Cognitive Ability and Bidding Behavior in Experimental Auction

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1. Introduction

Experimental auctions are a popular tool for applied economists to elicit people's willingness to pay (WTP) and/or willingness to accept (WTA) for new products and product attributes using non-hypothetical and incentive compatible mechanisms. These auctions are considered demand revealing since their (theoretical) incentive compatibility property induces subjects to reveal their true valuation of the products. Experimental auctions, however, may not always provide accurate measure of value given possible behavioral anomalies in bidding behavior (e.g., WTP/WTA disparity, overbidding/underbidding, preference reversal, etc.). Behavioral anomalies in auction experiments could reflect the failure of conditions for a valid controlled experiment (Harrison, 1992). Many studies have examined a number of behavioral anomalies in auction experiments (Shogren et al., 1994, 2001; List, 2002, 2003; Zhao and Kling, 2001; Goeree et al., 2001; Kling et al., 2013; Plott and Zeiler, 2005; Loomes et al., 2003; Corrigan and Rousu, 2006). However, there is still scant information about violations of individual rationality in experimental auctions. In this paper, we aim to fill this void by investigating how individuals' cognitive ability influence truthful bidding behaviors and bid variation in induced value auctions.

The behavior of people with higher cognitive ability can be different from those with lower cognitive ability in a variety ways. Some previous studies have examined the relationship between cognitive ability and economic behavior. Their results showed that high cognitive ability is positively correlated with patience (Parker and Fischhoff, 2005; Frederick, 2005; Slonim et al., 2007; Oechssler et al., 2009) while it is negatively associated with risk aversion (Frederick, 2005; Benjamin et al., 2006; Dohmen et al., 2010). People with higher cognitive ability are also more likely to join in financial markets and receive more financial return than people with lower cognitive ability (Smith et al., 2010; Agarwal and Mazumder, 2013; Korniotis and Kumar, 2011). In addition, cognitive ability is highly correlated with saving behavior and therefore it is a good predictor of saving performance (Ballinger et al., 2011). A number of studies have also investigated whether cognitive ability is related to individuals' behavioral biases. For example, Oechssler et al. (2009) found that people with higher cognitive ability are likely to exhibit lower incidences of the conjunction fallacy and conservatism fallacy. Hoppe and Kusterer (2011) replicated the finding of Oechssler et al. and found that high cognitive ability is less correlated with the base rate fallacy and conservatism bias. Bergman et al. (2010) investigated the relationship between cognitive ability and anchoring effect and found that greater cognitive ability moderate the anchoring effect. Andersson and Svensson (2008) also tested the hypothesis of a positive correlation between cognitive ability and scale bias in contingent valuation surveys. Their results indicated that respondents with higher cognitive skills give answers less flawed by scale bias.

Recent studies have also identified the connection between individuals' cognitive abilities and performance in behavioral tests for strategic behavior. For example, Gill and Prowse (2016) investigated the effects of cognitive ability and character skills on how people learn to play equilibrium in the *p beauty* contest. They found that subjects with higher cognitive ability more frequently meet equilibrium and also earn more money. Their results also indicated that people with higher cognitive ability appear better at learning to play equilibrium in which they interact. Burnham et al. (2009), Branas-Garza et al. (2012), and Carpenter et al. (2013) also found a similar relationship between cognitive ability and performance in the *p beauty* contest. Jones (2008) and Jones (2014) examined the link between individuals' cognitive abilities and the likelihood of cooperation in the repeated prisoner's dilemma games. They both found that subjects with greater cognitive ability are more likely to be cooperative and use complex strategies.

Previous studies have verified that individuals' cognitive abilities vary considerably and that cognitive ability can be an important determinant of people's decision making behaviors. They also indicate that behavioral biases are more likely to be pronounced for individuals with lower cognitive abilities, and that heterogeneity in cognitive ability can partially explain those biases. Despite the important role of cognitive ability in decision making and in explaining behavioral biases, however, to our knowledge no studies have examined how cognitive ability affects bidding behaviors in experimental auctions. Examining the effect of heterogeneity in cognitive ability on rational behaviors in auction experiments is important because it can be a potential reason for observed biased behaviors in auctions (i.e., overbidding/underbidding). The objectives of this study are therefore to investigate whether individuals' cognitive abilities influence bidding behaviors in experimental auction and to establish the role of cognition in the application of auction mechanisms.

To investigate our objectives, we first measured subjects' cognitive abilities using a nonverbal Raven test. We then classified subjects into two groups (i.e., a high cognitive group and low cognitive group) based on their Raven test scores. Each group then participated in a multi-round second price induced value auction.

2. Experimental Design

A total of 13 sessions were conducted, with each session comprising of 10 subjects. All sessions were conducted on weekdays between March 2017 and April 2017 at a behavioral lab at xxxxxxx (omitted for peer review), and each session lasted for approximately 90 minutes. The subjects, majority of whom were undergraduate students, were recruited from the behavioral lab's database of volunteers. The objective of the experiment was not revealed during the recruitment. The show-up payment fee was $10 and subjects were paid on average an additional $3.86 at the end of the experiment.

Upon arrival, participants signed a consent form and were then seated at a computer isolated from the other subjects. Both paper and computerized instructions were provided to each subject and were read aloud to the subjects. Each participants was also provided an ID number to ensure full anonymity. The experiment was composed of three main types of tasks: (1) cognitive ability; (2) induced auction; and (3) questionnaire. The experiment was conducted using the z-Tree program (Fischbacher, 2007).

We first measured the cognitive ability of all subjects using the Raven's Standard Progressive Matrices (RSPM) which is used for measuring abstract reasoning and is considered a nonverbal estimate of fluid intelligence (Gray and Thompson, 2004). The RSPM consists of 5 parts, labeled A to E, with 12 questions in each part. The subjects were given 3 minutes to complete each of the first two parts (i.e., part A and B) and 8 minutes to complete each of the last three parts (i.e., part C, D, and E). Subjects could move back and forth within each part and change their answers. We did not provide any monetary incentives for each correct answer during the Raven test to avoid a potential money effect influencing the following auction part of the study.

We then classified each subject as either of "high cognitive ability" if a test score was in the top half of all scores in a session or "low cognitive ability" if a test score was in the bottom half of all scores in a session. Each session was thus split into 2 groups after the Raven test (i.e., a high cognitive group and low cognitive group), with each group comprising of 5 subjects. Each subject was informed of his/her own cognitive ability type and the cognitive ability type of four other members of his/her group[1].

Each group then participated in five rounds of second price induced value auction where subjects submitted non-hypothetical bids for their private induced values. Prior to the auction, we carefully explained how the second price auction works and also provided subjects two practice auction rounds to help participants understand the procedure of auction mechanism. In every round in the actual auction, each subject was assigned his/her unique induced value for a good and each subject never learned the induced values of other members in a group. The sets of induced values were randomly drawn from 5 values (5.18, 11.26, 17.16, 23.82, and 29.12)[2] and the induced demand curve was identical in all sessions. Each subject experienced a different induced value from those of other subjects in a round and also experienced all the induced values during the 5 rounds of the auction. The whole demand curve is therefore induced in every round.

In the auction, subjects were asked how much they would be willing to pay for a fictitious good. The subject placing the highest bid bought the good at the second highest bid and then resale it to the experimenter at his/her own induced value at the end of each round. Feedback about the highest bid in the auction and other subjects' earnings was not provided between rounds. The highest bidder's profit in each round is equal to the difference between the induced value and the second highest bid. Profits of subjects who do not purchase the good are

[1] We did not the use words like "high cognitive ability" or "low cognitive ability". Instead, we chose to use more neutral words like "top half of all scores in the session" or "bottom half of all scores in the session".
[2] 5 induced values are randomly drawn from a distribution of $0 to $30.

zero. Subjects were paid their cumulative earnings from the 5 rounds at the end of the experiment.

After the auctions, the subjects were then asked to complete a questionnaire containing demographics and character skills (i.e., personality traits: openness, conscientiousness, extraversion, agreeableness, and emotional stability, grit: perseverance and passion for long-term goals, and consideration of future of consequences). We measured personality traits using the 10-item assessment of the Big Five personality traits (Gosling et al., 2003). We also measured grit using the 12-item Grit Scale (Duckworth et al., 2007) and consideration of future of consequences (CFC) using the 12-item CFC Scale (Strathman et al., 1994).

3. Experimental Results

Table 1 compares subjects' characteristics of the two groups (i.e., high cognitive ability group and low cognitive ability group) based on the Raven test scores. The two groups have similar characteristics. Specifically, the mean differences of demographics and character skills between the two groups are statistically insignificant except GPA (the mean GPA difference between two groups was statistically significant ($p=0.00$)). Previous studies have verified a high correlation between GPA and general cognitive ability (Jensen, 1998; Frey and Detterman, 2004) or have also used GPA as a measure of cognitive ability (Benjamin et al., 2006; Chen et al., 2013). The subjects' GPAs in our study are also positively correlated with their scores of cognitive ability test ($\rho=0.25$)[3].

[3] Based on the regression analysis, the 1 percent change in test score was associated with the 0.45 percent change in GPA and it was highly significant ($p=0.01$).

Table 1. Comparison of Subjects' Characteristics across Cognitive Groups

	All	High cognitive	Low cognitive
Age (years)	24.03 (7.19)	23.14 (3.73)	24.92 (9.42)
Gender (1: male, 0: female)	0.49 (0.50)	0.51 (0.50)	0.48 (0.50)
Grade Point Averages (GPA)	3.36 (0.52)	3.53 (0.47)	3.19 (0.52)
Employ (1: yes, 0: no)	0.58 (0.49)	0.58 (0.49)	0.58 (0.49)
Extraversion*	8.40 (3.00)	8.63 (3.01)	8.17 (2.99)
Agreeableness	9.47 (2.47)	9.49 (2.54)	9.44 (2.43)
Conscientiousness	10.55 (2.73)	10.17 (2.99)	10.92 (2.42)
Emotional stability	9.50 (2.89)	9.78 (2.89)	9.22 (2.87)
Openness	10.64 (2.23)	10.63 (2.21)	10.65 (2.27)
Grit	41.07 (6.88)	40.57 (7.23)	41.57 (6.53)
CFC	42.22 (6.41)	42.74 (6.38)	41.71 (6.44)

Note: Each value represents the average of each variable. Standard Deviation for each value shown in parentheses.
* The Big five personality traits use a seven-point Likert scale to measure responses to individual questions; Both Grit scale and CFC use a five-point Likert scale to measure responses to each question.

Figure 1 illustrates the distribution of all subjects' Raven test scores and the densities of the Raven test scores of each cognitive group. The mean test score for all subjects was 52.07, with scores ranging from 37 to 60. The average test score for the high cognitive group (the mean test score was 55.3, with score ranging from 48 to 60) was about 6.5 higher than that of the low cognitive group (the mean test score was 48.8, with score ranging from 37 to 56). The mean difference between test scores of two groups was statistically significant (p=0.00).

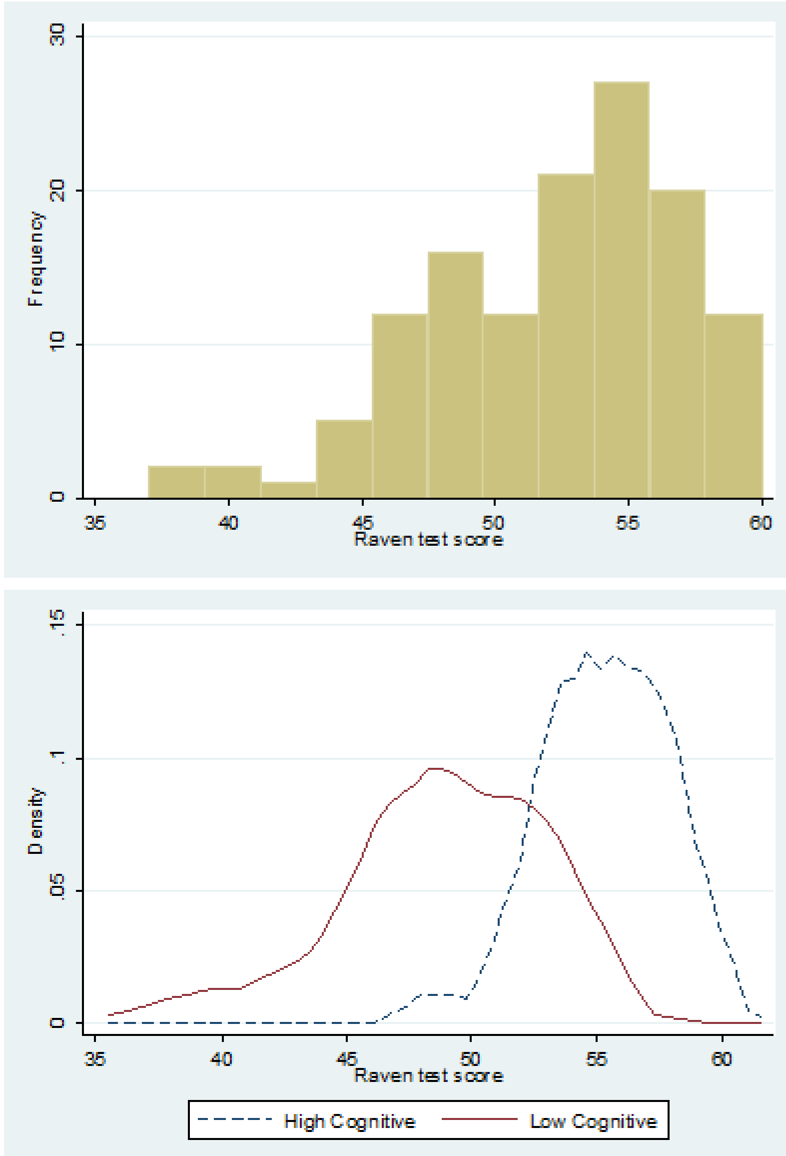

Figure 1. Histogram and densities of Raven test scores

We first examined aggregate bidding behavior by round in each cognitive group, following the framework used by Drichoutis et al. (2015). We constructed the ratio of the aggregate revealed demand (i.e., subjects' aggregate bid) over aggregate induced demand in each round. The aggregate induced value in each round equals 1125.02 (i.e., this is the sum of induced values times the number of sessions). Figure 2 shows the ratio of the revealed demand to the induced demand by round. Both cognitive groups have a similar ratio trend across rounds, and they are not perfectly demand revealing. The ratio in the high cognitive group is however everywhere below 110%, with the ratio in round 2 (101.76%) being quite close to the perfect demand revelation. The demand revelation ratio in the low cognitive group is above 110% in rounds 1, 3, and 4, and it has more variation compared to that in the high cognitive group. The average ratio of the revealed demand to induced demand across rounds is about 105.46% in the high cognitive group and about 109.83% in the low cognitive group. Interestingly, the demand revelation ratio of the two groups become similar in round 5, and they tend to converge to the perfect demand line, indicating that a learning effect may have occurred through the rounds.

The results generally indicate that regardless of cognitive ability, subjects at the aggregate level tend to overbid in the second price auction, which is consistent with previous findings (Kagel et al., 1987; Kagel and Levin, 1993; Cooper and Fang, 2008; Drichoutis et al., 2015). However, the pattern of overbidding is relatively moderated in the group of subjects with greater cognitive ability.

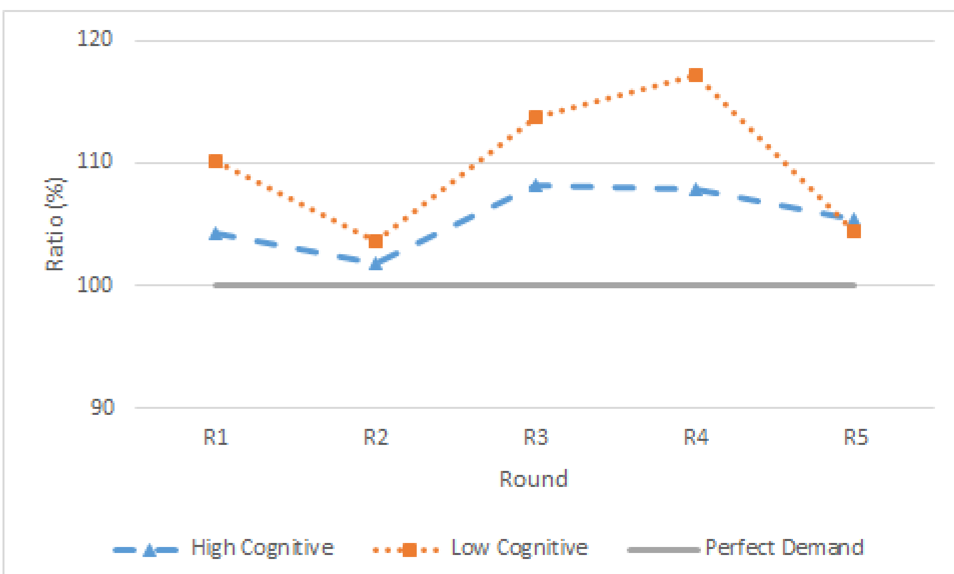

Figure 2. Aggregate behavior by rounds in each cognitive group

We also investigate aggregate bidding behavior by induced values in each cognitive group. Figure 3 shows the ratio of revealed demand to induced demand by induced values. The average demand revelation ratio across induced values in the high cognitive group is about 106.78%, while the average demand revelation ratio in the low cognitive group is about 116.75%. Moreover, the variation of the demand revelation ratio across induced values in the low cognitive group is much higher than that in the high cognitive group, indicating that subjects with greater cognitive ability are less sensitive to changes in induced values and thus aggregate behavioral bias is less pronounced for the group of subjects with greater cognitive ability.

Interestingly, the ratio of revealed demand to induced demand in both groups tend to converge to the perfect demand revelation when induced values increase, which is consistent with the findings from Lusk et al. (2007) and Drichoutis et al. (2015), indicating that individual bidders tend to have incentives to bid optimally in a second price auction as induced values increase. The speed of convergence is however faster in the high cognitive group as induced values increase. The demand revelation ratio of the high cognitive group starts to be close to the perfect demand from an induced value of 17.16, while that of the low cognitive group starts to be close to the perfect demand from an induced value of 23.82.

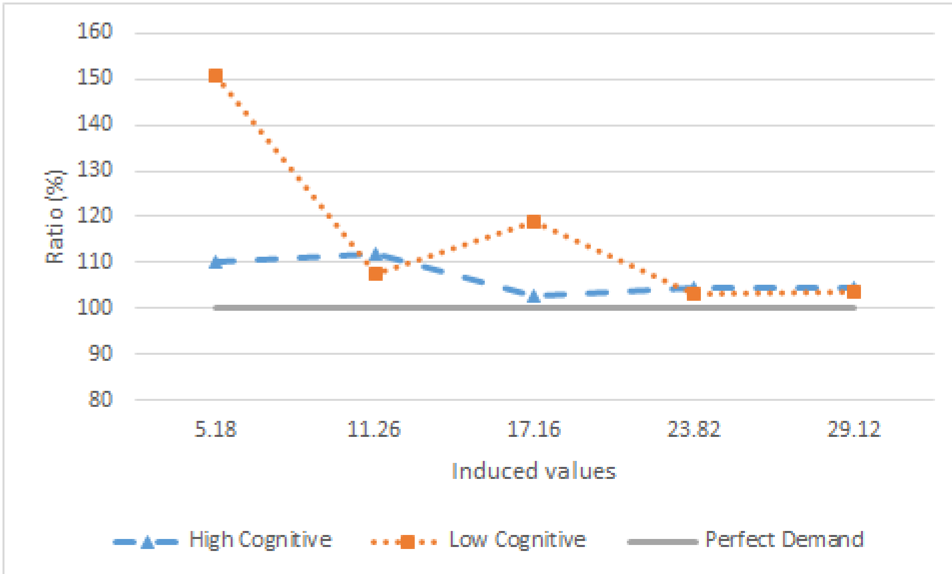

Figure 3. Aggregate behavior by induced values in each cognitive group

We then examined subjects' bidding behaviors in each round. Table 2 describes the distributions of bids across each round in each cognitive group. The results show that subjects on average in both groups generally bid close to induced value in each round. The mean difference between bid and induced value is only statistically significant in round 1 in both groups, indicating that subjects may need some time to learn the dominant strategy in a second price auction. Focusing on the comparison between the two groups, we observe that the mean difference between revealed bids and induced value is relatively small in the high cognitive group except bids in round 5.

Table 3 reports the frequency of bids relative to induced value in each round in both cognitive groups. Results show that on average 29.2 percent (ranging from 26.2 to 30.8) of bids in the group of subjects with greater cognitive skills are perfectly demand revealing while only 14.5 percent (ranging from 12.3 to 15.4) of bids in the lower cognitive group are perfectly demand revealing. In addition, more number of bidders in the higher cognitive group tend to overbid while those in the lower cognitive group tend to underbid in a second price auction.

Table 2. Bid distribution across rounds

Type	Round	Bid	IV	Bid-IV
High cognitive	R1	18.03(9.82)	17.31(8.62)	0.73(0.39)*
(N=65)	R2	17.61(8.85)	17.31(8.62)	0.30(0.36)
	R3	18.72(12.41)	17.31(8.62)	1.41(1.05)
	R4	18.65(11.48)	17.31(8.62)	1.35(1.09)
	R5	18.24(11.77)	17.31(8.62)	0.93(0.83)
Low cognitive	R1	19.07(12.33)	17.31(8.62)	1.76(0.93)*
(N=65)	R2	17.93(9.49)	17.31(8.62)	0.62(0.49)
	R3	19.69(19.09)	17.31(8.62)	2.38(2.12)
	R4	20.29(19.07)	17.31(8.62)	2.98(2.27)
	R5	18.07(9.34)	17.31(8.62)	0.76(0.63)

Note: Each value represent average of each variable. Standard Deviation for bid and IV and standard error for the mean differences shown in parentheses.
* denotes statistical significance at 10%.

Table 3. Frequency of bids relative to induced value

		Number			Percentage		
		=	>	<	=	>	<
High cognitive	R1	20	25	20	30.8	38.5	30.8
	R2	19	26	20	29.2	40.0	30.8
	R3	20	28	17	30.8	43.1	26.2
	R4	17	30	18	26.2	46.2	27.7
	R5	19	25	21	29.2	38.5	32.3
Low cognitive	R1	8	30	27	12.3	46.2	41.5
	R2	10	23	32	15.4	35.4	49.2
	R3	10	24	31	15.4	36.9	47.7
	R4	9	26	30	13.8	40.0	46.2
	R5	10	27	28	15.4	41.5	43.1

Note: =, >, and < denote bid equals induced value, bid is bigger than induced value, and bid is smaller than induced value.

Since individual bids may be influenced by other characteristics, we examine bidding behaviors at the individual level by estimating a conditional regression model. We first use individual round bids and test whether bids are demand revealing.

$$Bid_i = \alpha + \beta IV_i + \gamma X_i + \varepsilon_i \quad (1)$$

where Bid_i denotes individual i's bid in each round; IV_i denotes individual i's induced value in each round; X_i is a vector of control variables including demographic factors (age, gender, grade, and employ status) and individual characteristics (personality traits, grit, and consideration of future consequences); ε_i is the error term. In this specification, bids are demand revealing if $\alpha = 0 \ and \ \beta = 1$.

Table 4 reports both regression and joint hypothesis test results. They indicate that, after controlling for individual characteristics, the hypothesis of demand revealing bidding is not rejected in all round bids for subjects with higher cognitive ability. In contrast, the hypothesis of demand revealing is rejected in bids in round 4 for subjects with lower cognitive ability. Except the bids in round 4, bids in other rounds are also demand revealing for subjects with lower cognitive skills.

Table 4. Regression results in each round

	High cognitive			Low cognitive		
	Intercept	IV	Wald test	Intercept	IV	Wald test
Round 1	1.42(4.19)	1.06(0.05)***	P=0.37	-4.07(7.12)	1.12(0.12)***	P=0.62
Round 2	1.42(3.78)	0.95(0.04)***	P=0.59	0.91(3.79)	1.02(0.06)***	P=0.92
Round 3	-4.41(10.58	1.04(0.14)***	P=0.89	-5.39(16.27)	1.13(0.28)***	P=0.88
Round 4	-0.47(11.11)	0.89(0.14)***	P=0.73	-4.05(16.05)	0.39(0.28)	P=0.08
Round 5	-6.75(8.47)	1.12(0.10)***	P=0.43	7.93(4.96)	0.92(0.08)***	P=0.27

Note: Standard Error for each value shown in parentheses. *** denotes statistical significance at 1%.
We only reports intercept and the coefficient of induced value.

To this point the estimated models do not consider the panel nature of the bidding data (i.e., individual bids for multiple rounds). We therefore further analyze bidding behavior by estimating the random effect regression model.

$$Bid_{iR} = \alpha + \beta IV_{iR} + \gamma X_i + \tau_R + u_i + \varepsilon_{iR} \quad (2)$$

where Bid_{iR} is an individual i's bid in round R; IV_{iR} denotes individual i's induced values in round R; X_i is a vector of control variables as earlier defined; τ_R denotes round fixed effects; u_i is random effects which control for unobservable individual characteristics; ε_{iR} is the error term.

Table 5 reports panel regression and joint hypothesis test results. The results show that the hypothesis of demand revealing is not rejected in all three regression models (i.e., high cognitive, low cognitive, and pooled). To further analyze whether subjects in both cognitive groups have a similar bidding behaviors, we combined data from both cognitive groups and included a dummy for subjects with higher cognitive ability and its interactions with induced values (the regression result is at the third column in table 5). Bidding behavior between two cognitive groups is similar if the coefficients of the dummy and interaction are both zero. The joint test result shows that the hypothesis of similar bidding behavior is not rejected (p=0.34).

We do find heterogeneity in results, however, across a number of subjects' characteristics. For example, results suggest that males have a tendency to bid a higher value than females do which is consistent with the findings of many of previous auction studies. People, who are more agreeable, with high cognitive abilities also tend to bid higher than others who are less agreeable.

Table 5. Panel regression results

	High cognitive	Low cognitive	Pooled
Induced value	1.02 (0.02)***	0.94 (0.05)***	0.94 (0.04)***
Age	-0.12 (0.18)	0.08 (0.13)	-0.04 (0.10)
Gender	2.62 (1.30)**	3.41 (2.31)	2.87 (1.34)**
GPA	1.06 (1.51)	-0.64 (2.16)	0.13 (1.35)
Employ	0.32 (1.42)	3.31 (2.34)	1.43 (1.37)
Extraversion	-0.96 (0.72)	0.49 (1.19)	-0.44 (0.73)
Agreeableness	1.08 (0.64)*	-1.53 (1.23)	0.26 (0.69)
Conscientiousness	0.33 (0.60)	-1.45 (1.58)	-0.40 (0.73)
Emotional stability	0.14 (0.67)	-1.88 (1.34)	-0.78 (0.73)
Openness	-0.93 (0.73)	1.11 (1.18)	0.11 (0.72)
Grit	-0.44 (0.75)	-1.28 (1.52)	-0.50 (0.81)
CFC	0.63 (0.79)	-0.13 (1.32)	0.28 (0.78)
Round 2	-0.42 (0.71)	-1.14 (1.45)	-0.78 (0.81)
Round 3	0.69 (0.71)	0.62 (1.45)	0.65 (0.81)
Round 4	0.62 (0.71)	1.22 (1.45)	0.92 (0.81)
Round 5	0.21 (0.71)	-1.00 (1.45)	-0.39 (0.81)
Constant	-2.08 (6.07)	-0.61 (7.72)	0.89 (5.13)
High cognitive	-	-	-2.31 (1.76)
IV*High cognitive	-	-	0.08 (0.06)
σ_u	4.58 (0.46)***	7.73 (0.84)***	6.78 (0.50)***
σ_e	4.04 (0.18)***	8.29 (0.36)***	6.53 (0.20)***
N	325	325	650
Log-likelihood	-980.19	-1203.33	-2263.02
Wald-test	P=0.67	P=0.57	P=0.85

Note: Standard Deviation for each value shown in parentheses. *, **, and *** denote statistical significance at 10%, 5%, and 1%.

Regression results indicate that individuals' cognitive skills do not seem to have a significant effect on their bidding behaviors in a second price auction. After controlling for individuals' characteristics, bidding behaviors of subjects with greater cognitive ability are similar to those of subjects with lower cognitive ability. Regardless of cognitive skills, individual subjects' bids are demand revealing, indicating that (theoretical) incentive compatibility of the second price auction may induce people to bid optimally.

4. Conclusions

There is considerable unexplained heterogeneity in bidding behaviors in experimental auctions. Complete explanations of heterogeneity in bidding behaviors would explain and help understand violations of individual rationality in experimental auctions. Previous studies have verified that cognitive ability vary considerably across individuals and it is an important determinant of individuals' decision making behaviors. They also concluded that cognitive ability is a good predictor to explain behavioral biases. To our knowledge, no study has attempted to focus explaining behavioral anomalies in bidding behaviors using heterogeneity in cognitive skills. To fill this void, we investigated the effect of individuals' cognitive ability on truthful bidding behaviors in an induced second price auction.

To examine how cognitive skills influence bidding behaviors in an experimental auction, we first measured the cognitive ability of all subjects using a nonverbal Raven test. Based on test scores, we then classified subjects as either of "high cognitive ability" or "low cognitive ability". Subjects in each cognitive group then participated in five rounds of induced second price auction. Our results showed that at the aggregate level, the pattern of overbidding is moderated for a group of subjects with greater cognitive ability and they are also less sensitive to changes in induced values. At the individual level, more subjects in the high cognitive group submitted bids which were perfectly demand revealing than in the low cognitive group. However, after controlling for individual characteristics, subjects' bidding behaviors in both cognitive groups were statistically similar.

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