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Group decision making in Newsvendor game: a pilot human experiment

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Abstract: Well established behavioral studies in Operations Management highlight that the Human's behaviour deviates from the optimal solution, even in simplified operating conditions such as those represented by the famous Newsvendor problem. Built on the results of controlled human experiments, this study proposes a decision-making model that accounts for the heuristics of anchoring and adjustment. Two experimental conditions, differing in the provision of demand information to couple of decision makers, are used to generate data. The model estimated shows that anchoring and adjustment behaviour differs in the two conditions: demand information knowledge enables smoothing partially the pull to center effect.

Keywords: Behavioral operations management, Inventory management; Controlled human experiments; Anchoring and adjusting metric.

1. INTRODUCTION

The Newsvendor problem is one of the main dilemmas related to the inventory management under uncertainty conditions. It can be summarized as the issue of who needs to determine the quantity to reorder before knowing demand and not being able holding inventories for a long time. The goal is to maximize profit by balancing revenue, unsold and backlog costs.

The Newsvendor problem appears in many business contexts. Controlled human experiments is one of the most commonly used research methods; this method involves submitting the Newsvendor problem to practitioners or students in order to evaluate how individuals make decisions and thus what management style they adopt. While conducting controlled human experiments, decision makers are provided with information that should allow them to maximize the expected profit; nevertheless, it is observed that they move considerably away from the behavior that we might call rationale (e.g., pull to center effect).

The humans' inability to replicate systematic behaviors that ensure optimal choices depends on a set of causes that also belong to the cognitive sphere and are linked to emotional, behavioral factors, personality, or excessive trust. Evidence shows how often individuals are more overconfident than correct.

The primary goal of the study is to verify an emerging anchoring and adjusting model of human behavior in controlled newsvendor game experiments.

Moreover, clustering observations by associating individuals to distinct groups, and reaching a deeper and more aware understanding of the choices made about orders, not only in relation to the individual but to groups of players is a further result. The group allows overcoming individual observation limits and overlooking the negative effects of cognitive mapping that greatly influence decision-making and problem solving skills.

The paper presents a brief description of the Newsvendor problem, the mathematical structure, as well as the various fields of application referring the state-of-the-art.

The structure of the controlled human experiments, performed at the University of Catania for the case of single player and player pairs, is also described.

The model adopted is also depicted: this is the Anchoring & Adjustment (A&A) model, according to which the players establish a first quantity to order, namely, *anchor*, and then try to *adjust* this quantity according to the evolution of the game. Finally, the results of the A & A model and the hierarchical cluster analysis, applied to the case of single player and pair of players, are presented.

2. LITERATURE REVIEW

In its simplest formulation, the Newsvendor problem considers a decision maker who must choose the quantity Q_t to be ordered from a supplier, in each period t, before the customer demand, D_t, is known. Typically, the decision maker has some information on the demand distribution parameters to aid the decision, such as mean, standard deviation, and cumulative distribution function of the demand; purchase cost, c; sale price, $p > c$; and salvage value of unsold goods, $s < c$.

The optimum order is chosen by maximizing the expected profit, depending on the level of service that is assumed for the description of the problem, such as the coverage of stocks (Bedonly et al., 2006):

$$Q_{opt}=F^{-1}[(p - c)/(p - s)] \quad (1)$$

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where (p - c)/(p - s) is the so called critical ratio, *CR*, and the inverse function $F^{-1}[(CR)]$ depends on the nature of the demand probability distribution. The critical ratio is used to define two different conditions of the problem: the high profit condition, when $CR > 0.5$, implying that the optimal period order quantity is higher than the mean demand; and the low profit condition, when $CR < 0.5$, in which the optimal period order quantity is less than the mean demand.

Several controlled human experiments have shown that the observed deviations are partially due to a series of behavioral biases that pervade decisions. Schweitzer and Cachon (2000) were the first to identify a systematic deviation of the mean value of the quantity ordered from the optimal value in a controlled experimental environment. They conducted experiments studying the decisions made by participants in a 30-period Newsvendor game playing both the high-profit and low-profit conditions. Subjects were provided with information about the demand distribution, and feedback on market demand and profitability at the end of each period of play. In the high-profit scenario, participants ordered, on average, less than the optimal amount whereas in the low-profit scenario, participants ordered more than the optimum. This behaviour was defined *pull to center effect*.

Deviations from the optimal choice were asymmetric, since orders were slightly closer to the normative order quantity in the high-profit case than they were in the low-profit case. Schweitzer and Cachon (2000) argued that choices were not explained by alternative preference functionals (e.g. risk aversion, Prospect Theory, loss aversion, etc.), but rather by the heuristic of *anchoring and insufficient adjustment*. With anchoring and insufficient adjustment, a decision maker identifies a focal value, and then adjusts towards a second value during the game. The initial value, or anchor, could be the result of an initial calculation and the adjustment is typically insufficient. Within the class of anchoring and adjustment heuristics, Schweitzer and Cachon (2000) considered the mean anchor heuristic and the demand chasing heuristic. Several studies based on human experiments have replicated the pattern of ordered quantities observed by Schweitzer and Cachon (2000), among which Benzion, Cohen, Peled, and Shavit (2008), Bostian et al. (2008), Bolton and Katok (2008), Bolton, Ockenfels, and Thonemann (2012), and Moritz et al. (2013).

Comparing Chinese and American players, Feng, Keller, and Zheng (2011) find that average order quantities of Chinese subjects are closer to the anchor of mean demand than those of American subjects, thus suggesting that Chinese are more prone to a pull to center effect (Bolton & Katok, 2008). Ren and Croson (2013) test whether overconfidence, i.e. an excessive confidence in the decision maker's own abilities, is responsible for the behavior shown by decision makers in the newsvendor problem. The authors show that there is a positive correlation between overconfidence and the deviation from optimal ordering during the run of the game.

Deviations from normative values and the use of anchoring and adjustment heuristics are also expected to depend on contextual factors, such as the information available to the decision maker, the feedback received after each period of play, and experience gathered. Concerning the impact of information, Benzion, Cohen, and Shavit (2010) run human experiments dividing participants into two groups. The first group knows the characteristics of the demand, while the second group does not. Participants in the first group are expected to order a quantity closer to the optimal one if compared to those of the second group, and to achieve higher profits. However, both groups converge to a mean order quantity different from the optimum, suggesting that information regarding customer demand is not an important factor in decision. In their study, Bolton and Katok (2008) find that providing extended experience (by increasing the periods of play from 30 to 100) improves Newsvendor performance, but slowly. In a second experiment, the authors study the impact of feedback on forgone payoffs but profitability does not vary significantly with the degree of feedback.

Although many experimental papers on the newsvendor problem have found evidence generally consistent with ''anchoring and adjustment", the relevance of the mean anchor vs. the demand chasing varies across experiments. For instance, Moritz et al. (2013) find more demand chasing than previously observed.

Further, Lau et al. (2014) show that group features differ considerably from those of each individual experiment participant, and that calculating the average value, per se, leads to false conclusions. In particular, while pull-to-center seems ubiquitous based on aggregate data, individual data suggest a lot more heterogeneity in behaviour, and even more surprising, show that mean anchoring is not the modal decision rule. These results underscore the need to engage in a broader evaluation of the individual behaviour in human experiments, considering more in particular the frequency distribution with which each type of heuristic occurs (De Vericourt, Jain, Bearden, & Filipowicz, 2013). One beneficial effect of allowing for heterogeneity in preferences and heuristics adopted is the possibility to design more appropriate contracts for buyers (Becker-Peth, Katok, & Thonemann, 2013).

Relatively little has been written about group decision making in newsvendor game (Gavirneni and Xia, 2009). (Wu and Seidmann, 2015) with different results.

3. METHODOLOGY

3.1 Controlled human experiments

Controlled human experiments have become an established empirical methodology for studying the impact of cognition and decision processes in operations management (Boyer & Swink, 2008), due to the high internal validity of findings and their replicability.

Human experiments can supplement operations management research by providing insight into how the human factor influences operational decisions and by exploring how human characteristics interact with operational and organizational aspects (Boyer & Swink, 2008; Croson & Donohue, 2002).

Generally, in experiments a group of individuals (students or professionals) performs, in a controlled environment, hypothetical choices that do not involve actual losses or gains. The researcher manipulates the specific conditions and parameters of interest.

During the course of the experiments, real incentives may be used to motivate participants and to encourage them ''to take the task seriously" (Narayanan & Moritz, 2015). The main limitation of human experiments regards their external validity, since the experimental environment is artificial and simplified, and may not adequately represent real life conditions.
The experiments on the Newsvendor game for this paper were performed on a sample of 20 couple of operations management graduates at the University of Catania (Italy). Preliminarily, through a tutorial, all students received instructions on the Newsvendor problem.
In the course of the tutorial, students were taught how to calculate the optimal solution of the game under different conditions. The experiment was carried out the following day, inside a computer lab with workstations uniquely assigned to each participant. Couples of decision makers played the game by means of a MS Excel spreadsheet application. Each couple of decision makers found the first round of the game already played (the order quantity $Q_{t=1} = 100$ was fixed for all individuals) in order to facilitate learning of the tool. The spreadsheet allows couples to play 50 periods; they were not provided with information about the game horizon; it was stopped after 30 periods in order to avoid any end game speculation.
To increase the motivation of participants, students received an incentive in terms of academic credits, based on their performance.
Our experiments focus only on the high-profit scenario of the game.
We experimentally manipulated information provided to experiment participants about the parameters of demand; a subset of participants were briefed on the statistical features of the demand, while the remaining subset were not provided with any starting information on the features of demand. In what follows we shall refer to the experimental condition with known demand distribution with the label INFO, while we shall term the experimental condition with unknown demand distribution NO INFO.
Table 1 summarizes the information provided to participants at the start of the game.

Table 1. Newsvendor game starting information

Experiment	*INFO*	*NO INFO*
Mean demand	D_m=100	*n.a.*
Standard deviation of demand	σ_d=30	*n.a.*
Critical ratio	0.75	0.75
Number of played periods	50	50

At the end of each round, each participant was also provided with the following feedback information: demand per period, D_t; progressive mean demand, Dmp_t; progressive standard deviation of demand, σ_{Dpt}; and information on the quantity sold, revenues, profit per period, and cumulative profit. Some of this information was also provided with graphical aids.
Participants were instructed that their goal was to choose the quantity to be ordered in each period in order to maximize the overall profit. For the known demand distribution condition, the optimal order quantity was equal to 120.

3.2. The decision model

Previous human experiments show that individuals playing the Newsvendor game change the order quantity continuously. The decision makers are usually provided with statistical information about the parameters of the demand distribution; they know the game horizon and receive feedback from previous rounds; they are usually graduate students or practitioners; they know the basics about Statistics; the game setting is fixed; demand is the only variable that changes. Nevertheless, they change the order quantity period after period: in line with extant literature, we suppose that they adjust the order quantity moving from some kind of anchor (e.g. mean demand anchor, mean demand progressive anchor, optimal order quantity anchor).
The anchoring and adjustment heuristic features behaviours in which subjects consider a value as a starting point, known as an anchor, and adjusts this information until an acceptable value is reached (Tversky & Kahneman, 1974).
The following model, (D'Urso et al., 2017), aims at replicating the cognitive process followed by a decision maker who applies a generic anchoring and adjustment heuristic to a repeated decision setting.
Let:

$$Q_t = An_t + Ad_t = aDmp_{t-1} + C + kA_t \quad (2)$$
$$An_t = aDmp_{t-1} + C$$
$$Ad_t = kA_t$$

where:
a is the weight of progressive mean demand up to period $t-1$ ($0 \leq a \leq 1$);
Dmp_{t-1} is the progressive mean demand up to period $t-1$;
C is the deviation of order quantity from the mean demand;
k is an adjustment coefficient;
$A_t = b(D_{t-1} - Dmp_{t-1}) + (1-b)\, An_{t-1}\, D_{t-1}$ is the demand of period $t-1$; b is a smoothing coefficient of time series data ($0 \leq b \leq 1$).

The proposed model *(2)* consists of two terms: the first term An_t, i.e. the anchor, is a function of personality, risk posture, culture, intuition, and ability of the decision maker in relation to the Newsvendor problem. The cognitive process leading to the anchor assessment is based on the following activities: evaluation of information and past data about the demand, i.e. the mass probability function, the mean and standard deviation; calculation of the optimal order quantity.
In order to find the optimal order quantity, the rational player should evaluate equation *(1)* and find a unique and long range solution under the INFO condition, otherwise a local solution, until steady state conditions are reached, if starting demand information is not available (NO INFO condition).
More in particular, we hypothesize that Humans can create an anchor by means of two alternative patterns: the explicit and the implicit one. The explicit anchor is generated by summing a time dependent surplus *C(t)* to the expected demand. This cognitive dynamics could model the anchor and insufficient adjustment that Schweitzer and Cachon (2000) called pull to center effect. The *C(t)* surplus could depend on the demand standard deviation that individuals estimate during the game execution. So, according to Ren and Croson (2013) findings, the explicit anchor pattern can capture the behaviour by which individuals underestimate the

demand standard deviation (i.e. over-precision bias) and, as a consequence, over/under-estimate the order quantity calculating equation *(1)* under a misperceived value of demand uncertainty. The implicit anchoring process occurs when individuals define the anchor once and for all (i.e. a = 0; $C \in N^+$), without taking into account the mean value of the progressive demand.

The explicit and implicit anchor metrics can accommodate variations in the cognitive human process following variations in the information content available to individual decision makers. Under full initial information about demand (i.e. INFO treatment), the player should perform the implicit anchor evaluation assuming lower a values; on the contrary, under less than full initial information about demand (NO INFO), the decision maker should follow the explicit anchor process because she builds an estimate of demand step by step.

The second term (Ad_t, see equation *(2)*) is the adjustment, which, in turn, can be divided in two components: one that simulates how the subject takes into account the difference between the current demand and the progressive mean, exponentially smoothing the data of time series (*b*), and another one (*k*) that amplifies this latter result.

The *b* parameter captures which depth of demand time series individuals consider when performing an exponential smoothing process; high *b* values should characterize individuals who change the order quantity very quickly. The *k* parameter amplifies the results of the latter cognitive smoothing process and defines also the sign of the adjustment; a positive value results in the demand chasing effect; on the contrary, a negative value mimics the gambler fallacy effect according to which decision makers assess the next demand realization as if it was somehow correlated to the previous ones. Equation *(2)* fits the rational decision maker if the adjusting term Ad_t is null (i.e. $k = 0$ or $b = 0$ and $A_t = 0 = 0$), the anchor An_t is calculated by means of equation *(1)* taking into account the mean demand or the mean progressive demand whether demand information is complete or not.

4. RESULTS

Fig. 1 and 2 show the mean order for each period of the game and for each experimental condition. First, we notice that players operated a continuous process of adjustment of the ordered quantity along the game. However, no process of convergence towards the optimal amount of 120 pieces seems to take place, with oscillations around the mean order being comparable both in the early and late phases of the game (see Fig. 2).

In the high-profit scenario the optimal amount to be ordered is 120 pieces. However, the mean order quantity is consistently lower, thus confirming results obtained by Schweitzer and Cachon (2000) and other human experiments. Mean order is at 100.1 pieces in the NO INFO condition and at 108.9 pieces in the INFO condition. Therefore, from this summary descriptive analysis, it appears that lack of information about demand affects mean orders while demand information knowledge enables mitigating the pull to center effect.

Table 2. Human experiments results

Experiment	INFO	NO INFO
Mean ordered quantity	108.9	100.1
Average profit	15.628,55	15.262,12
Number of couples of players	10	10

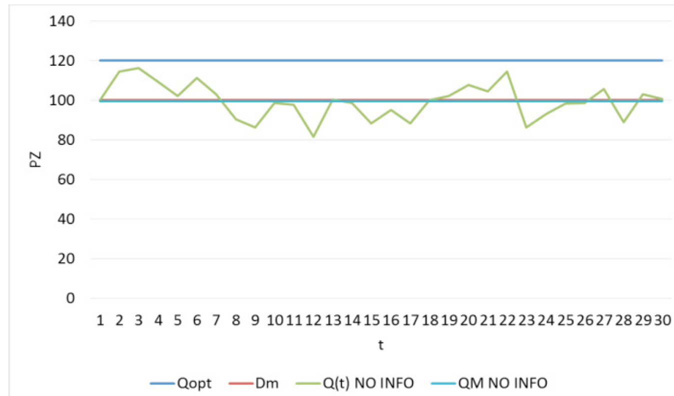

Fig.1 Average order quantity per period (NO INFO treatment)

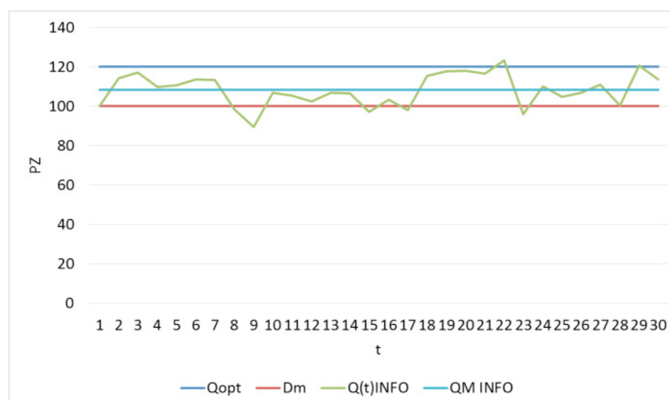

Fig.2: Average order quantity per period (INFO treatment)

As regard to average profits, however, the fact that individuals or groups have or not information does not appear as an important factor while the difference in profits matured in the group case becomes almost insensitive to the level of information.

It is possible to think that the relational dynamics characterizing the groups positively influence decision-making processes and help overcoming the difficulties associated with cognitive limitation that hardly induces individuals to rational behavior. In order to make a good choice, all the possible alternatives must be assessed, and therefore the greatest benefits that can be attributed to the group dynamics are the ability to guarantee a plurality of opinions, to encourage discussion, to exchange views and to leverage the derive from synergy collaboration.

6. CONCLUSIONS

As regards to the pilot human experiment performed, group decision-making seems to improve performances mitigating the pull to centre effect when demand knowledge is known.

The explanation of why individuals or groups of individuals adjust their decisions along the Newsvendor game experiment is not clear yet.

Therefore, future studies are called to investigate what determines the model parameters. Recent studies in this direction have focused on behavioral determinants such as cognitive reflection and over-confidence. We conjecture that the pathways by which an individual believes in the statistics of small numbers are the basis of the attempt to influence profit in the short term, and lead to the phenomenon that is described by means of the adjustment heuristics.

In addition, it would be of interest to investigate whether the differences in the application of the anchoring and adjustment heuristics that have been observed for the high profit condition of the newsvendor game hold also in the low profit condition.

Future research is called to clarify these issues and to provide a greater understanding of the cognitive processes governing decisions in the supply sphere; future research is called also to clarify how the controlled human experiment deals with the Newsvendor problem results.

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