* $P = 100$ *Purchase cost* $C = 60$ *Salvaged cost* $S = 0$ $N = 30$			*Uniform demand* $(0, 100)$ *Retail price* $P = 100$ *Salvaged cost* $S = 0$ $N = 30$			*Uniform demand* $(0, 100)$ *Retail price* $P = 100$ *Purchase cost* $C = 60$ $N = 30$		

3. **Results and Analysis.** 39 experiments were included in this research. Before the experimental data statistics, we exclude the flawed data submitted not in accordance with the requirements. The flawed data mainly include: (1) Some subjects forgot to answer the two questions left before the experiments or did not give the right answers; (2) More flawed data were submitted by the subjects who had only completed parts of the required experimental projects, that we could not accept them for the lack of its corresponding data for the trend analysis and contrast analysis; (3) Some subjects did not complete the enough rounds of decisions. As a result, we exclude the above flawed data from the analysis, and report results from 41 subjects for experimental project 105, 106, 107 and 108, 44 subjects for project 109 and 110, 42 subjects for project 111 and 112.

T-test assesses whether the means of two groups are statistically and significantly different from each other. It can aid in showing how the same group of subjects responds in two different categories of testing. By running it, we can find whether the difference between the two means order quantities is statistically significant, which will allow us to gauge if the same group tested similarly or differently on two different categories, and how much the answers of the subjects varied and the standard error. Figure 1 to Figure 4 demonstrate the relationship between the subjects' actual mean order quantities and the optimal newsvendors' order quantities (q_n) with the increase or decrease in the quantity of the four parameters (demand scale, retail price, purchase cost and salvaged cost). Table

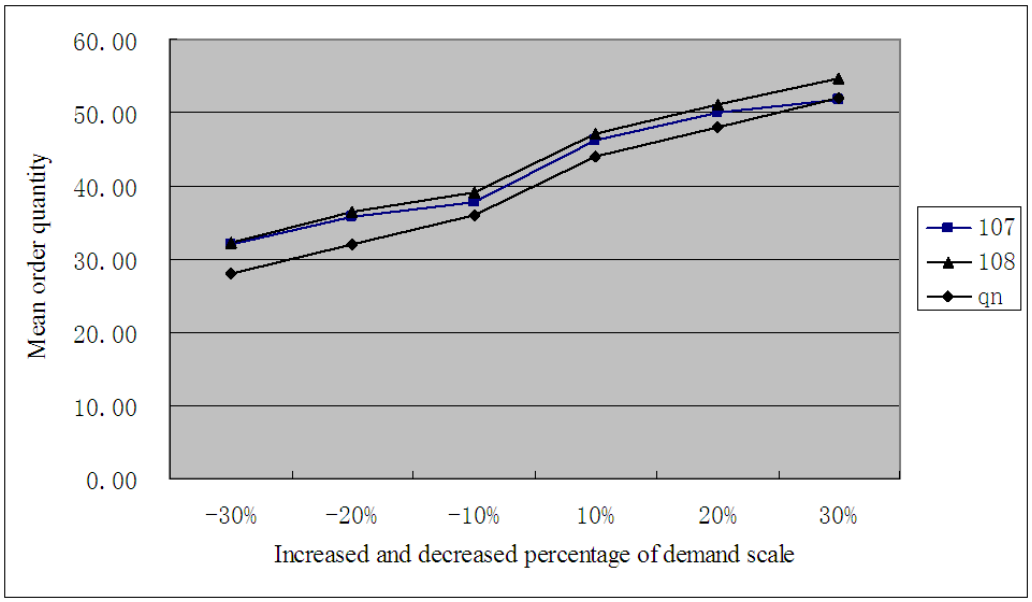

FIGURE 1. Mean order quantity with the change of demand scale

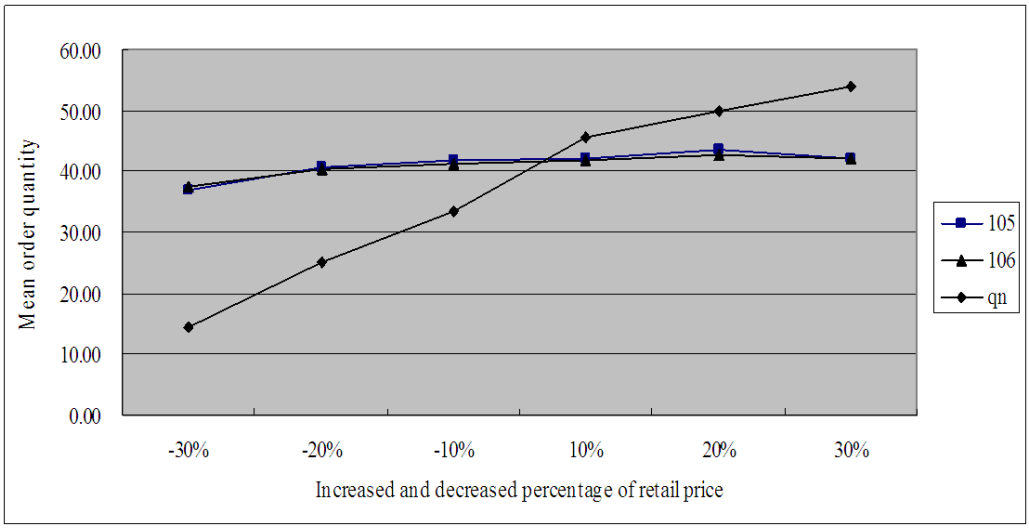

FIGURE 2. Mean order quantity with the change of retail price

2 demonstrates the T-test analysis between two sets of results which are similar to each other.

From Figure 2 to Figure 4 and Table 2, we can see that only in one case (111-1 Retail price = 10, Purchase cost = 60, Salvaged cost = 10), the actual mean order quantity is equal to the optimal order quantity approximately; in all the other remain cases, the differences between the subjects' actual mean order quantities and the optimal newsvendors' order quantities are significant (see Figure 2 to Figure 4 and Table 2). Therefore, we reject Hypothesis 1.

From Figure 1 to Figure 4 we can see that the four parameters have obvious effect on the subjects' actual ordering behavior; moreover the effects of each of the four parameters on the subjects' actual ordering behavior are different. The experimental results on retail price, purchase cost and salvaged cost show that when the optimal order quantities are lower, the subjects' actual mean order quantities are greater than the optimal order quantities; when the optimal order quantities are higher, the subjects' actual mean order quantities are fewer than the optimal order quantities; the higher (the lower) the optimal order quantity is, the greater the difference between the two is. Figure 5 shows the

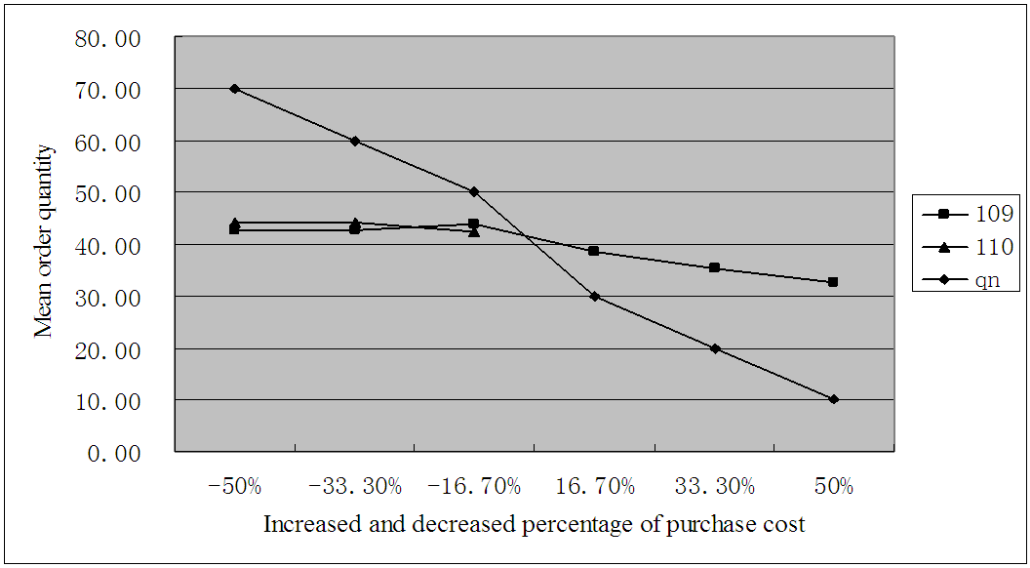

FIGURE 3. Mean order quantity with the change of purchase cost

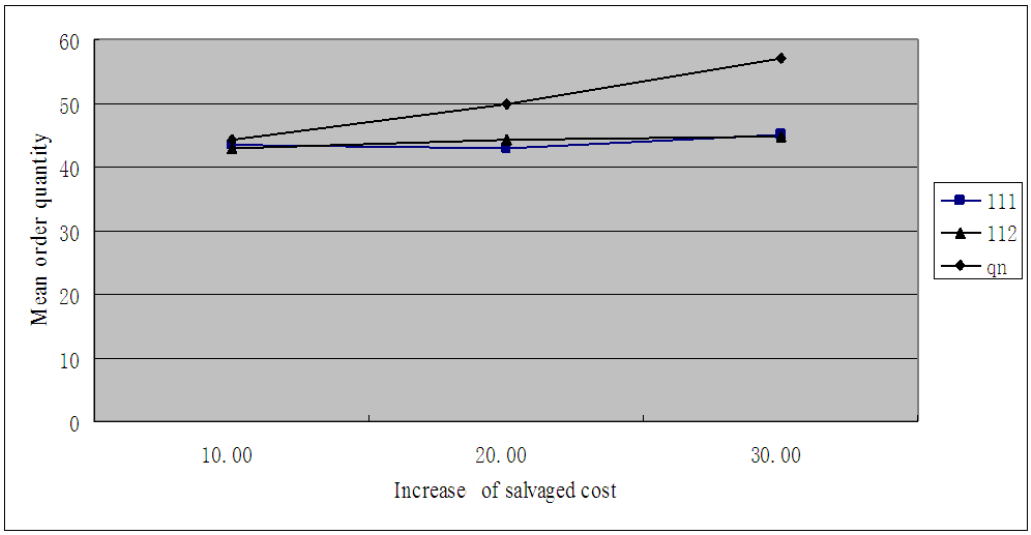

FIGURE 4. Mean order quantity with the change of salvaged cost

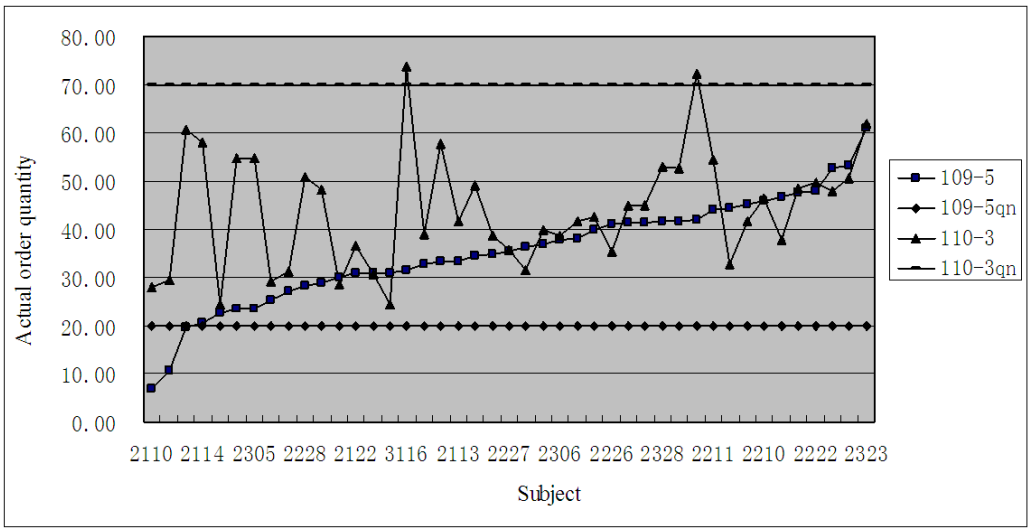

FIGURE 5. Actual order quantities of subjects under high and low profits situations

TABLE 2. T-test analysis between the corresponding results

T-test analysis between the corresponding experiments			*T-test analysis between the actual order quantities and its optimum values*		
Corresponding exp. No.	*two-tailed test value*	*t Stat*	*Corresponding exp. No.*	*two-tailed test value*	*t Stat*
107-1 vs. 108-1	*2.02269*	*−1.4209*	*107-1 vs. 107-1qn*	*2.02269*	*1.3635*
107-2 vs. 108-2	*2.02269*	*−0.5511*	*107-2 vs. 107-2qn*	*2.02269*	*3.3918**
107-3 vs. 108-3	*2.02269*	*−0.1146*	*107-3 vs. 107-3qn*	*2.02269*	*3.3959**
107-4 vs. 108-4	*2.02269*	*−0.6284*	*107-4 vs. 107-4qn*	*2.02269*	*1.5720*
107-5 vs. 108-5	*2.02269*	*−0.9686*	*107-5 vs. 107-5qn*	*2.02269*	*1.1441*
107-6 vs. 108-6	*2.02269*	*−2.1197**	*107-6 vs. 107-6qn*	*2.02269*	*−0.0757*
			105-4 vs. 105-4qn	*2.02269*	*2.1785**
			109-1 vs. 109-1qn	*2.01081*	*−4.3855**
			111-1 vs. 111-1qn	*2.02108*	*−0.6373*
			112-2 vs. 112-2qn	*2.02108*	*−4.4999**

$P < 0.05$. *The values with * mean that in such a case the difference is significant.*

distribution curve of subjects under high profits and low profits situations, it shows that the subjects' actual order quantities are almost entirely within the limits of the optimal order quantities, and it once again proved the "Anchoring" effect put forward by previous scholars. It is discovered that the impact of retail price and salvaged cost on the subjects' actual mean order quantities has a similar "Anchoring" effect of purchase cost, and this is one of the contributions of this paper. Therefore, we reject Hypothesis 2.

Figure 1 shows the effect of demand scale on the subjects' actual mean order quantities; from it we can see that the effect of demand scale on the subjects' actual mean order quantities is different from that of retail price, purchase cost and salvaged cost. With the increase and decrease in the quantity of demand scale, the subjects' actual mean order quantities are higher than the theoretical optimal order quantities by a nearly constant difference, and the difference between the subjects' actual mean order quantities and the optimal order quantities is not obvious (see Figure 1 and Table 2). The interpretation for this experimental results is that the ratio "the critical fractile $(p-c)/(p-s)$" does not consist of the parameter of demand scale. Of course, the experimental result was obtained under the specific experimental environment, where the purchase cost is not too high nor too low, and we suggest that the results obtained from such experimental environment had better to be further confirmed by expanding the scope of purchase cost and salvaged cost.

Experiments 105, 107, 109, 111 were referred to the profitable state, and experiments 106, 108, 110, 112 were the corresponding loss state. From the figures and Table 2, we can conclude that the decision environment (profit or loss) has no significant effect on the subjects' actual mean order quantities. Therefore, we accept Hypothesis 3. We could not interpret the reason why the experimental findings are not consistent with the description of Prospect Theory. We wonder how much extent could the actual experimental environments induce the subject to feel that he or she was really in a position of "gain" or "loss", and the experimental findings had better be further verified by improving the processes of experiments.

4. **Conclusions.** Behavioral experimental results have exposed the defects of the assumption that decision-maker is perfectly rational. In this paper, we first reexamine the "Anchoring" effect put forward by previous scholars. Then we extend the previous behavioral experimental researches from the relationship between human subjects' order behavior and purchase cost to the relationship between the order quantities of human

subjects and the parameters such as demand scale, retail price and salvaged cost; especially we demonstrate the trend of human subjects' order quantities with the increase and decrease in the quantity of demand scale, retail price, purchase cost and salvaged cost. After that we compare the trend of human subjects' order quantities with the parameters rise and fall when the decision-maker is in a state of profit or loss. The main contributions of this paper are as follows. First, it is discovered through the behavioral experiments that the impact of retail price and salvaged cost on the subjects' actual mean order quantities has an "Anchoring" effect similar to purchase cost. Second, with the increase or decrease in the quantity of the parameters, it is found that when the optimal order quantity is lower or higher, there is a gap between the subjects' actual mean order quantities and the optimal order quantities; the higher (the lower) the optimal order quantity is, the greater the difference between the two is. Third, with the increase or decrease in the quantity of the parameters, it is found that the effect of demand scale on the subjects' actual mean order quantities is different from that of retail price, purchase cost and salvaged cost. Finally, it is found that the decision environment (profit or loss) has no significant effect on the subjects' actual mean order quantities.

The experimental results indicate that people respond irrationally to the decision parameters (demand scale, retail price, purchases cost and salvaged cost), but their responses can be reasonably well predicted. Although our research provides some insights into the effect of the relevant parameters on human subjects' order behaviors, there is ample room for future research, for example, to assess the value of irrational behavior quantitatively, and incorporate the irrational behavior parameters into the traditional newsvendor model to establish a supply chain ordering model with bounded rationality. The significance of the experimental findings is to apply the conclusions of the experimental research to the practical decision-making of supply chain management. The managers who are aware of this might consider redesigning their order decision process and introducing new parameters to correct the optimization of the traditional inventory theory. Introducing the conclusion of this research into the traditional newsvendor model, it will be potentially effective in improving the accuracy of decision making in practice.

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