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# Are Strategies Anchored?

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## Abstract

Anchoring is one of the most studied and robust behavioral biases, but there is little knowledge about its persistence in strategic settings. This article studies the role of anchoring bias in private-value auctions. We test experimentally two different anchor types. The announcement of a random group identification number but also of an upper bid limit in the first-price sealed-bid auction result in higher bids. We show that such behavior can be explained as a rational response to biased beliefs. In Dutch auctions, the effect of a starting price, is negative. We demonstrate that the long-established ranking that the Dutch auction generates lower revenue than the first-price sealed-bid auction crucially depends on the size of the anchor.

*Keywords:* Anchoring Bias; Games; Incomplete Information; Auctions

*JEL Codes:* D44, D91, C72, C91

## 1 Introduction

Since the initial discovery of Tversky and Kahneman (1974), anchoring is recognized as one of the most prevalent kinds of behavioral biases. As Kahneman (2011) argues, it stems from an estimate of an unknown value that is biased toward a particular irrelevant number observed before estimating

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that value. The pervasiveness and relevance of the anchoring effect have been shown in many real-life situations including trivial judgments, price estimates for lotteries, purchasing decisions, and negotiations.<sup>1</sup> Despite the well-documented bias in individual decision-making, there is surprisingly little knowledge about how anchoring affects behavior in strategic interactions. In this paper, we study whether and how strategies are influenced by anchoring in games of incomplete information.

The concept of anchoring in games appears in the experimental as well as the empirical literature, but, to the best of our knowledge, a systematic controlled test is missing. There is experimental evidence that anchoring plays a role in asset markets (Baghestanian and Walker, 2015), negotiation (Galinsky and Mussweiler, 2001) and different auction settings (Holst et al., 2015; Medcalfe, 2016; Wolk and Spann, 2008; Peeters et al., 2016; Trautmann and Traxler, 2010; Ku et al., 2006).<sup>2</sup> However, it is a common feature of these studies that they do not systematically control for information sets. Hence, unambiguous causal inference is difficult. First, subjects in these experiments are typically exposed to other numerical values that may serve as anchors and influence behavior. Second, all these papers, with the exception of Peeters et al. (2016), do not use induced types and cannot specify whether anchoring comes from impaired judgment about the own type or whether this is a direct effect on choice.<sup>3</sup>

Our article tests hypotheses of prevalence and the direction of anchoring bias in games. In doing so, we make use of laboratory experiments with differently framed anchors in a competitive bidding game. Thereby, we focus on anchors that are clearly irrelevant for the computation of the (optimal) strategy. As our evidence shows, there is a significant anchoring bias: exposing players to irrelevant numbers has a significant effect on their choice of strategy. As we induce subject types, judgment on the own type cannot influence the outcomes. Hence, we argue that the observed bias is a direct

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<sup>1</sup>A substantial literature, mainly in psychology, analyzes anchoring, focusing on robustness and prevalence (Meub and Proeger, 2015; Green et al., 1998; Ariely et al., 2003; Simmons et al., 2010) and the role of cognitive process and abilities (Bergman et al., 2010; Mussweiler, 2001; Epley and Gilovich, 2001).

<sup>2</sup>Luccasen (2012) investigates anchoring effects in a public good game with complete information and finds no evidence of anchoring.

<sup>3</sup>Peeters et al. (2016) show that a temporary buy price in English auctions with proxy-bidding may be considered as a particular type of an anchor. Since the buy price is informative, distinguishing the information effect from the anchoring effect is not possible.

effect of the anchor on the subjects' strategic choices.

Following Kahneman (2011), we define an anchor as an *obviously irrelevant number* that might influence behavior in a way that is inconsistent with rational decision-making. Focusing on games, we use a more detailed terminology as we are specifically interested in strategic behavior. Based on the two-process theory of reasoning (Stanovich and West, 2000; Kahneman, 2011), we distinguish between two different anchor types, type 1, “*uninformative*”, and type 2 or “*informative*” anchors. We consider a number as a type 1 anchor (henceforth uninformative anchor) if it does not provide any useful information for decision-making. Such a value has no meaning in the context of the game and its effect can be interpreted as a non-conscious decision-making process tied to intuition and thus associated, using the terminology of Stanovich and West (2000), with System 1.<sup>4</sup> Such a value is akin to most anchoring studies. It appears to the agent before forming a judgment and comes in various contexts including irrelevant numbers about value estimates, forecasts, identification numbers, etc. (Furnham and Boo, 2011; Chapman and Johnson, 2002).

A type 2 anchor (henceforth an informative anchor), however, might lead to changes in the decision environment by censoring the strategy space. Anchors that fit into this definition are plentiful and are present in a wide array of settings. In actual markets, sellers often impose an upper price or quantity limit. Some retailers routinely maximize the number of units available to a single customer. Vendors in a marketplace start bargaining by setting a price well above the wholesale price. Several auction markets use limits of some sort. For example, in Dutch auctions, the starting price is such a limit by design. Informative anchors can be interpreted in the context of the game. Anchoring of this type, if present, can be linked to a conscious and controlled adjustment process that is responsible for analytical thinking, and is thus associated with System 2 (Stanovich and West, 2000).<sup>5</sup>

We investigate the role of anchors in auctions and hypothesize that anchoring could be a relevant determinant of bidding behavior. In particular, we seek to elaborate on well-established choice patterns in auctions, such as overbidding and ranking auction formats by linking them to anchoring.

In our experiment, we employ independent private-value first-price sealed-

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<sup>4</sup>System 1 is a cognitive process defined in the psychology literature as automatic, largely unconscious, relatively fast, and undemanding of computational capacity.

<sup>5</sup>In contrast to System 1, System 2 is considered to be a rational choice encompassing analytic intelligence, relatively slow, and demanding of computational capacity.

bid (henceforth first-price) and Dutch auctions. This choice is motivated by multiple considerations. First, these auction types are common examples of static games of incomplete information. Second, they are relatively simple formats commonly used in the field. Third, finding the optimal strategy is non-trivial as, unlike in second-price and English auctions, they exhibit no dominant strategy. Fourth, they are isomorphic, i.e., strategic equivalent, and hence share the same Bayesian equilibrium set.

As uninformative anchors, we employ integer numbers used to determine the group matching in the auctions. Obviously, this value carries no useful information to the player regarding the choice of the bid. As informative anchors, the numbers constitute either a starting price in the Dutch or a commonly known upper bid limit in the first-price auction. All numbers used as anchors are higher than the upper bound of the interval from which bidder valuations are drawn, and consequently, above the upper bound of the equilibrium strategy set.

We test for the prevalence and direction of the effects of the two different anchor types and the interplay between them. Our results contribute to the understanding of the scope of anchoring effects and their role in the cognitive process of Systems 1 and 2.

Varying the informative anchor in Dutch auctions enables us also to identify the effect of an irrelevant starting price in dynamic auctions (Trautmann and Traxler, 2010). Comparing first-price and Dutch auctions in this environment allows for separately testing anchoring triggered by the maximal permissible bid and the time effect. While the Dutch format imposes on subjects an externally given time frame, there is no time limit to decide on a bid in first-price auctions. Hence, differences in behavior may be due to the time span available for analytical and rational thinking.

Our analysis delivers evidence on the prevalence of anchoring bias in games of incomplete information. In first-price auctions, we find consistent and robust effects. Introducing an uninformative anchor or a high informative anchor (upper bid limit) results in higher bids. With a simple model, we demonstrate that accounting for upward-biased beliefs explains the over-bidding phenomenon in first-price auctions. In contrast, in Dutch auctions, an informative anchor (higher starting price) leads to lower bids. The latter result is consistent with the potential effect of stronger bid shading triggered by a longer time frame. Our results also shed new light on the classical non-isomorphism problem between the two auction formats (Kagel, 1995). We show that the conventional wisdom that Dutch auctions exhibit lower bids

may be driven by the maximal permissible bid (upper bid limit resp. starting price) and may not hold in general.

In the following, Section 2 formally defines anchoring in Bayesian games. Section 3 gives a description of the experimental design. Next, Section 4 includes a detailed analysis of the data, including robustness checks. Section 5 offers a model to show that our observations on anchoring are consistent with biased beliefs. Finally, we conclude with a discussion in Section 6.

## 2 Theory

In this section, we discuss anchoring in Bayesian games. By doing so, we extend the model of Harsányi (1967) with additional dimensions of the type space.

### 2.1 Anchoring in Games of Incomplete Information

Consider a normal-form game of incomplete information with a set of players  $\mathcal{I}$ . Each player  $i \in I$  has a payoff function  $u_i(v_i, a_1, \dots, a_I)$ , where  $a_i$  is the action choice of player  $i$ . The type of each player,  $v_i$ , is a random variable chosen by nature that is observed only by player  $i$ . The joint probability distribution of the types is given by  $F(v_1, \dots, v_I)$ , which is assumed to be common knowledge among players. A strategy of player  $i$  is a function  $b_i(v_i)$  that specifies player  $i$ 's action choice  $a_i$  for each realization of their type  $v_i$ .

Next, consider an extended game of incomplete information. The type of each player  $i$  is a vector  $(v_i, c_i)$ , where  $c_i$  may be multi-dimensional, i.e.,  $c_i = (c_{i1}, \dots, c_{ik})$ ,  $k \geq 1$ . The joint probability distribution of players' types is given by  $F(v_1, \dots, v_I, c_1, \dots, c_I)$ . A strategy of player  $i$  is a function  $b_i(v_i, c_i)$  that specifies player  $i$ 's action choice  $a_i$  for each realization of their type  $(v_i, c_i)$ . Player  $i$ 's payoff function, however, remains  $u_i(v_i, a_1, \dots, a_I)$ , i.e., depends on the action choices of all players as well as on one part of the player  $i$ 's type,  $v_i$ , but not on  $c_i$ . All elements of  $c_i$ ,  $v_i$  as well as  $a_i$  are drawn from the same ordered set  $(S, \succeq)$ .

In the following, we distinguish *anchors* as the elements of  $c_i$ , based on their role in shaping the components of the game. That is, each element of  $c_i$ , shall be one of two anchor types.

An uninformative anchor is a number  $c_{ij} \in S$  which is included in the player's type but does not imply any further changes in the game structure,

neither in the set of the permissible strategies nor in the payoff function.

In contrast, an informative anchor,  $c_{ij} \in S$ , does imply a change in the set of the permissible strategies as follows: First, it restricts the range of the strategy function such that  $c_{ij} \succeq a_i$  must hold. Second, in that way, it only eliminates weakly dominated strategies. However, the informative anchor does not change the payoff function, that is,  $u_i(v_i, a_1, \dots, a_I)$  remains the same for all feasible  $a_i$ .

This model allows for single or multiple anchors with uniform or mixed types. Consider a Bayesian game  $G$  where weakly dominated strategies do not belong to any Bayesian equilibrium of the game. Suppose  $G'$  is the corresponding anchoring game as defined above. Then, the set of Bayesian equilibria in  $G$  and  $G'$  are the same.

## 2.2 Auction Model

The setting studied in our experiment employs two bidders who compete for a single indivisible good. A bidder's valuation  $v_i$  is independently drawn from a uniform distribution with a support  $[\underline{v}, \bar{v}]$ , where  $0 < \underline{v} < \bar{v}$ . In a Dutch clock auction, an observable clock displays a price that starts at a number and gradually sinks. The starting price is strictly above the upper bound of the valuations,  $\bar{v}$ , i.e., the highest possible valuation. The format is a winner-pay auction. That is, the winner receives her valuation for the good and pays an amount equal to her bid, giving payoff  $v_i - b_i$ . The loser receives a payoff of 0. The first-price sealed-bid auction entails a simultaneous submission of bids. The winner and payoffs are determined in the same way as in the Dutch auction.

The two auction mechanisms can be easily augmented to fall into the set of Bayesian games defined in the previous subsection. Consider a two-dimensional vector of anchors  $c_i = (c_{i1}, c_{i2})$ ,  $c_{ij} \in \mathbb{R}^+ \cup \emptyset$ , with no more than one of each anchor type. Any positive number  $c_{i1}$  that does not change any components of the auction game can be employed as an uninformative anchor. An informative anchor is present by design in the Dutch auction, as the starting price serves as an upper limit of bids. A starting price higher than the highest possible valuation,  $\bar{v}$ , can be considered as an informative anchor  $c_{i2}$ . The first-price sealed-bid auction has an equivalent anchor if an upper limit  $c_{i2}$  is set such that only bids satisfying  $b_i \leq c_{i2}$ , where  $c_{i2} > \bar{v}$  are permitted.

In equilibrium, if bidders are rational, regardless of the anchor types,

		Limit/Starting Price		
		Low	High	No
First Price	Group Number	FPGN95	FPGN115	FPGN
	No Group Number	FPNA95	FPNA115	FPNA
Silent Dutch	Group Number	SDGN95	SDGN115	-
	No Group Number	SDNA95	SDNA115	-

Table 1: Summary of the treatments

Treatment	Starting Price/Limit (Informative Anchor)	Group Number (Uninformative Anchor)	Sessions	N
FPNA	-	No	1	24
FPNA95	95	No	1	24
FPNA115	115	No	1	24
FPGN	-	Yes	1	24
FPGN95	95	Yes	1	22
FPGN115	115	Yes	1	24
SDNA95	95	No	1	22
SDNA115	115	No	1	24
SDGN95	95	Yes	1	22
SDGN115	115	Yes	1	22
Total			10	232

Table 2: Summary of sessions

$b_i^*(v_i, c_{i1}, c_{i2}) = b_i^*(v_i)$ . The two auction mechanisms are strategically equivalent. Hence, the symmetric Bayesian equilibrium with risk-neutral players is

$$b_i^*(v_i, c_{i1}, c_{i2}) = b_i^*(v_i) = \underline{v} + \frac{1}{2}(v_i - \underline{v}) \quad (1)$$

for both auction formats.<sup>6</sup>

### 3 Experimental Design and Hypotheses

In the experiment, randomly matched pairs of subjects played either a first-price sealed-bid or a (silent) Dutch auction for 20 consecutive rounds divided

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<sup>6</sup>There is a rich literature addressing differences between static and dynamic auction mechanisms. We provide a discussion of the failure of isomorphism in Subsection 4.5.

into four blocks of five auctions each. In each auction, the player with the highest bid won the auction and obtained a payoff equal to her value minus her bid. The loser did not pay and did not receive anything. Subjects received no feedback on either their payoffs or the opponents' bids until the end of all 20 auctions. Hence, each bid yields an independent observation. Furthermore, this design characteristic allows us, in contrast to previous studies, to observe behavior that is not potentially anchored by any type of feedback effects. It is reasonable to assume that *interim* feedback has such an effect (Peeters et al., 2016).

All values were denoted in a fictitious currency termed ECU for Experimental Currency Unit. The private valuations of the bidders in each round were randomly drawn integers from the set  $V = \{30, 31, \dots, 89, 90\}$  with all valuations  $v_i \in V$  being equally likely. After seeing their valuation draw, subjects were asked to submit their bid. In the first-price (FP) auctions, subjects could choose non-negative integer bids no higher than 95 or 115 in some treatments. In other treatments, no bid limit was imposed. This was common knowledge. In the silent Dutch (SD) auctions, a clock was displayed on the screen showing the current price. The starting price was set to either 95 or 115 and was sinking at a rate of 1 ECU per 0.5 seconds. Bidders were able to stop the clock at any point, and the clock value in that moment determined their bid. Thus, in both auction types, bidders could submit bids below the lowest possible private valuation  $v_i = 30$  as well as above the highest possible valuation  $v_i = 90$ . Unlike in a standard Dutch auction, bidders received no feedback in the silent format.<sup>7</sup> That is, the clock reached zero and there was no indication of the other subject's bid.

In the experiment, we employed a between-subjects design. Table 1 gives an overview of all treatments. The fundamental statistics are summarized in Table 2. The treatments differ with respect to the existence and the type of the anchor as well as the auction format.

In the Group Number (GN) treatments, at the beginning of each block, a number between 91 and 120 was randomly assigned to each subject in the following way.<sup>8</sup> Each participant draws a chip from one of two identical

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<sup>7</sup>Turocy et al. (2007) use this mechanism in order to achieve the feedback environment of a first-price sealed-bid auction in the Dutch auction. Levin et al. (2016) coined the terms *active* and *silent* clock auctions.

<sup>8</sup>The numbers were predetermined and were as follows: 91, 93, 95, 98, 101, 103, 108, 111, 113, 115, 118, and 120 for 24 subjects; 91, 93, 95, 98, 101, 106, 111, 113, 115, 118 and 120 for 22 subjects.

urns, without replacing the chip. The numbers on the chips in both urns were the same, and the number of chips in the urns was the same as the number of participants in a session. Thus, there was always a pair of subjects receiving the same number. This number determined the subject's group for five auctions and it was reassigned at the beginning of each block. The No Anchor (NA) treatments featured no uninformative anchor. In those treatments, groups were assigned using z-Tree's random number generator function.

The informative anchor, i.e., the maximal permissible bid, varied between but not within treatments. In the '95' treatments, the starting price in the silent Dutch auction, respectively the bid limit in the first-price auction, was set to 95, in the '115' treatments, to 115. There is no such a number in the names of the treatments with no upper limit. For example, treatment FPNA features first-price auctions without anchors, i.e., with no group number and no upper limit of bids. Similarly, in SDGN115, subjects participated in silent Dutch auctions with an uninformative anchor and a starting price of 115.

At the end of each session, we also collected data on cognitive abilities using a 5-minute Raven test, individual risk preferences using a lottery experiment, and some demographic characteristics such as gender and age.

The experiment was conducted between May 2018 and January 2019, at the Technische Universität Berlin. Participants were students (33% female), mostly from economics, natural sciences, or engineering. We ran 10 sessions with 232 subjects. In each session, an even number of subjects, between 22 and 24, participated. All experimental sessions were conducted with the use of the computer-based software system z-Tree (Fischbacher, 2007). The average length of a session was 70 minutes. The cash conversion rate was: 1 ECU = 0.04 EUR.<sup>9</sup> After explaining the rules, subjects had to fill out a short test before they were allowed to participate in the experiment. The average total earnings per subject amounted to 16.36 EUR including a show-up fee of 5 EUR.<sup>10</sup> A translated version of the instructions as well as the test questions can be found in the web appendix.

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<sup>9</sup>1 EUR = 1.15 USD at the time of the experiment.

<sup>10</sup>In order to guarantee non-negative payoffs, subjects received a payment of 0 for the auction part of the experiment if the total profit in that part was negative.

### 3.1 Hypotheses

If one assumes that subjects are rational, their bidding behavior should not be influenced by the existence of anchors. However, based on previous research from other domains showing strong anchoring effects, we hypothesize that the presence of anchors may systematically bias bidding behavior. Given the cumulative evidence that high anchors increase value judgments, we hypothesize that bids in the anchoring games would be higher than bids in the control games in both auction formats.

**Hypothesis 1** (Uninformative Anchors):

*The announcement of the group number has a positive effect on bids.*

**Hypothesis 2** (Informative Anchors):

- 2a: *The announcement of a bid limit has a positive effect on the bids in first-price sealed-bid auctions.*
- 2b: *In first-price as well as in Dutch auctions, the value of the bid limit, resp. starting price has a positive effect on bids.*

The experiment was designed with the intent of testing the role of uninformative as well as informative anchors. By design, an informative anchor is always present in a Dutch auction in the form of a starting price. Therefore, testing Hypothesis 2a is not feasible in Dutch auctions.

Hypothesis 2b is consistent with several theories offered in the auction literature. The utility of suspense theory (Cox et al., 1983) assumes that players exhibit an additional utility from playing the game that diminishes in time.<sup>11</sup> In the context of Dutch auctions, it means that at any price,

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<sup>11</sup>The model of Cox et al. (1983) expresses the expected utility of player  $i$  in the additively separable form

$$U_i(b_i) = \alpha_i(t) + \beta [v_i - b_i]^{r_i} F_i(b_i) \quad (2)$$

in which  $\alpha_i(t)$  is the utility from playing for time  $t$ ,  $\beta$  is a weight parameter,  $F_i(b_i)$  is the probability of winning, and  $1 - r_i$  is the Arrow-Pratt measure of constant relative risk aversion. The second term expressing the utility from the auction does not increase with a higher starting price in a symmetric game as  $F_i(b_i)$  is the probability of  $v_i > v_j$ . Assuming that  $\alpha_i(t)$  is concave, at any point of time, the marginal utility of postponing stopping the clock is lower.

agents obtain lower marginal utility from keeping the clock running. Hence, a higher starting price results in higher equilibrium bids.

Performing experiments in two-sided auctions, Isaac and Plott (1981) and also Smith and Williams (1981) find evidence of the so-called “Buffer hypothesis”: bids significantly bound away from a binding or non-binding upper limit set by the experimenter.<sup>12</sup> Consistent with their findings, in our experiment, higher limit may result in higher bids if the difference between the limit and the maximum of observed bids is sufficiently high.

Furthermore, the starting price also determines the time frame of choosing the bidding strategy. As evidenced in the literature, time effects persist in dynamic auctions. Using data from both first-price and Dutch auctions, it is possible to identify the effect of the starting price.

**Hypothesis 3** (Multiple Anchors):

3a: *The exposure to both anchors has a positive effect on bids.*

3b: *The interaction between the two anchors has a negative effect on bids.*

In actual settings, when making a decision, agents are often exposed to an array of anchors. While the aggregate effect may be positive, (Whyte and Sebenius, 1997), there is no sound empirical evidence for the existence of explosive anchoring effects. In fact, Zhang et al. (2014) provide laboratory and empirical evidence of negative interaction effects.

## 4 Results

### 4.1 Overview of Bidding Behavior

In the experiment, we observe a total of 4,640 bidding decisions, (first-price auction: 142 bidders  $\times$  20 auctions = 2,840; Dutch auction: 90 bidders  $\times$  20 auctions = 1,800). With the experimental parameters, a rational risk-neutral agent bids according to the unique symmetric Bayesian equilibrium  $b_i^*(v_i) = 15 + \frac{1}{2}v_i$ . The distributions of the relative deviation of the observed bids from the equilibrium bids, i.e., overbidding ratio  $\frac{b_i - b_i^*}{b_i^*}$ , for the different

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<sup>12</sup>A non-binding limit is not an uninformative anchor in our framework as it is interpreted in the context of the strategy space. However, in our framework, the binding limit constitutes an informative anchor as it censors the strategy space.

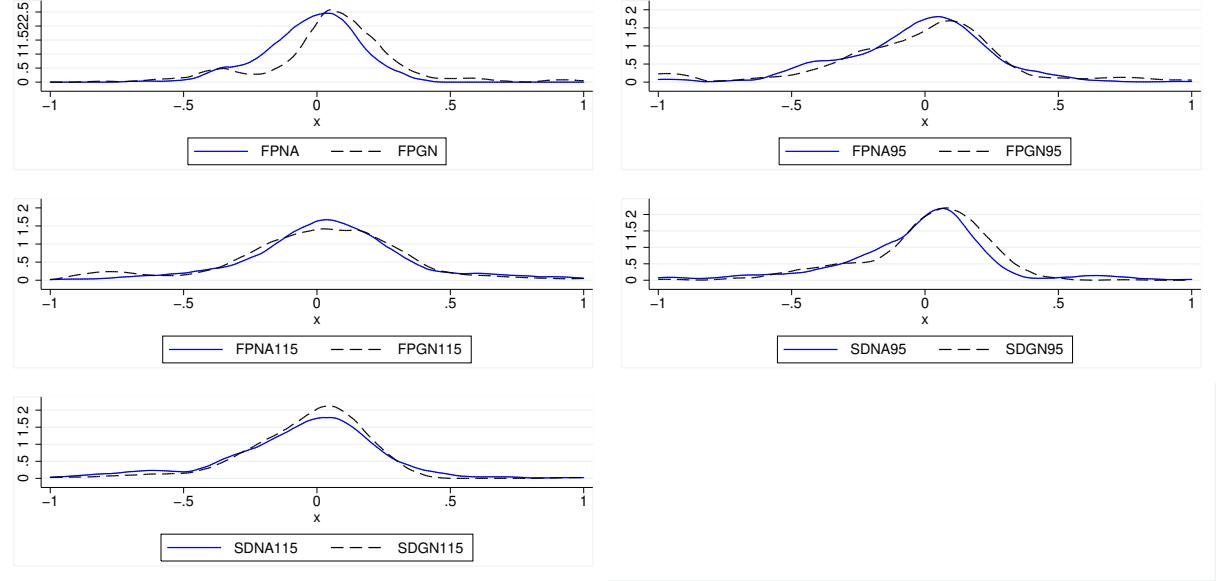


Figure 1: Kernel density estimates of the overbidding ratio (*Uninformative anchor*) in first-price and silent Dutch auctions

treatments are shown in Figures 1 and 2. Figure 1 illustrates the role of the uninformative anchor, Figure 2 the role of the informative anchor.

Figure 1 is consistent with Hypothesis 1. The upper-left graph in that Figure compares the treatments in which there is no informative anchor (FPGN vs. FPNA) and illustrates that using an uninformative anchor (group number) increases bids.

In all other comparisons between treatments with and without an uninformative anchor, there is no clear evidence. As these comparisons feature treatments with an informative anchor, this observation is consistent with Hypothesis 3b which implies that anchoring effects are not additive.

As evident from Figure 2, comparisons of treatments with different informative anchors support Hypothesis 2a but Hypothesis 2b only partly. Introducing a (higher) bid limit does increase bids in first-price auctions, as evidenced by the two upper graphs. This, however, is not the case in Dutch auctions, where a higher starting price decreases bids, as evidenced by the two lower graphs. We perform two-sample Kolmogorov-Smirnov tests to provide statistical evidence on all these results. Coefficients show these

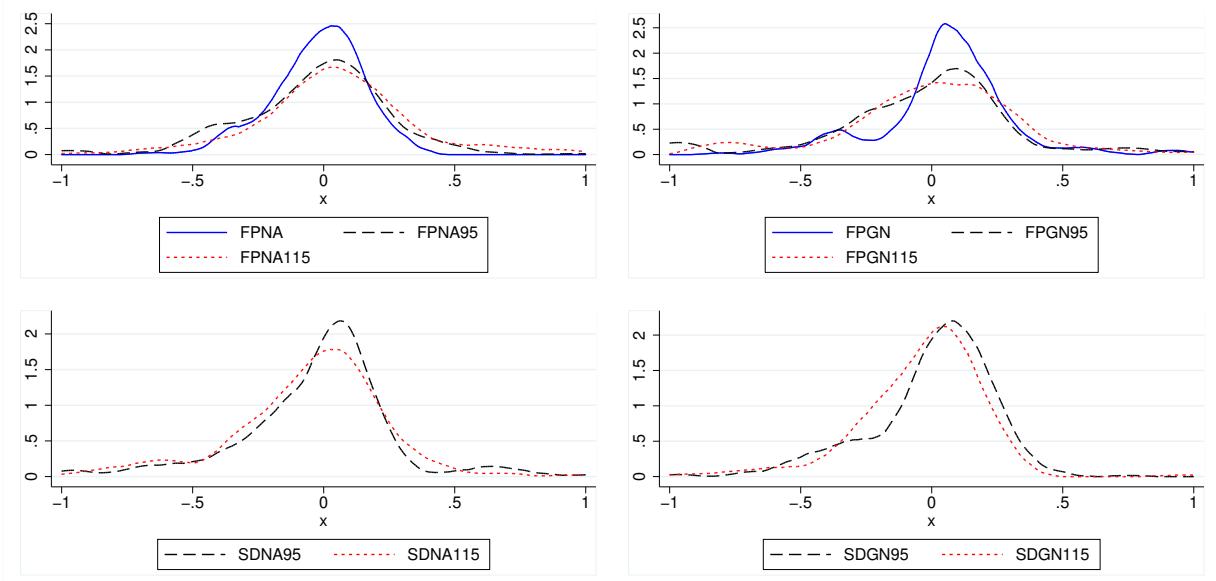


Figure 2: Kernel density estimates of the overbidding ratio (*Informative* anchor) in first-price and silent Dutch auctions

differences hold with a 5% or lower significance level.<sup>13</sup>

## 4.2 Anchoring in First-Price Auctions

The aim of our estimation strategy is to test for the presence of anchoring effects in bidding as hypothesized in Section 3.1. As we demonstrate, the informative and the uninformative anchor play a role in the bidding strategy.

The experimental design distinguishes first-price auction treatments along two dimensions. First, they differ in their upper bid limit, which is either not imposed or it is fixed to either a (low) value of 95 or a (high) value of 115. Second, each of these conditions is implemented with and without providing a group number. The two dimensions correspond to the informative and uninformative anchors, respectively. Keeping our hypotheses in mind, we estimate Model (3).

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<sup>13</sup>A complete list of tests is provided in the web appendix.

$$b_{it} = \alpha + \beta_1 v_{it} + \beta_2 D + \beta_3 D_{115} + \beta_4 GN + \beta_5 D \times GN + \beta_6 D_{115} \times GN + \phi X_i + \varepsilon_{it} \quad (3)$$

In the equation above, the decision of bidder  $i$  in auction  $t$  over bid  $b_i$  is modeled as a function of the bidder's valuation. The effects of the different types of anchors are captured by the dummy variables  $D$ ,  $D_{115}$ , and  $GN$ :  $D$  is equal to 1, if there is a bid limit,  $D_{115}$  is equal to 1 if the bid limit is high (115),  $GN$  is equal to 1 if there is a group number. The literature suggests that exposure to multiple anchors may have a non-zero interaction effect. In order to address this, if the subset of data allows, we also include interaction terms that test for interaction effects between informative and uninformative anchors. In all models,  $X_i$  is the set of control variables including period, gender, age, measures of risk preferences and cognitive abilities, and  $\varepsilon_{it}$  denotes the error term with standard normal distribution.<sup>14</sup>

Using model (3), we estimate the average treatment effects and test the hypotheses. The regression results for different specifications of the model are listed in Table 3. In all specifications, the highly significant coefficient of valuation  $v_i$  is consistent with the descriptive data. First, bids are mainly driven by valuation. Second, the estimates around 0.68 show that bidders are sensitive to these values which greatly surpass the Bayesian equilibrium prediction of 0.5. These results corroborate the well-established overbidding phenomenon in first-price auctions. Specification (1) offers support for Hypothesis 1. It shows that introducing an uninformative anchor, i.e., having a group number, does increase bids. The coefficient is large and significant at 0.1% level.

The subsample in specification (4) includes all observations without a group number and allows us to investigate the effect of the existence and size of the informative anchor (i.e., the upper bid limit). Specification (4) shows that the very presence of a bid limit has no effect on bids. However, introducing a high informative anchor ( $D_{115}$ ) has a significant positive effect: it increases bids by 4.07 on average. This provides support for Hypothesis 2b.<sup>15</sup>

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<sup>14</sup>A complete list of the variables can be found in web appendix.

<sup>15</sup>The positive effect of the upper limit is consistent with the buffer hypothesis of Isaac and Plott (1981) and Smith and Williams (1981). As they present it, removing limits may increase offers. However, we find evidence that the uninformative anchor also affects

Specifications (2) and (3) indicate that, if there is a bid limit (95 or 115), introducing an uninformative anchor has a weakly significant positive (if the bid limit is low) and negative (if the bid limit is high) effect on bids. Specification (5) also addresses the effect of the exposure to a second anchor. It reveals no significant effect of the introduction of a bid limit when an uninformative anchor is already present. Taken together, the results of all three specifications, (2), (3), and (5), indicate that if multiple anchors are present, the observed anchoring effect is driven mainly by the uninformative anchor.

Finally, specification (6), which includes all observations, indicates that the mere existence of a bid limit has no effect on bids. However, a high limit does anchor bidders and increases bids by 5.04 on average. A similar pattern is observed when the group number is used. Exposure to an uninformative anchor increases bids by 2.63. Both coefficients are significant at a 0.1% level.

We pay special attention to the interaction terms. The estimates provide some support for Hypothesis 3b as both of them are negative. Hence, introducing a second anchor if one anchor has already been applied has a weaker total effect on bids than without it. That is, the estimated difference between FPGN and FPGN115 equals  $\beta_2 + \beta_3 + \beta_5 + \beta_6 = -1.04 + 5.04 - 0.67 - 5.76 = -2.43$ . In contrast, the same difference between FPNA and FPNA115 is  $-1.04 + 5.04 = 4.00$ . Yet, the total anchoring effect, the difference between FPNA and FPGN115 is estimated to be  $\beta_2 + \beta_3 + \beta_4 + \beta_5 + \beta_6 = -1.04 + 5.04 + 2.63 - 0.67 - 5.76 = 0.20$ , which is positive. This corroborates Hypothesis 3a.

We find no evidence that the sequence of periods plays a role in bidding. This pattern is probably a consequence of the experimental design as participants were not given feedback at any point before the end of the 20 auctions. The other control variables are also not significant or if significant, not robust.

### 4.3 Anchoring in Dutch Auctions

Anchoring in the Dutch auctions is investigated using a similar model. By design, Dutch auctions always feature an informative anchor as a starting price has to be set. Thus, in the case of the Dutch auction we use a slightly

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behavior. This pattern cannot be explained by the buffer theory as the group number has no context as a limit.

Table 3: Bidding in first-price auctions

	(1) Bid	(2) Bid	(3) Bid	(4) Bid	(5) Bid	(6) Bid
$v_i$	0.69*** (0.019)	0.62*** (0.028)	0.73*** (0.028)	0.69*** (0.019)	0.67*** (0.023)	0.68*** (0.015)
$D$ (inf. anchor)				0.12 (0.83)	-0.67 (0.98)	-1.04 (0.68)
$D_{115}$					4.07*** (0.82)	-1.41 (0.99)
$GN$ (uninf. anchor)	3.40*** (0.71)	2.27* (0.98)	-2.09* (1.06)			2.63*** (0.71)
$D \times GN$						-0.67 (1.19)
$D_{115} \times GN$						-5.76*** (1.41)
Period	0.092 (0.056)	0.022 (0.082)	-0.0058 (0.086)	0.16** (0.057)	-0.090 (0.067)	0.038 (0.047)
<i>Includes observations</i>						
With Group Number				No	Yes	Yes
Without Group Number				Yes	No	Yes
Without limit	Yes	No	No			
With limit 95	No	Yes	No			
With limit 115	No	No	Yes			
Observations	960	920	960	1440	1400	2840
Adjusted $R^2$	0.5836	0.3888	0.4366	0.4947	0.4274	0.4347

OLS regressions. Standard errors in parentheses. \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ .

All specifications include controls (gender, age, measures of risk preferences, and cognitive abilities).

modified model:

$$b_{it} = \alpha + \beta_1 v_{it} + \beta_3 D_{115} + \beta_4 GN + \beta_6 D_{115} \times GN + \phi X_i + \varepsilon_{it}. \quad (4)$$

The notations are analogous to that of the first-price auction. In the context of Dutch auctions, dummy variable  $D_{115}$  denotes treatments with a high starting price of 115.

As Table 4 shows, similarly to the first-price auction, bids are driven by valuations and the coefficients are comparable. Again, there is no time trend as none of the coefficient estimates of the period number is significant at a 5% level.

However, compared to the first-price auction, there are remarkable differences regarding the role of anchors. The uninformative anchor has a positive effect on bids only in treatments with a high starting price, as evidenced in specification (2). The informative anchor's effect, i.e., the level of the starting price, is the opposite of what we evidenced in the first-price auction: Higher starting price results in significantly lower bids. This result is robust independently of the perspective we take in our sample: whole sample, specifications (5), two disjoint sub-samples, with and without an uninformative anchor, specifications (3) and (4). Thus, the negative starting-price effect contradicts not only Hypothesis 2b but also the utility of suspense theory that predicts higher bids with higher starting prices. We investigate this remarkable result in detail in Subsection 4.5.

There is a crucial difference in the bidding process between the two auction formats. After the auction start, the time interval for making a decision is only restricted in the Dutch auction. Thus, in the treatments SDNA115 (resp. SDGN115), compared to the SDNA95 (resp. SDGN95), there is effectively more time available to reach a decision. This allows subjects to be engaged for a longer time span in analytical and rational thinking, which is needed for the adjustment process of “moving” from the anchor (i.e., the starting price). In the context of auctions, this means improving the decision in the sense of mitigating overbidding and, consequently, achieving a higher profit.

#### 4.4 Revenue and Efficiency

In the context of auctions, one may wonder whether anchoring affects revenue and efficiency. In an auction, efficiency is solely determined by the final

Table 4: Bidding in silent Dutch auctions

	(1)	(2)	(3)	(4)	(5)
	Bid	Bid	Bid	Bid	Bid
$v_i$	0.70*** (0.023)	0.69*** (0.021)	0.69*** (0.025)	0.71*** (0.019)	0.70*** (0.016)
$GN$		0.87 (0.84)	3.23*** (0.85)		-0.34 (0.81)
$D_{115}$				-3.92*** (0.94)	-1.54* (0.73) -3.41*** (0.80)
$D_{115} \times GN$					1.30 (1.20)
Period	0.066 (0.069)	-0.025 (0.062)	0.037 (0.076)	-0.00081 (0.055)	0.019 (0.048)
<i>Includes observations</i>					
With Group Number			No	Yes	Yes
Without Group Number			Yes	No	Yes
With starting price 95	Yes	No			
With starting price 115	No	Yes			
Observations	880	920	920	880	1800
Adjusted $R^2$	0.5551	0.5605	0.4742	0.6323	0.5287

OLS regressions. Standard errors in parentheses. \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ .

All specifications include controls (gender, age, measures of risk preferences, and cognitive abilities).

allocation of the good. The outcome is efficient if and only if the winner is the bidder with the highest valuation. In the symmetric Bayesian equilibrium, the bid strategy is monotone in valuation, hence, the allocation is always efficient. However, if bidders exhibit anchoring bias, this result does not hold anymore.

To see this, consider the following simplified example with two players. Suppose bidders are exposed to an uninformative anchor akin to our first-price auction with a group number but no limit (FPGN). Valuations are drawn independently and identically from  $[\underline{v}, \bar{v}]$  and anchors  $c_{i1}$  are drawn from  $[\underline{c}, \bar{c}]$ , both with uniform distribution. Assume that the two bidders submit a strategy  $b_i(v_i, c_{i1})$ , resp.  $b_j(v_j, c_{j1})$ , which is monotone in both parameters and symmetric. Suppose two bidders  $i, j$  have anchors  $c_{i1} > c_{j1}$ . If  $j$  has a higher valuation, it is possible that the difference in anchors dominates.<sup>16</sup>

Table 5 presents descriptive statistics for the variables of interest for both formats. Average prices (column 1) and profits (column 2) as well as efficiency (columns 3 and 4) are quite comparable to those reported in other auction experiments.<sup>17</sup> There are no substantial differences in the average prices between the two auction formats. The lowest price plus the lowest variance are observed in first-price auctions without anchors. In first-price auctions, the exposure to both types of anchors leads to significantly higher revenue, and consequently lower bidder earnings. Moreover, efficiency is significantly reduced when an informative anchor (bid limit) is present. In contrast, we do not observe considerable anchoring effects on price or efficiency in the Dutch auctions.<sup>18</sup>

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<sup>16</sup>Note that this example does not rely on imposing an equilibrium concept on behavior.

<sup>17</sup>In the experiment, we measure the efficiency rate as  $\mathcal{E} = \frac{v_{\text{winner}}}{\max\{v_j, v_j\}}$ .

<sup>18</sup>We estimate the reduced-form model  $\mathcal{E}_t = \alpha + \beta Y_t + \varepsilon_t$  in which the independent variables include dummies for the maximal permissible bid (95,115), group number, and the interaction terms. We perform this for both auction formats separately and find that the only significant coefficient is the presence of a bid limit in the first-price auction with a negative value -0.022 (standard error 0.008). The same model for the seller's revenue yields that it is 7.78 higher if the bid limit is higher (se. 1.49) and 6.22 higher if there is a group number (se. 1.49).

Table 5: Descriptive statistics (mean values; std. deviation in parentheses)

Treatment	Price	Profit	Efficiency	
			Average	% of eff. allocation
FPNA	52.25 (11.72)	8.35 (10.57)	0.98 (0.07)	87
FPNA95	52.91 (14.45)	6.55 (11.26)	0.96 (0.09)	73
FPNA115	60.70 (20.42)	3.39 (14.52)	0.95 (0.11)	75
FPGN	58.48 (15.85)	4.72 (11.06)	0.97 (0.08)	83
FPGN95	56.55 (16.92)	4.51 (13.27)	0.95 (0.12)	73
FPGN115	58.73 (17.01)	5.05 (11.47)	0.97 (0.09)	78
SDNA95	57.02 (17.15)	5.62 (14.15)	0.96 (0.10)	78
SDNA115	54.90 (14.45)	6.85 (11.34)	0.97 (0.08)	82
SDGN95	55.38 (12.98)	6.39 (9.23)	0.97 (0.08)	80
SDGN115	52.37 (12.59)	7.72 (10.86)	0.96 (0.08)	77

## 4.5 The Failure of Isomorphism Between First-Price and Dutch Auctions

The estimates reported in Tables 3 and 4 reveal the inconsistent but significant effects of the informative anchor on bids in the two auction formats. While in the first-price auction a higher bid limit does result in higher bids, in the Dutch auction, the effect is the opposite, with a higher starting price resulting in lower bids.

Table 6 tests for the source of the non-isomorphism between the two auction formats using the whole subsample in which bids are limited either by an explicit maximum bid or by a starting price. All specifications estimate the effect of a higher maximal permissible bid separately in the two auction formats. We achieve this by including an interaction term between the auction format and the maximal permissible bid (upper bid limit resp. starting price).

Specification (1) confirms the well-known ranking result from the literature, showing that bids are significantly lower in the Dutch than in first-price sealed-bid auctions (Kagel, 1995). Two alternative hypotheses that explain the non-isomorphism between the two auction formats are the utility of suspense theory and the Bayesian miscalculation (Cox et al., 1983).

In Dutch auctions, the utility of suspense theory implies that a higher starting price should result in higher bids. However, as shown in the previous section, we observe the opposite effect.

The Bayesian miscalculation hypothesis concerns another type of behavioral bias. In a Dutch auction, a bidder, upon observing the clock, learns whether the opponent pressed the button at a given price. While this does not imply any Bayesian updating of one's strategy, this information suppresses bids and constitutes a Bayesian miscalculation. Generally speaking, Bayesian updating assumes that the player correctly or incorrectly incorporates information on the actions of other players.

In our data, Bayesian miscalculation may not influence bidding in the same sense. In a silent Dutch auction, players observe a clock but receive no information about the opponent's strategy as it is common knowledge that the clock will continue to go down until 0. Thus, a subject never learns whether the opponent pressed the button or not at any given price.

The failure of isomorphism between first-price and Dutch auctions in our data appears to be mainly driven by the starting price or bid limit and may be arbitrary. We identify two opposing patterns. First, in specifications (2)-

(4), the coefficients reveal that a higher informative anchor, i.e., higher bid limit, resp. starting price, of 115 (dummy variable  $D_{115}$ ), is associated with higher bids (significant in all cases at a 0.1% level). However, the interaction term reveals that the opposite happens in Dutch auctions (significant in all cases at a 0.1% level). Overall, the total effect is negative in the dynamic format. Controlling for the auction format suggests that changing to the Dutch auction itself does not change bidding behavior substantially for a lower bid limit. Finally, the effect of the uninformative anchor (i.e., the group number dummy  $GN$ ) is not significant.

We also perform OLS estimations on the seller's revenue and the winner's payoff. Models (5) and (6) yield consistent results. Bids are negatively affected in the Dutch and positively in the first-price auctions by the maximal permissible bid. We can observe the same effect in terms of the seller's revenue. For the winner's payoff, we find that the auction winner enjoys a higher payoff with an increase of the starting price in the Dutch auction. The estimates are also consistent in the sense that the effect of the bid limit (dummy variable  $D_{115}$ ) as well as the interaction effect ( $D_{115} \times Dutch$ ) are highly significant in all models.

Based on our data, Figure 3 illustrates the non-isomorphism between the auction formats. Using Specification (3) of Table 6, we display the predicted mean bid as a function of the upper bid limit in the first-price and of the starting price in the Dutch auctions. The two functions show that the gap is heavily influenced by the maximal permissible bid. In fact, depending on this parameter, one may observe any ranking between the two auction formats.<sup>19</sup>

The experimental literature usually supports that Dutch auctions deliver lower bids. In particular, when comparing first-price sealed bid and (silent) Dutch experimental auctions with identical maximal permissible bids, Turcoy et al. (2007) find the same empirical regularity. However, there is also empirical evidence of a reversed ranking in prices. Reiley (1999) observes higher prices, on average, in Dutch vs. first-price auction field experiments on the Internet. Our results suggest that the sign and the magnitude of the gap between bidding strategies and revenue in the two formats may be driven

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<sup>19</sup>Note that this figure merely illustrates that the lack of isomorphism as well as the direction of the difference between the first-price and Dutch auctions can be explained by the differences in maximal permissible bids. It does not imply that outside of the examined range, there is a monotonic relationship between maximal permissible bid and expected bids in either auction format.

Table 6: Bidding, revenue, and winner's payoff in first-price and silent Dutch auctions

	(1) Bid	(2) Bid	(3) Bid	(4) Bid	(5) Revenue	(6) Winner's payoff $v_{winner} - b_{winner}$
	$b_i$	$b_i$	$b_i$	$b_i$	$b_{winner}$	$v_{winner} - b_{winner}$
$v_i$	0.68*** (0.013)	0.68*** (0.013)	0.68*** (0.013)	0.68*** (0.013)		
Dutch	-1.33** (0.46)		1.17 (0.66)	0.57 (0.66)	1.38 (1.07)	0.85 (1.00)
$D_{115}$		2.17*** (0.56)	2.75*** (0.65)	2.40*** (0.64)	4.64*** (1.05)	-2.72** (0.98)
$D_{115} \times Dutch$		-3.71*** (0.65)	-4.89*** (0.93)	-4.35*** (0.92)	-7.41*** (1.50)	5.26*** (1.40)
GN			-0.64 (0.46)	-0.30 (0.46)	-0.37 (0.75)	0.65 (0.70)
Period			0.015 (0.040)	0.015 (0.039)	-0.055 (0.064)	0.11 (0.061)
Control Variables	No	No	No	Yes	No	No
Observations	3680	3680	3680	3680	1840	1840
Adjusted $R^2$	0.4154	0.4192	0.4195	0.4363	0.0317	0.0206

OLS regressions. Standard errors in parentheses. \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ .

All specifications include controls (gender, age, measures of risk preferences, and cognitive abilities).

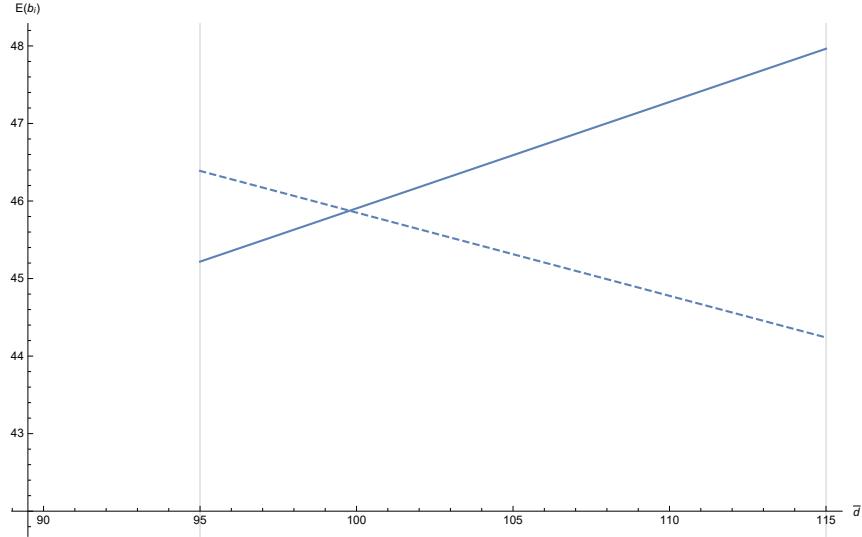


Figure 3: Estimated mean bids in first-price (solid) and Dutch (dashed) auctions as a function of the maximal permissible bid for the range of bids above the upper bound of the interval from which bidder valuations are drawn,  $\bar{v} = 90$ .

by the size of the maximal permissible bid.<sup>20</sup>

#### 4.6 Control With Low Anchors

We find evidence of upward bias if bidders are exposed to irrelevant numbers that are above the highest possible valuation. To check whether the anchoring bias persists if the subjects are exposed to other numbers, for example, that are below the lowest possible valuation, we perform a robustness check by conducting an additional treatment. The new treatment, FPLGN, is identical to the treatment with a group number (FPGN), only with one difference. Instead of high numbers between 91 and 120, the group number assumes values between 1 and 29.<sup>21</sup> Note that the numbers used as uninformative anchors are distinct from valuations and fall below the lower limit of equilibrium bids.

<sup>20</sup>Katok and Kwasnica (2008) demonstrate that the ranking of the two auction formats may also depend on the clock speed in Dutch auctions.

<sup>21</sup>The uninformative anchors are 1, 3, 5, 8, 11, 14, 16, 19, 22, 25, 27, 29 for 24 subjects.

Overbidding with anchors is a robust finding. Comparing the FPNA treatment (first-price auction without group number) and FPLGN treatment shows that introducing a low uninformative anchors leads to higher bids. The OLS estimate yields a significant coefficient (4.5021) of the treatment dummy (which equals 1 if there is a group number) at a 5% level (with a standard error 0.7649).<sup>22</sup>

In the spirit of Kahneman (2011), we perform a comparison between low (FPLGN) and high (FPGN) uninformative anchors. High numbers do induce higher bids, but the estimated coefficient of the treatment dummy (which equals 1 if the group number is high) is not significant at a 5% significance level (0.1347 with a 0.9508 standard error).<sup>23</sup>

## 5 Anchoring Bias in Equilibrium

Our experimental results have shown that, indeed, anchoring can affect bidder behavior. One possible explanation for anchoring bias in a strategic setting is that the exposure to an obviously irrelevant number affects a payoff-maximizing player in the sense that her behavior is a rational response to biased beliefs.

Biased bidding is consistent with two strongly related arguments. First, an anchored bidder may adjust her bid upward to increase the probability of winning. Alternatively, a player's beliefs about the opponent's actions may be biased upwards. As the probability of winning is equivalent to the probability of having a higher bid, the two arguments are observationally equivalent in an auction setting.

In the following, we propose a model built on the assumption that bidders exhibit anchoring bias in the context of uninformative anchors in first-price sealed-bid auctions. This simple model provides an additional explanation for the overbidding phenomenon in first-price auctions. Intuitively, if a bidder expects to be confronted with a higher bid of her opponent due to the anchoring bias, the best response is to shift the own bid upwards.

Consider, for example, the first-price auction with an uninformative anchor treatment (FPGN). The maximization problem of a bidder  $i$  with valuation  $v_i$  in this treatment, facing an opponent  $j$  who uses identical bidding

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<sup>22</sup>Same model as specification (1) in Table 3 with variable GN replaced by a dummy variable for the corresponding treatment effect.

<sup>23</sup>Same as the previous model.

strategy  $b_j$ , is

$$\max_{b_i} (v_i - b_i) \Theta_c(v_i),$$

where  $\Theta_c(v_i)$  is the probability of winning, in which  $c$  denotes the anchor observed by both bidders. In a Bayesian game, in the spirit of our hypotheses, a bidder knows  $v_i$ . Hence, her payoff  $(v_i - b_i)$  conditional on winning is not influenced by the anchor. However, since the bidding strategies are (upward) biased, an anchored player solves an objective function with a biased  $\Theta_c(v_i)$ . We assume that  $\Theta_c(\cdot)$  first-order stochastically dominates the type distribution that we denote by  $F(v_i)$ , i.e.,  $\Theta_c(b_i^{-1}(b_i)) = \Theta_c(v_i) < F(v_i)$ .<sup>24</sup>

In a symmetric equilibrium, we get for the *interim* expected payoff of bidder  $i$

$$(v_i - b_{ic}^*) \Theta_c(b_{ic}^{*-1}(b_{ic}^*)). \quad (5)$$

where  $b_{ic}^* = b_i^*(v_i, c) = b_i^*(v_i)$  is the unique symmetric Bayesian equilibrium with anchor  $c$ . Using the envelope theorem and that the lowest type  $\underline{v}$  wins with zero probability (Myerson, 1981), the equilibrium bidding function equals

$$\begin{aligned} b_{ic}^*(v_i) &= v_i - \frac{\int_{\underline{v}}^{v_i} \Theta_c(\tilde{v}) d\tilde{v}}{\Theta_c(v_i)} > v_i - \frac{\int_{\underline{v}}^{v_i} F(\tilde{v}) d\tilde{v}}{F(v_i)} = b_i^*(v_i) \\ &\iff \frac{\int_{\underline{v}}^{v_i} \Theta_c(\tilde{v}) d\tilde{v}}{\Theta_c(v_i)} < \frac{\int_{\underline{v}}^{v_i} F(\tilde{v}) d\tilde{v}}{F(v_i)} \end{aligned} \quad (6)$$

where  $b_i^*(v_i)$  is the unique symmetric Bayesian equilibrium with no anchor. The second line of (6) is implied by first-order stochastic dominance. For any  $v_i$ , there exists  $v'_i$  such that  $F(v'_i) = \Theta_c(v_i)$ . As  $\frac{\int_{\underline{v}}^{v_i} F(\tilde{v}) d\tilde{v}}{F(v_i)}$  is decreasing, (6) holds.

The argument is identical for the comparison of different anchors. Suppose  $c' > c$  and  $\Theta_{c'}(v_i)$  first-order stochastically dominates  $\Theta_c(v_i)$ . With the same argument,

$$\frac{\int_{\underline{v}}^{v_i} \Theta_{c'}(\tilde{v}) d\tilde{v}}{\Theta_{c'}(v_i)} < \frac{\int_{\underline{v}}^{v_i} \Theta_c(\tilde{v}) d\tilde{v}}{\Theta_c(v_i)}. \quad (7)$$

<sup>24</sup>Armantier and Treich (2009) provide evidence that overbidding can be explained by biased beliefs. The elicited bidder expectations reveal that subjects underestimate their probability of winning the auction.

## 6 Conclusion

Anchoring is known to be a pervasive behavioral judgment bias. We extend our understanding in the domain of games with incomplete information by performing controlled experiments. In this article, we study whether strategies are anchored. By randomly exposing subjects to numbers that are potential anchors in the sense of Tversky and Kahneman (1974), our design allows for drawing a causal inference and identifying anchoring bias in games of incomplete information.

We define two concepts, uninformative (type 1) and informative (type 2) anchors that are linked to the framework of Kahneman (2011), and apply them in first-price sealed-bid and Dutch auctions. In treatments with an uninformative anchor, subjects receive an irrelevant number. This number is presented as an identification number of the bidding group, hence it has no meaning in the context of the particular auction. In treatments with an informative anchor, bids are censored by a number that serves as an upper limit of bids (in Dutch auctions a strategically equivalent starting price).

We investigate whether anchoring bias persists in auctions if subjects are exposed to uninformative and informative anchors, and whether such exposure increases bids. The adoption of two different anchor types allows us to identify interaction effects. Thus, we also test whether anchoring effects are non-additive.

Our study provides a couple of interesting findings. Comparing treatments with and without an uninformative anchor clearly demonstrates that anchoring bias does exist and exposure to irrelevant numbers does increase bids. Our data reveal a strong anchoring bias triggered by the informative anchor. A higher maximal permissible bid increases bids in first-price auctions whereas the effect is the opposite in Dutch auction. Using all observations with a starting price or upper limit in both auction formats, we learn that the difference is due to the auction format itself. However, in Dutch auctions, there is a secondary effect that prevails and suppresses bids. This result is consistent with the two-process theory of reasoning as a higher starting price provides a longer time span for analytical reasoning. Finally, the interaction effects of the two different kinds of anchors are unanimously negative. This result is consistent with the literature as anchoring bias does not tend to be additive.

Our experimental results provide evidence that strategies in games can be anchored. Tversky and Kahneman (1974) define anchoring as a cognitive

bias that influences judgment. Our experiment shows that the anchoring bias also extends to the realm of strategic interaction.

We demonstrate that the observed deviations from rational behavior can be explained either by the fact that subjects are not engaged in payoff-maximizing behavior or that the beliefs are biased. Consider two interrelated but different cognitive processes – Process I: The anchored agent forms beliefs about the strategy of the other player which are influenced by the anchor; Process II: The agent’s strategy is biased directly by the anchor, beliefs may be correct. A straightforward test for the difference between anchored beliefs and direct anchoring in games is possible if upward biased beliefs induce lower rather than higher best-responses.<sup>25</sup> In games like auctions, however, the difference between the two processes cannot be identified unless beliefs are elicited.<sup>26</sup> Identifying the two processes is the natural next step of improving our understanding of the nature of the anchoring bias in games.

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<sup>25</sup>For example, a Cournot duopoly game with privately known marginal costs yields different predictions for the two effects as the best-response function of players is downward-sloping.

<sup>26</sup>In a similar vein, Kirchkamp and Reiß (2011) demonstrate that deviations from equilibrium bids is likely due to deviations from a best reply rather than to wrong beliefs.

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