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Impulse balance in the newsvendor game ☆

Axel Ockenfels [a,*], Reinhard Selten [b]

[a] University of Cologne, Germany
[b] University of Bonn, Germany

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ABSTRACT

One striking behavioral phenomenon is the "pull-to-center" bias in the newsvendor game: facing stochastic demand, subjects tend to order quantities between the expected profit maximizing quantity and mean demand. We show that the impulse balance equilibrium, which is based on a simple *ex-post* rationality principle along with an equilibrium condition, predicts the pull-to-center bias and other, more subtle observations in the laboratory newsvendor game.

1. Introduction

In the newsvendor game, the newsvendor faces stochastic demand for a perishable product. Prior to seeing the actual demand draw, she must decide how much of the product to stock in inventory. The newsvendor model was first introduced and analyzed by Arrow et al. (1951). They show that, from a normative perspective, the expected profit maximizing order is straightforwardly computed. However, starting with the paper by Schweitzer and Cachon (2000), many researchers found that subjects in laboratory experiments order too much, relative to the expected profit maximizing order, when the ordering cost is high, and order too little when the cost is low.[1] This pattern is called "pull-to-center" bias. The deviation from optimality is strong and robust: it persists for various feedback conditions (Bolton and Katok, 2008) and demand distributions (Benzion et al., 2008), with extensive learning possibilities and strong incentives (Bostian et al., 2008), with different

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* Corresponding author at: University of Cologne, Albertus-Magnus-Platz, D-50923 Cologne, Germany.
E-mail address: ockenfels@uni-koeln.de (A. Ockenfels).

[1] The newsvendor problem is related to the probability matching phenomenon, where the decision maker must press either a red or a green button. One of the buttons yields a given prize with a fixed but unknown probability. The optimal choice is the button with the highest probability. Unlike what we see in the newsvendor game, however, experienced and properly incentivized subjects solve the probability matching problem well (see Shanks et al., 2002 and the references cited therein). The newsvendor problem differs in a number of dimensions, such as that the underlying stochastics are known to the decision maker, the prize is stochastic, and that the option that maximizes expected profit may not be the risk-averse choice.

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framings of the context (Kremer et al., 2010), and for different types of subject pools, including undergraduate and graduate students as well as experienced managers who are familiar with newsvendor-kind of situations (Bolton et al., 2012).

There appears to be no simple explanation for the pull-to-center bias. As noted by Schweitzer and Cachon (2000), the bias cannot be explained, for instance, by risk-aversion, risk-seeking, prospect theory, loss aversion, waste aversion, and stockout aversion. Each of these models would predict that newsvendors either always overorder or always underorder, regardless of whether the optimum is below or above the center (see also Kremer and Minner, 2008). However, based on their observation that "*Subjects were more likely to adjust their order quantities toward prior demand than away from prior demand. . . . Most of the time, however, subjects did not adjust their decisions, and across rounds the average order quantity was relatively stable*" (p. 418), Schweitzer and Cachon (2000) propose two more potential explanations. For one, bounded rationality, including what they call the *chasing demand heuristic*, which "*assumes a decision maker anchors on a prior order quantity and adjusts towards prior demand*." Second, because overall average behavior appears rather stable, Schweitzer and Cachon (2000) speculate that subjects may alternatively "*behave as if their utility function incorporates a preference to reduce ex-post inventory error*."

In a newsvendor game study which is probably most closely related to ours, Ho et al. (2010) investigate the potential of utility-based equilibrium explanations in more detail. Their model of reference-dependent preferences assumes that subjects maximize a utility function that includes psychologically costs of leftovers and stockouts. One advantage of their model is that it nests the standard model and Schweitzer and Cachon's (2000) idea of *ex-post* inventory error minimization as special cases, and so allows a simultaneous, structural estimate of all three models. The estimates suggest that their model explains newsvendor behavior and profits better than the other tested models.

Ho et al.'s (2010) model might be partly interpreted as an extension of Su's (2008) work, which assumes that individuals make utility-maximizing decisions with noise: while newsvendors choose the stock optimally with a higher probability than suboptimal orders, they do not so with certainty. His quantal response framework of noisy decision making can predict the pull-to-center bias, because there is more room to deviate from the optimum toward the mean demand (the center) than toward extreme demands. Ho et al.'s paper extends his approach by providing a psychological basis for why decision makers might appear to make errors.[2]

Econometric models by Bostian et al. (2008) investigate the adaptive nature of behavior as observed by Schweitzer and Cachon in more detail. Their study suggests that the demand-chasing heuristic performs well.[3] However, the explanations put forward by Schweitzer and Cachon do not fully organize the learning and treatment effects observed in their data. Yet, a larger learning model, which permits noisy adjustments, recency and reinforcement effects, captures the dynamics well.

These approaches are useful in showing that models of motivation and adaptation can go a long way to capture certain aspects of newsvendor behavior. At the same time there are limitations. For instance, the equilibrium models to explain newsvendor behavior are all static in nature and so do not capture the chasing demand pattern. Pure adaptation models such as the demand chasing heuristic, on the other hand, cannot easily explain treatment effects. Our study complements approaches based on limited motivation and adaptation by a *limited cognition* approach, the "impulse balance equilibrium" (IBE). While IBE has been developed in other contexts, we demonstrate that it predicts the pull-to-center bias along with other observations made in the laboratory newsvendor game.[4] It is based on a simple principle of *bounded* (*ex-post*) *rationality* that guides how decision makers adjust behavior over time, along with a straightforward *equilibrium* condition. The basic assumption of IBE, when applied to the newsvendor game, is that newsvendors respond to "impulses", which occur if a larger order would have been better in the last period (upward impulse) or a lower order would have been better (downward impulse). Assuming that newsvendors have a tendency to move in the direction of the impulse and to balance upward and downward impulses (as specified in Section 2), IBE predicts the central tendency of the stationary distribution of the newsvendors' orders. It does so without *ex-ante* parameter estimations.

Section 2 derives the IBE in the context of a typical laboratory newsvendor game with uniformly distributed demand, which is the distribution most often applied in laboratory settings. Section 3 shows that IBE predicts various behavioral phenomena, including the pull-to-center bias, and provides additional experimental evidence. Section 4 discusses the evidence and the limitations of IBE, and concludes.

2. The impulse balance equilibrium of the newsvendor game

IBE makes quantitative predictions about the central tendency of the stationary distribution of a decision parameter on the basis of the principle of *ex-post* rationality. IBE is applicable to the repeated decision on the same parameter in situations in which the decision maker receives feedback not only about the payoff for the decision taken, but also about

[2] Other utility-based models include Becker-Peth et al. (2013) and Wu and Chen (2014). Ren and Croson (2012) demonstrate that overconfidence is also a consistent explanation for suboptimal stocking. Here, overconfident newsvendors are assumed to believe their information or their estimate to be more precise than it actually is.

[3] Nelson and Bearden (2013) show that some of the measures used in the literature to identify demand chasing are prone to false positives and so tend to overestimate demand chasing. They argue that a simple correlation measure does not suffer from this problem. Ockenfels and Selten (2005) point to a similar problem in a related context.

[4] See Selten and Buchta (1999) for learning direction theory, which is the basis for impulse balance, and Selten et al. (2005), Avrahami et al. (2005), Ockenfels and Selten (2005), Brunner et al. (2011), and Selten et al. (2011) for the performance of IBE in other games, such as in auction games and various 2×2 games. Crawford (2013) discusses IBE in comparison to other models of boundedly rational behavior.