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Modelling Human Behaviour in Newsvendor Game

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Abstract: The production systems are made up of technologies, organizational styles, management models and, above all, individuals. The human contribution in operations management is particularly critical because it has a significant effect on the outcomes and it is difficult to predict. The literature review shows that, even in simplified operating conditions, such as those represented by the famous problem of newsvendor and in conditions of complete information, the behavior of human managers deviates considerably from the optimal. The literature review also shows that, although the concept of bounded rationality is now well established, the modeling of human behavior is still incomplete, often limited to the verification of a single type of bias without considering their simultaneous presence. This study, based on the results obtained from controlled human experiments on newsvendor game, proposes a decision-making model that takes into account more than just one bias and is based on the heuristics of anchoring and adjustment. The model shows a promising capacity to reveal the individual's behavior.

Keywords: Newsvendor game; Decision making; Human and controlled experiments.

1. INTRODUCTION

We often have to make decisions under uncertainty so that the consequences are not fully known. It's important to understand, therefore, the way in which people act when, facing a complex problem, the time available for deciding is limited, the information is partial and the uncertainty on the consequences is remarkable.
As part of the Operations Management, research tackles extensively the study of how individuals make decisions when orders are to be placed to suppliers in order to meet the customer demand (Tversky, 1974). In recent years it has been the subject of in-depth study of the newsvendor problem. It is now a model of purchase of products in the presence of demand uncertainty.
The newsvendor problem idealizes the dilemma that the newspaper seller faces every morning. At the beginning of the mission the newsvendor must choose how many copies of a newspaper to buy from his supplier in order to meet the daily demand, without having an accurate prediction of how many copies effectively serve. At the end of the day, he/she will incur a loss of profit if demand has been underestimated on the contrary he/she will incur in operating cost of unsold.
Generalizing, the problem characterizes all situations where before the market demand is realized an effort that involves costs must be taken.
The producer who chooses the order quantity to be produced in a market in rapid obsolescence (computer or mobile phones), or that deals with special promotions, lives the same problem: too little order creates ineffectiveness against the customer while ordering too much creates internal inefficiencies.
There are numerous case studies that suggest that the decisions of the newsvendor may be common in reality. In conclusion, the newsvendor problem concerns the decision maker who should define the quantity Q_t to be ordered to the supplier, in each management period, before the customer demand, D_t, occurs.
The decision maker has, usually, some information: mean, standard deviation and cumulative distribution function of demand D_t; purchase cost, c; sale price, p> c, and salvage value of unsold, s <c.
The optimum amount to be purchased is evaluated by differential calculus, looking for the maximum value of the expected profit depending on the level of service that is assumed for the description of the problem, such as the coverage of stocks:

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

where (p–c)/(p–s) is the named critical ratio.

The critical ratio is used to define two different conditions of the problem: high profit when $(p-c)/(p-s) \geq 0,5$; in this condition the optimal order quantity, per period, is higher than the mean demand; low profit when $(p-c)/(p-s) < 0,5$; in this condition the optimal order quantity, per period, is less than the mean demand.
Despite the newsvendor problem has a simple structure and is well known the optimal amount to be ordered, as demonstrated by some experimental studies (Schweitzer and Cachon 2000, Bolton and Katok 2008, Bostian et al. 2008, Ren and Croson, 2013 etc.), it often happens that the human decision makers address this dilemma deviate systematically from the order quantity that maximizes profit.

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Despite the experimental evidence, is not yet understood the cause of these behaviors and understanding it would have a profound impact in finding *debiasing* techniques.

The aim of our study, therefore, is to evaluate models of reasoning, or heuristics, adopted by humans during the formulation of the order, and check whether these are dependent on the particular personal characteristics of individuals and analyze the impact.

This paper presents, below, a review of literature that describes the problem of newsvendor from the theoretical point of view and shows some studies that have been taken as principal reference. Subsequently, the methodology used is presented; more in particular are described the human and controlled experiments which were used for the detection of the personal characteristics of individuals and for the conduction of the newsvendor game; it is also codified the model proposed for representation of the behavior of individuals; the latter involves two basic heuristics leading to the decision: the anchoring and the adjustment.

The discussion of the results allows us to appreciate the quality of the model and its capacity to detect the characteristics of human behavior of each decision maker. The detection of the limits of the analysis and its future developments complete the study.

2. LITERATURE REVIEW

The newsvendor problem is one of the most studied topics in the field of supply chain management; its structure is close to many business problems, which explains the considerable attention to him (Moritz et al, 2013). Although the problem of the newsvendor describes a case study relatively simplified, with known optimal solution, previous experimental studies and observation of behavior in industrial contexts have shown that human decision makers do not take optimal decisions; they order, on average, an amount that does not maximize the expected profit. The adoption of a rational and optimizing behavior by the decision-maker in the context of the problem of newsvendor, would lead to always order the same amount at each period of sale. In particular, many research works have shown that partially the observed deviations are due to a series of biases that pervade the decision makers. The studies on the subject have generally focused on a single bias at a time trying to better identify the influence on the final results.

Schweitzer and Cachon (2000) were the first to identify a systematic deviation of the mean value of the quantity ordered by the optimal value. They conducted experiments studying the decisions made by the participants at a thirty sales periods newsvendor game with respect to two different conditions, high profit and low profit. Subjects were provided with feedback on market demand and profitability at the end of each period. The researchers found that: in the high profit scenario participants ordered, on average, an amount less than the optimal; in the opposite scenario, low profit, participants ordered, on average, an amount greater than the optimal. Moreover, this phenomenon was asymmetric, because the quantities ordered were closer to the optimal quantity in the first case than in the second. For the two researchers this *too low/too high pattern of choices* could not be explained by factors such as risk aversion or loss aversion. Schweitzer and Cachon suspected, rather, that a process of anchoring and insufficient adjustment was the antecedent sought. This heuristic highlights how individuals, in many situations where they have to give an answer, make estimates starting from an initial value and then adjust the estimate during the formulation of the final answer. The initial value, or anchor, could be the result of an initial calculation and the adjustment is *tipically insufficient*.

In the case of the problem of the newsvendor the anchor may be, for example, the average value of the demand, the quantity ordered in the previous period, a particular value of the time series.

In particular, to give an explanation to the results of their experiment, Schweitzer and Cachon have considered two heuristics based on the process of anchoring: the mean anchor heuristic, assumes that the decision maker is anchored on the average demand and then adjust to the optimal order amount; the demand chasing heuristic, for which the decision maker, starting from the quantity ordered previously, adjusts in the direction of the last known value of demand. They found that the behavior adopted by the participants was consistent with the first heuristic and identified a weak support for the second.

Lau and Bearden (2012), starting from the considerations of Schweitzer and Cachon, show that acceptance tests of demand chasing behavior, often give rise to false positives; these detect the presence of an attitude of following the previous demand, even when this is actually absent; these authors have proposed and tested a different method that seems to be not prone to this risk: simply evaluate the correlation between the quantity ordered at each sale period (Q_t) and the demand which occurred the period before (D_{t-1}).

Benzion, Cohen and Shavit (2010) conducted an experiment by dividing 121 participants into two groups: the first know the characteristics of the demand, the second not. In such a situation what is expected is that subjects belonging to the first group order a quantity closer to that optimal compared to those of the second group. The results were surprising, however, because the knowledge of information regarding the customer demand was not an important factor in order to obtain a higher profit: the subjects of both groups converged anyway on a mean order quantity different from the optimal.

Ren and Croson (2013) have attempted to assess whether the overconfidence is responsible for the behavior shown by decision makers.

Overconfidence can be defined as an excessive confidence in our own abilities; a declination of the overconfidence, called over precision, measures the excessive confidence of individuals regarding the accuracy of their forecasts and information; this is also defined as the tendency to underestimate the standard deviation of a random variable defining confidence intervals smaller than they really are.

Ren and Croson (2013) have shown that there is a positive correlation between overconfidence and the deviation from optimal ordering during the run of the game.

The assumption of the authors is the belief that the individual's overconfidence leads to an underestimation of the variance of the customer demand; this bias pushes the individuals to compress, in their perception, the domain of existence of the demand and, consequently, to move away slightly from the mean demand when they order.

The cognitive mechanism explained by the authors is fascinating but their regression model has a very low coefficient of determination (R^2 = 0.031); furthermore the correlation found by the authors, although robust, does not explain a fundamental question: why individuals continuously adjust the quantities ordered? Why individuals do not order a constant amount, even lower than the optimal due the contribution of overconfidence?

The literary context presents, therefore, at least two elements of weakness.

On one hand, it focuses only on a single factor that can explain the deviation from optimal behavior occurred during the controlled experiments; on the other, a link between causes and effects is always sought without trying to encode a model of human behavior that takes into account more than a single management profile and try to clarify how the individual operates the decision-making process and, in particular, how the decision maker perceives the demand uncertainty, how the decision maker perform the demand forecast and even how the decision maker takes into account the balance between costs and benefits, moving away the order quantity from the expected demand, which prejudices make stable decisions (anchoring) and which tend to instability (adjustment) in particular following the evolution of the demand (demand chasing) or moving away from it.

In the following is proposed, therefore, to reproduce the behaviour of individuals playing the game of newsvendor using a model that takes into account multiple profiles of behaviour to determine what weight those profiles have in the decisions and whether they are linked to the characteristics of the individuals. The model is coded considering the same information content available to players of controlled experiments and assuming that humans are characterized by bounded rationality. In this context, the purpose of our research is to reach a better understanding of the behaviour in the real processes to identify techniques or approaches to mitigate the distortions and improve the quality of decision making.

3. METHODOLOGY

The research methodology, according to the mainstream of literature, consists of two phases. In the first, the collection of empirical data is done through the conduction of behavioural and controlled experiments.

During the experiments a group of individuals is asked to perform, in controlled environments, hypothetical choices that do not involve actual losses or gains. The researcher manipulates the specific conditions of development.

The main limitation of the experiments regards their external validity, since the experimental environment is however artificial and simplified and may not adequately represent the actual conditions.

During the course of the experiment are used incentives to motivate participants and simulate conditions more relevant to reality.

In the second phase, a mathematical model that simulates the behaviour of individuals is developed; the arguments on which the model is based and, more particularly, the weights that they assume during the calibration phase reveal the average or the individual characteristics shown by those involved in the game.

The experiments regarding the newsvendor game were performed on a sample of students of the Master Degree in Management Engineering (University of Catania); more particularly the first experiment was conducted in the spring of 2013 and involved 45 students; a second experiment was replicated on a sample of 36 students in the spring of 2014.

Preliminarily, through a lecture, all students were provided with general guidelines regarding the problem of the newsvendor; the two different conditions in which the game can be played, varying the critical ratio, were also briefly described (high and low profit conditions). The optimal solution of the game was therefore explicitly presented to the students.

The experiment was conducted, after one day, within a computer room with workstations uniquely assigned to each participant. To increase the motivation of the participants, an incentive in terms of academic credits was promised.

With the purpose of detecting the characteristics and personality of the players was also conducted a set of preliminary tests.

Individual risk aversion (RA) was measured by using a sequence of ten pairs of risk options that belong to the multiple price list type (Di Mauro et al., 2004); the level of individual overconfidence (OC) was also measured according to the test of Richardson that engages individuals through questions of general knowledge (Moore et al, 2008; Ancarani et al. 2011). The measure that is obtained is not related to the problem of newsvendor; so, in order to observe the personal characteristics in an area closer to that in which the business game is played, a special technical test was conducted; we argue it is able to capture the *technical overconfidence* (OCT).

During this test, the students, who play the role of a manager, face demand forecasting of a product over 30 distinct periods knowing the mean, standard deviation and cdf of the demand time series; during each period of analysis each individual is then asked to give his/her best estimate of the demand that will occur during the next round; every five periods, finally, each individual is asked to indicate a range of values of the demand, characterized by an upper bound (UB) and a lower bound (LB), such to contain the next demand value with a cumulative probability equal to 90%. The time series is stationary and not seasonal, this implies that the best forecaster should always estimate the average demand and show-like an anchored behaviour without any adjustment.

The measure of technical overconfidence is obtained by using the following equation:

$$OCT = (4{,}5-n)/m \quad (2)$$

where n is the number of correct estimates and m=5 is the overall number of asked estimations.

The newsvendor game was played by two teams dealing with the problem in the low profit scenario or in the high profit one.

The participants of the tests conducted during the spring of 2013 were briefed on the statistical features of the demand as well as those relating operating costs; the same participants

were also made known again of the value of the optimal order quantity.
The participants of the tests conducted during the spring of 2014 have not been provided with any starting information on the features of the demand.
Table 1 shows the summary of information on the experiments which were conducted. Each participant at the end of each round was also provided with the following information: demand per period, D_t; progressive mean demand D_{mpt}; progressive standard deviation of demand, σ_{Dpt}; and other information on the quantities sold, revenues and profit per period and the progressive profit. Some of this information was also provided with graphics support.

Table1 Starting newsvendor game information.

Test	2013		2014	
Newsvendor game scenario	HP	LP	HP	LP
Expected demand	D_m=100	D_m=100	n.a.	n.a
Std deviation of demand	σ_D =30	σ_D =30	n.a.	n.a.
Number of participants	18	17	24	20
Critical ratio	0,8	0,6	0,8	0,6
Optimal order quantity	120	80	n.a.	n.a.

The goal was to determine the quantity to be ordered at any time in order to maximize the overall profit.
Also in this experiment, every 5 periods, participants were asked to indicate a range of demand values that, with a cumulative probability of 90%, contains the demand of the next period. With the data thus obtained was calculated again the "in-task" overconfidence, through the equation (2).
The core of work is, finally, the encoding of the model that can replicate the reasoning process followed by individuals in the decision of the quantity to be ordered.
The model developed aims to capture more profiles of behavior, the anchoring and adjustment; it recovers the echo of Sterman (Sterman, 1989); it is formulated as follows:

$$Q_t = An + Ad = aD_{mp,t-1} + CP + kA_t \qquad (3)$$

$$An = aD_{mp,t-1} + CP$$

$$Ad = kA_t$$

where:

$$A_t = b(D_{t-1} - D_{mp,t-1}) + (1-b)\, A_{t-1}$$

a is the weight of progressive mean demand up to period $t-1$ ($0 \le a \le 1$);

$D_{mp,t-1}$ is the progressive mean demand up to period $t-1$;

CP is the deviation of order quantity from the mean demand;

k is an adjustment coefficient;

D_{t-1} is the demand of period $t-1$;

b is a smoothing coefficient of time series data ($0 \le b \le 1$).

The proposed model consists of two terms: the first term (An) is a function of culture, intuition and the ability of the decision maker in relation to the problem of newsvendor, this term can be considered as the anchor that every decision maker has in mind during the business game; the second term (Ad) is the adjustment and, in turn, it can be divided into two contributions: one that simulates how the individual takes into account the difference between the current demand and the mean progressive, smoothing exponentially the most recent data and the most remote of the time series, and another that amplifies this latter result.

4. RESULTS AND DISCUSSION

Figures 1-2 show the cumulative distribution functions of risk aversion (RA), overconfidence (OC) and technical overconfidence (OCT) measured during the preliminary testing phase (RA and OC) and during the run of the game newsvendor (OCT). Individuals are weakly risk averse (mean RA=3.5); they exhibit less overconfidence when they are engaged in a technical evaluation (OCT) rather than in answering general knowledge questions as in the case of the Richardson test (OC).

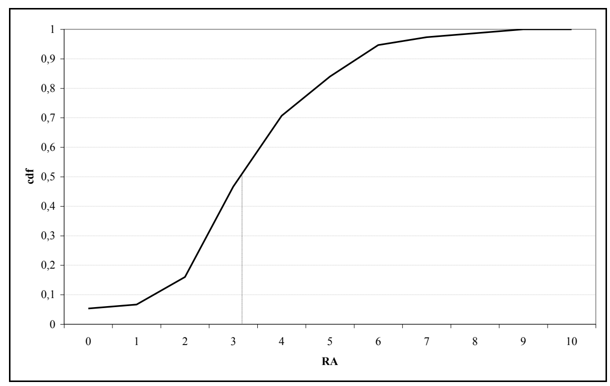

Figure1 Cumulative distribution of individual risk aversion (RA).

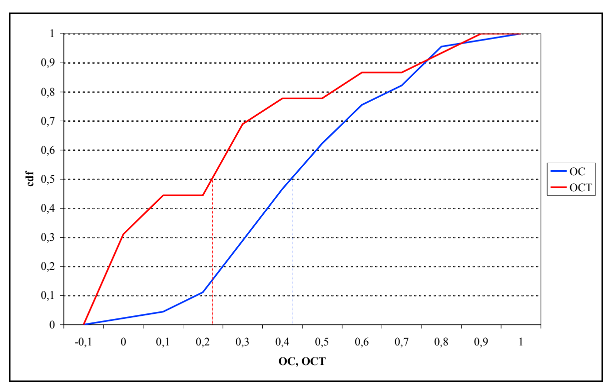

Figure 2 Cumulative distribution of overconfidence (OC) and technical overconfidence (OCT).

The variance of the in-task demand estimation σ_{De}, that was performed by individuals, differs little from that of the demand D_t during the simulation of the game (see table 3); this implies that the attitude of the individual and his willingness to show overconfidence changes depending on the type of test that sustains.
The measure of σ_{De} was performed by means of Bostian equation (Bostian et al. 2008):

$$\sigma_{De} = (UBm - LBm)/3{,}2 \qquad (4)$$

where UBm and LBm are respectively the mean value of upperboud and lowerbound of demand which individuals estimated during the newsvendor game test.

With regards to the results of the newsvendor game, it should be noted first that people usually change continuously their decisions on order quantities: they operate a continuous process of adjustment (Fig. 3-4).
Figures 3-4 illustrate the outcome of the business game; in particular: the ordered quantities for each period of the game and for each scenario (LP-Qt, Qt-HP), the optimal order quantities for each scenario (LP-Qopt, HP-Qopt), the mean individual order (LP-Qm, HP-Qm) and the mean values of the demand simulated (LP-Dm, Dm-HP; the tests conducted during the spring of 2014 has a different demand profile for each scenario).

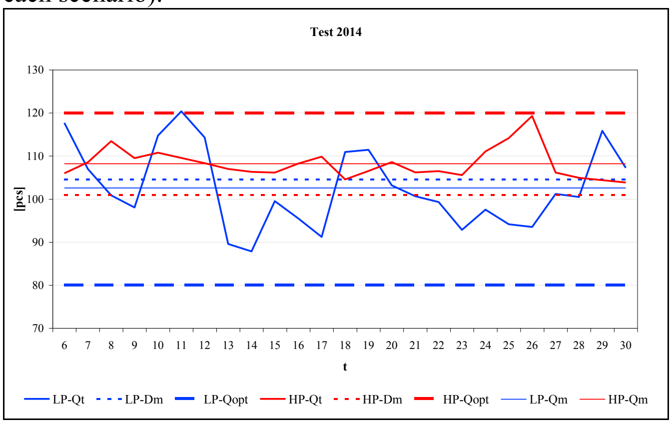

Figure 3 Newsvendor outcomes (test 2014)

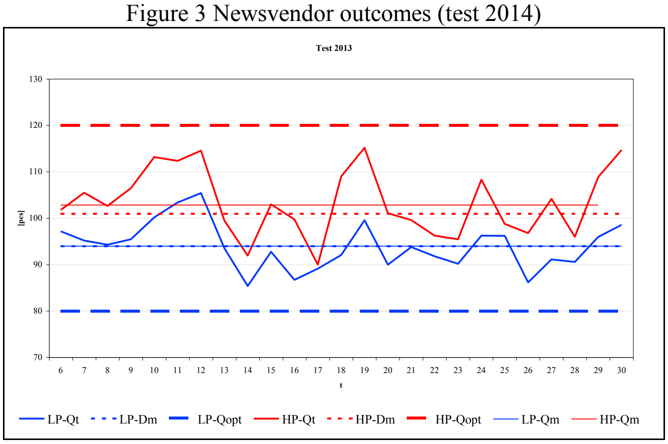

Figure 4 Newsvendor outcomes (Test 2013)

In the scenario of high profit the mean order quantity is lower than the optimal amount; in the scenario of low profit the mean order quantity is greater than the optimal amount. The results confirm those obtained by Schweitzer and Cachon (2000).
The results show that, although only the participants of 2013 knew the optimal order quantity, the deviation from the mean demand is comparable in the two games; furthermore the decision makers that have more information don't obtain any advantage. This conclusion is consistent with the results of Benzion, Cohen and Shavit (2009).
It also verified the asymmetry in the behaviour of the players; they order, moving away from the average value of the demand towards the optimum amount, to a greater extent in the case of high-profit scenario rather than in the remainder.
This is not confirmed for the group of students who played the scenario LP during the spring of 2014; in this case the mean order quantity, LP-Qm, was higher than the mean demand LP-Dm.

The parameters of the analytic relation (3) were determined, finally, for each individual in order to minimize the sum of squared deviations between the quantities effectively ordered, in each period, and the amount decided by the proposed model.
It was decided to not consider the results obtained by the individuals who played the low profit newsvendor game in the spring of 2014, because of the variability in the order quantities; a significant error in relation to the proposed model were detected by means of the statistical test of Mann -Whitney; the explanation for this behaviour is related to the modalities of conduction of the newsvendor game; this latter was conducted immediately after the lecture without giving to the decision makers a sufficient period to mature expertise about the business game.
The model presents a significant ability to reproduce the results of the decision makers (the coefficient of determination is $R^2=0.55$).
The analysis of the coefficients of the model allows to add further comments: in both scenarios, HP and LP, the order quantity is significantly influenced by the progressive mean demand due to the *a* contribution; the correction that is applied to the value of the progressive mean demand, established by each individual through the contribution of *CP*, is not negligible. In general the anchor fully influence the choice of each decision maker (the mean values of *a* and *CP* are respectively: $am=0.50$ and $CPm=46.09$). The correlation between *a* and *CP* presents coefficient $c=-0.92$; furthermore the frequency distribution of *a* (fig.5) has high values to the extremes of its domain; this implies that individuals have two modes of reasoning for finding anchor:

1. they consider the value of the progressive mean demand, due to the contribution of the *a* parameter, and then they add the term *CP* according to the type of newsvendor (*CP* is negative or positive and contributes to a greater extent in the scenario high profit as shown in the literature; fig.6);
2. they summarize a value of anchor without making the process described above; in this case the parameter *a* is zero and the anchor is equal to *CP*.

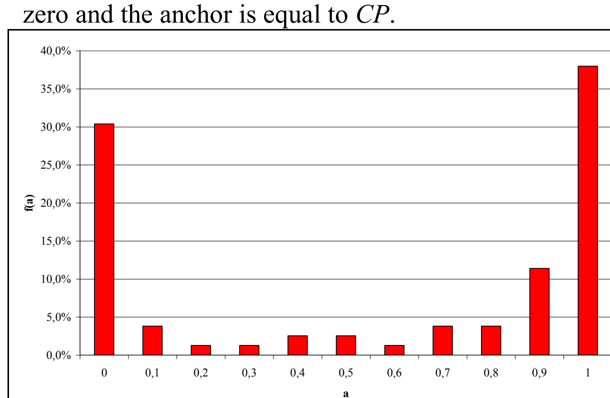

Figure 5 Frequency distribution of *a*.

The adjustment coefficient *k* shows considerable variability around the mean; an analysis of the correlation between the ordered quantity (Q_t) and demand of the previous period (D_{t-1}) reveals a positive link c'= 0.54; few individuals have a negative correlation coefficient, which implies that most of the decision makers adjust orders chasing the customer demand.

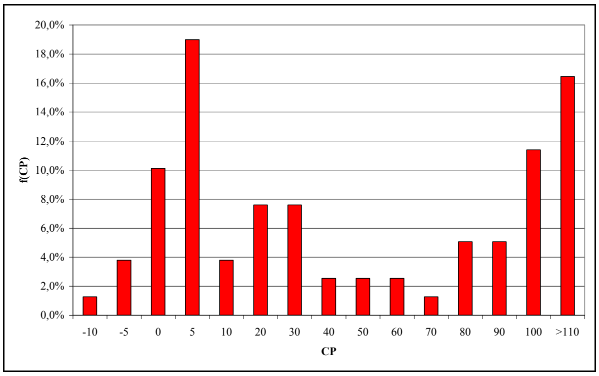

Figure 6 Frequency distribution of *CP*.

The weight that each individual attributes to the recent or remote past of the time series, varying the parameter *b*, appears equally distributed; consequently, on average, the decision maker shows equal attention to the recent past as well as to the remote past.
The study of the correlation between the individual features of the participants (risk Aversion RA, overconfidence OC, technical overconfidence OCT) and the parameters of the proposed model (*a, b, CP, k*) has not yet revealed significant links.

Table 2 Behavioural model parameters

		Scenario	
	Symbol	HP	LP
Nominal demand	D_m	100	100
	σ_D	30	30
Simulated demand	D_m	99,88	104,60
	σ_D	29,37	25,79
Std deviation of in-task demand estimation	σ_{De}	26,88	22,32
Order quantity	Qm	108,22	93,93
	σ_O	18,98	20,09
Coefficient *a*	a_m	0,50	
	σ_a	0,44	
Coefficient *CP*	CPm	46,09	
	σ_{CP}	47,28	
Coefficient *k*	k_m	-0,29	
	σ_k	7,68	
Coefficient *b*	b_m	0,59	
	σ_b	0,37	
Coefficient of determination	R^2	0,55	

6. CONCLUSIONS

Human behaviour in operations management is fascinating; it has a high influence on the economic results of the management and depends on a set of causes belonging to the sphere of the individual features.
What seems certain now, depending on the outcome of the experiments whose results are widely disseminated in the literature, is the inability of humans to replicate a systematic behaviour as that of the optimal decision maker while they always tend to change continuously their estimations.
Although the research has already been studied in depth the problem of newsvendor, the above mentioned behaviour misses an explanation.
The proposed model of human behaviour has enabled us to demonstrate that individuals follow a logical process that leads them to establish a value anchor of order and, at the same time, to adjust depending on the time series demand; the model demonstrates the simultaneous presence of both heuristics of anchoring and adjustment.
The explanation of the adjustment is not yet clear, however, appears to come from the same set of considerations for which humans are unable to be systematic and to privilege, for example in the economy field, the future than the present. Probably the ways in which an individual believes the statistics of small numbers are the basis of an attempt to influence the profit in the short term sparking, so, the phenomenon of the adjustment.
The current research path and the results achieved, anyway, must to be better confirmed by considering a wider data set coming from of further controlled human experiments.

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