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Does Size Matter in Group Decision Making? Simulation Experiments with LNG Professionals Bidding in Auction Markets

F. Javier Otamendi[1], Félix-Fernando Muñoz[2]

[1] *Universidad Rey Juan Carlos (Spain)*
[2] *Universidad Autónoma de Madrid (Spain)*

franciscojavier.otamendi@urjc.es, felix.munoz@uam.es

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Abstract:

Purpose: An important issue in decision-making processes is whether groups decide better than individuals. This paper compares the bidding behavior of groups of professionals while playing a business game that simulates, in a controlled environment, the sequential unit capacity auctions in the Spanish LNG market.

Design/methodology/approach: First, we randomly grouped professionals in groups of different size–SOLOs, DUOs, and TRIOs–and played the game in-situ under both First and Second price unit capacity auctions, with SOLOs outperforming groups. Second, we ran non-parametric simulations mixing professionals in groups of different size, in which bids were coupled with those registered during the in-situ sessions. Third, we ran non-parametric simulations in which the players were either 'rational machines' that bid according to Nash equilibrium or groups of 'professionals' of different size.

Findings: The size of the decision group does matter. After the in-situ and the bootstrapped simulated games, the main result is that size is critical, and groups are not necessarily superior to individuals bidding alone. SOLOs bid closer to MACHINEs and lower than DUOs or TRIOs, while obtaining about the same number of units and higher payoffs than groups. Additionally, the 'degree of rationality' of the participants does also matter.

Research limitations/implications: Even after applying the hybrid simulation methodology to increase sample size and allow for additional experimental settings, some of the scenarios are fictitious. Modification of the business game to allow for an even more realistic game could be implemented.

Practical implications: After the hybrid simulation approach, the main implication of the paper is that to increase efficiency in resource allocation professionals should bid individually while using the theoretical knowledge of rational machines.

Originality/value: To our knowledge, this is the first time that this double-experiment simulation methodology is used to analyze bidding behavior in auctions.

Keywords: individual versus group decision-making, sequential capacity auctions, professional bidders, business games, non-parametric simulations

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1. Introduction

1.1. Auctions and Group Decision Making

Auctions have become a main price-determination mechanism, especially when trading commodities or physical goods along the supply chain (Chen & Xiao, 2015). Auctions are everywhere in current life, and they adopt many different forms. In this paper we are especially interested in sequential capacity auctions. These auctions are particularly important in construction (major infrastructures); transportation companies (special transportation jobs); energy (transmission of LNG); radio taxi services; customer response management (CRM) software, etc. In this context, understanding the bidding behavior of professionals that participate in these auctions is very important since their behavior may impact on the performance and reliability of the supply chain (Jin & Yu, 2015; Kleijnen & van Schaik, 2011).

In this paper we analyze the bidding behavior of the LNG professionals when participating in sequential capacity auctions of transmission rights. We build on the auction-based LNG transmission problem (Otamendi & Doncel, 2012) and focus on the behavior and performance of professionals as a function of the size of the groups that take the bidding decisions. The capacity allocative problem in LNG markets in countries like Spain is very important and recently has been resolved by means of capacity auctions. The companies involved in these auctions are willing to know what the best strategies to follow should be, what the size of the groups that participate in these auctions should be, etc. In this context, two research questions arise: Do professionals bidding in groups perform better than those that bid individually? What happens if the composition of the market is a random mix of a few individuals, groups or even machines?

The main hypothesis of this research is that a priori one might expect that 'group decisions were better from those taken individually' (Charness & Sutter, 2012). Groups would present an important advantage: by combining the knowledge of different people the decisions should be more efficient that those of individuals. However, other features of group decision-making could operate in the opposite direction –for example, the so-called groupthink (Janis, 1972), a concept from psychology that refers to the negative effect on decision caused by the desire for consensus and harmony in a group, or the presence of self-selection effects (Otamendi, Brocas & Carrillo 2018; Palfrey & Pevnitskaya, 2008). On the other hand, some groups tend to take more extreme decisions that would take individuals separately (Moscovici & Zavalloni, 1969) –a phenomenon known in psychology as group polarization (Myers & Lamm, 1976).

The question 'individuals vs groups', related to bidding auctions, has attracted the interest of experimental economists and game theorists. Moreover, it is in this literature where some very interesting and challenging issues arise. For example, Sheremeta and Zhang (2010) study whether groups can avoid over-bidding in contests concluding that groups choose less risky alternatives than individuals–bidding up to a 25% less and getting higher profits. Cox and Hayne (2006) compare group decisions to individual ones in bids to establish whether small groups are rational on the grounds of the theoretical model they choose and conclude that groups are less rational than individuals in decision-making processes. Casari, Zhang and Jackson (2016) try to identify the conditions under which group decisions outperform individual ones in the literature on acquisition of firms. Finally, Kocher and Sutter (2005) find that when individuals compete against groups, the latter significantly outperform the former in terms of payoff. It is very interesting to see that there is no clear-cut agreement in terms of how large the group size should be whenever bidding to obtain benefits in the form of available resources and profits.

A remarkable feature in this literature is that experiments typically operate with small groups–usually two people per group and always competing against groups of the same size–that is, individuals against individuals, duos against duos, or trios against trios. Another characteristic is that usually experiments are conducted with undergraduate students. In this paper we explore some alternative venues, including business professionals participating simultaneously in groups of different size. As such, we follow the literature of group decision making and experimental economics and correspondingly set an experiment focused on understanding and quantifying the importance of group size in auctions. In particular, and as a test case, we analyze the bidding behavior of the LNG professionals when participating in sequential capacity auctions of transmission rights.

1.2. The Hybrid Simulation Approach to Increase Sample Size

These two questions are answered in this research with a hybrid approach, after running experiments not only in a controlled environment with LNG professionals but also after expanding the results with non-parametric bootstrap simulations.

First, we use an experimental economics approach –a discipline that focuses in understanding the behavior of subjects while participating in controlled laboratory experiments. More specifically, we follow Otamendi et al. (2018) and use a dynamic single-unit capacity sequential game to auction transmission rights. Thus, we design a business game that simulates, in a controlled environment, the sequential capacity auctions in the Spanish LNG market, to analyze the optimum group size of the participating professionals when bidding in this type of auctions. In this kind of sequential auctions bidders fulfil their needs once they have obtained one good and drop out of the market for subsequent ones. This kind of auctions are common, for example in electricity markets –Brandts, Reynolds and Schram (2014), De Silva (2005), Madden and Ahmad (2013), etc. The objective of the experimental business game is to maximize profits (payoffs) in an auction market in which 4 players bid to obtain at most 1 of the 3 LNG transmission rights that are sequentially at stake (see section 2.1 for further details of the game). However, as will be elaborated later, the results are partially explained by the desire to obtain the right during the auction game, and not just the objective to maximize profits.

We compute three types of key performance indicators (KPIs): (1) those related to the bidding behavior of the players during the games as a function of Nash equilibrium; (2) those related to the resource allocation of units to the players during the games; and (3) those related to the economic rewards obtained by the participants. These KPIs are used to determine the optimum size of the bidding group while participating in sequential capacity auctions under different auction mechanisms.

Secondly, since the sample size is small due to the number of available professionals, in this paper we also propose a follow-up simulation methodology that builds on the results of the laboratory experiment with real professionals. It is worth stressing at this point that, even if the potential of experimental economics for analyzing decision problems is enormous, its performance is usually hampered by the quality of the sample, both in its internal homogeneity and the reduced sample size. In fact, students are usually the experimental subjects, so the sample size is somewhat larger due to its accessibility. It is worth noting that the participants in the main references of this research are always students with the sample sizes being as low as 15 and as large as 500 (100 groups of 5), with normal values around 100. On that regard, if the experimental subjects had to be professionals of any industry, it is usually very difficult to obtain a representative sample.

We resort to non-parametric bootstrap to increase the sample size using 'virtual players' that resemble the original LNG professionals. The simulated environment allows for the testing of both the initial in-situ setting as well as different mix of bidders that could have never been tested with just an experimental economics setting. We are then able to play auction simulation games with different combinations of bidders (or players), whether they are groups of different sizes or machines that bid according to Nash equilibrium.

The virtual players replicate in a non-parametric simulated environment the bidding behavior and game results of the in-situ games with professionals. Besides, the virtual players during the simulated games are randomly selected after using as control factors the group size (between 1 and 3) and the 'degree of rationality' (incorporating machines). The game was therefore played in this research under two related and coupled controlled environments: first, in-situ in the laboratory, by real players–professionals of the LNG market–and, second, by virtual players–'virtual professionals' and rational machines. To our knowledge, this is the first time that this double-experiment simulation methodology is used. Figure 1 shows the description of the game as well as the experimental framework.

The paper has two main contributions. First, we find that not necessarily groups are superior to individuals. Contrary to most of the papers in the experimental economics literature, in our experiments SOLOs (professionals in our case) economically outperform on average both DUOs and TRIOs after bidding closer to Nash equilibrium. Second, we have developed a hybrid methodology to increase sample sizes by means of bootstrap simulations which has allowed us to test and analyze different combinations of bidders, where 'rational machines' have shown superior bidding performance over real players. Thus, to increase efficiency in resource allocation in auction markets, professionals should bid individually but using the theoretical knowledge of rational machines.

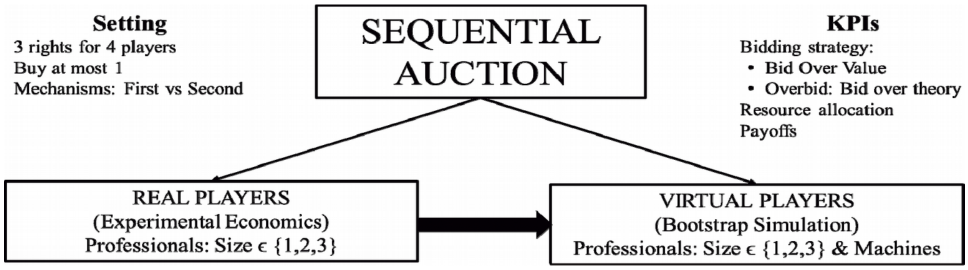

Figure 1. The business game and the experimentation framework

The paper is organized as follows. Section 2 describes the methodology used in the business game and the double playing environment–that is, in-situ experimentation with real professionals and the simulation platform with virtual players. Section 3 presents the experimental results concerning optimum bidding patterns and discusses capacity resource distribution and allocation efficiency (in this case, of LNG transmission rights). Section 4 concludes.

2. Methodology

2.1. The Auction Game

The LNG market is represented by a sequential capacity auction (Milgrom & Weber, 1982, 2000). In this type of auctions, bidders fulfil their needs once they have obtained one resource and drop out of the market for subsequent ones. Thus, obtaining a resource means that the capacity of the bidder saturates for a time, restricting the possibility to bid in the subsequent auctions. In our setting, based on Otamendi et al. (2018), the sequential unit capacity game (Figure 2) includes the assignment of three independent LNG transmission rights or auction 'resources' (R1, R2 and R3) among four players of any size (SOLOs, DUOs and TRIOs) or nature (professionals, 'virtual professionals', and machines) who can only obtain at most one of them. For resource R1, all four players bid and the one with the highest bid obtains the resource or right and an economic reward and cannot bid again for R2 and R3 (the TRIO in Figure 2). The three remaining players bid for the second resource R2, which is assigned to the highest bidder who cannot bid again for R3 (the SOLO bidder in Figure 2). Finally, the two remaining players bid for R3, which is assigned to the highest bidder (the MACHINE in Figure 2). The looser (the DUO in Figure 2) obtains no resource and no economic reward. We run the games with z-Tree software (Fischbacher, 2007).

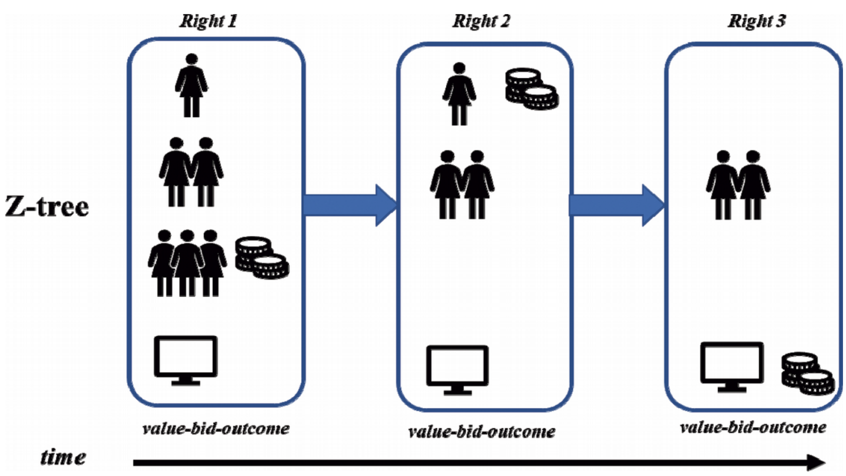

Figure 2. A representation of the business game: a sequential auction in which participants might be individuals or groups of different sizes. Rational machines could also be included as participants. Auctions might follow either of two mechanisms: First or Second price

More specifically, at the beginning of the experiment, each player (individuals or groups of different size) participating in the auctions has a private value randomly assigned for each resource uniformly distributed between 30 and 90 monetary units. Not all three values of the resources are known at the beginning of the experiment: it is not until one resource is auctioned that the players know the assigned value for that resource. Therefore, the players know the values of the transmission right at stake but not the ones that will be auctioned later.

Each session of the experiment is composed of 8 rounds or periods–according to z-Tree terminology–of 3 rights. Each period may be run under either of two mechanisms: First price (F) and Second price (S) sealed-bid auctions. The first four rounds of the game are run under one mechanism and the last four periods under the other one. The order of the mechanisms changes between sessions with different participants.

Under either mechanism, the winner of the auction of a given right is the one that bids the highest, but the price to pay differs between mechanisms. Under F, the price is the winner's bid (that is, the highest bid), whereas under S, the price corresponds to the second highest bid. The winner correspondingly gets a payoff (the difference between value and price), which may be positive or negative, whereas the looser obtains a payoff of 0.

The aim of the game therefore is to understand the bidding behavior of the players in terms of their characteristics and how that behavior relates to resource allocation and payoffs. The complete set of instructions of the game that are read out loud to the participants for their understanding of the game are included in Appendix 1.

Table 1 shows the main indicators used in the analysis.

Thus, we perform the traditional analysis of auctions in terms of the bidding behavior in terms of (1) and (2), the allocation of resources is then analyzed with (3), and, finally, the payoffs conditional on winning rights is assessed with (4) and (5).

Key Performance Indicator	Definition	Objective
1. 'Bid Over Value (%)'	Difference between bids and values. Theoretically, the bids should always be below the value to avoid potential negative payoffs	Minimization
2. 'Overbid (Avg.)'	Difference between experimental bids and theoretical optimal bids	Minimization
3. 'Wins (%)'	Percent of allocated rights to each type of bidder	Proportional to the mix of bidders
4. 'Payoffs when winning <0 (%)'	Percent of resources obtained with losses	Minimization
5. 'Payoffs when winning (Avg.)'	Difference between value and price	Maximization

Table 1. Main KPIs

2.2. Real Professionals in a Controlled Environment

We ran 4 sessions of the experiment with 32 professionals from the LNG industry. In each session, 16 games were played (8 rounds, 2 groups of 4 players), so a total of 48 rights were auctioned. In each game 9 bids were placed (4 for R1, 3 for R2, 2 for R3), for a total of 144 bids per session. For sessions #1 and #2, 4 subjects participated individually and the other 8 in pairs (DUOs). For sessions #3 and #4, 4 subjects participated individually (SOLOs) and the other 12 in TRIOs. For sessions #1 and #4 the first four periods of auctions were run under the F mechanism (First-price) and the last 4 under the S mechanism (Second-price), or sequence F→S. The reverse sequence, S→F, was the order for sessions #2 and #3. Table 2 summarizes the number and type of the groups of participants as well as the order of the mechanisms within the sessions.

A distinctive feature of this setting of the in-situ experiment with professionals was that contrary to the literature where either SOLO, or DUOs or TRIOs played against each other, SOLOs were allowed to face SOLOs, DUOs or TRIOs. These combinations tried to mimic more realistic settings. Moreover, since the combination of the four bidders (players) was random in terms of group size, and the randomness of the experiment changed the combination after any period, there is a chance that the four groups bidding for the same rights were at one point all SOLOs, all DUOs, all TRIOs or, more likely, a mix of SOLOs and either DUOs or TRIOs.

Sessions	SOLOs	DUOs	TRIOs	Order	Games	Rights	# of Bids
#1	4	4		*F*→*S*	16	48	144
#2	4	4		*S*→*F*	16	48	144
#3	4		4	*S*→*F*	16	48	144
#4	4		4	*F*→*S*	16	48	144
Total	16	8	8		64	192	576

Table 2. Description of the in-situ sessions

2.3. Virtual Players in Non-Parametric Simulations

A second execution of the same business game was carried out via simulation. Instead of using physical subjects, we used 'virtual professionals' and/or 'rational machines' to carry out further auctions, while using and coupling the bidding behavior of the first in-situ experiment. The purpose of the simulation was triple fold: first, to increase the number of games played, which was 64 in a real setting; second, to allow for SOLOs, DUOs and TRIOs to compete against each other at the same time; and third, to control for the 'degree of rationality' of the players, by including Nash 'rational machines'–or MACHINEs.

It should be taken into account that the 'degree of rationality' depends on the context: in closed-systems (as a theoretical game or auction), MACHINEs would be more rational because they fit to the conditions of the game or auction. However, when we refer to real players, they decide in open-systems, so there are other circumstances that affect their decisions such as cognitive biases etc. Contrary to perfect rationality of MACHINES, real players always show 'bounded rationality' (Simon, 1955; Tversky & Kahneman, 1986; Gigerenzer, 2019).

We developed a simulation platform using WITNESS simulation software (Release 23.0) in which virtual professional players of different size and rational machines randomly played many times the unit sequential game. At the start of each round, each of the four players were randomly defined in terms of group size (SOLO, DUO, TRIO) and type (virtual professional or MACHINE). Therefore, one sequential auction of 3 resources could be played by 4 SOLOs and another with four MACHINEs, although most of them were played by a mixture of groups of different size and degree of rationality.

When each resource was at stake during the simulation runs, a pair (value, bid) was assigned to the virtual players. For the MACHINEs, the assignment was straightforward: the values were randomly drawn between 30 and 90 as per experimental design, and the bids calculated directly using the theoretical Nash-equilibrium equations, varying across rights and mechanisms (Otamendi et al., 2018). For the virtual professionals, the pairs (value, bid) were randomly resampled from the data that was obtained in the laboratory during the in-situ experiments, once again varying across rights and mechanisms.

For example, let's suppose that a SOLO player was going to play in a sequential auction under the first-price mechanism. For resource R1, the assigned pair to the SOLO player is one of the pairs that was collected during in-situ experiments for SOLO real professionals while bidding for R1 under F (64 available pairs in the database). The selection is randomly performed among the available pairs. Similarly, if the SOLO player is still bidding for R2, the selected pair is selected among the 51 available pairs for SOLOs while bidding for R2 under F. Moreover, if the SOLO player is still in the hunt for R3, the selected pair is selected among the 34 available pairs for SOLOs while bidding for R3 under F.

We ran two different simulations. We ran first 12,000 rounds of the game (6,000 F and 6,000 S) with just 'virtual professionals' (about one third of each size) to validate the platform while comparing the results with the experimental results. Thereafter, we ran 16,000 additional rounds of the game (8,000 F and 8,000 S), including MACHINEs as players (about 25% of the total bidders are MACHINES, 25% SOLOs, 25% DUOs and 25% TRIOs).

3. Results

3.1. Experiment with Real Professionals

We first used the in-situ sessions to investigate with the available professionals whether group size has an impact on the outcomes when participating in sequential capacity auctions of LNG transmission rights.

3.1.1. Overall

Table 3 shows the results after comparing the real professionals in terms of group size. The highlighted cells correspond to the group size that outperforms both of the other two group sizes (white numbers on black background) or just one of the other two group sizes (grey background). To determine that one group size outperforms another group size, we conducted a two-way comparison using traditional hypothesis testing on the differences at the 0.05 level (full tables with p-values are available in Appendix 2).

The table shows a clear indication of the ranking of group sizes in terms of bidding: SOLOs (13.88) overbid significantly less than DUOs (15.33) and TRIOs (17.01), with DUOs overbidding significantly less than TRIOs. There are no significant differences in terms of 'Bid over Value'.

The rest of KPIs did not show significant differences. In terms of the total number of bids, SOLO participants had to submit more bids (302 for SOLO (52.4%) vs 274 for DUOs+TRIOs), indicating that they stayed longer in the games, reaching right R3 more often.

In terms of payoffs conditional on winning, SOLOs incurred in losses less often than DUOs and TRIOs (8.1%, 14.9% and 17.4%, respectively), but they were ranked in reverse order in average payoff (6.91, 7.12 and 8.13, respectively). Statistical differences were however not found among the group sizes. More rights were allocated to SOLOs (99 or 51.6%) than to DUOs+TRIOs.

Group Size	Bidding				Payoffs		Resource Allocation	
	Count of Bids	Total Bids (%)	Bid Over Value (%)	Overbid (Avg.)	Payoff Conditional Winning < 0 (%)	Payoff Conditional Winning (Avg.)	Count of Wins	Total Wins (%)
SOLO	302	52.4%	36.1%	**13.88**	8.1%	6.91	99	51.6%
DUO	136	23.6%	42.6%	**15.33**	14.9%	7.12	47	24.5%
TRIO	138	24.0%	43.5%	17.01	17.4%	8.13	46	24.0%
Total	576		39.4%	14.97	12.0%	7.26	192	100.0%

Table 3. Experimental game: comparisons by group size

3.1.2. By Mechanism and Right

We looked for additional understanding on the influence of group size on the decisions while participating in auctions based on the interactions between mechanism and right. We ran hypothesis testing on the pairwise difference (proportions or averages) in terms of size not only in overall terms (ALL) but also by mechanism (First or Second), right (R1 or R2 or R3) and any of their combinations. Table 4 shows the results in terms of the 'Bid Over Value (%)'.

SOLOs are superior to groups and bid less times over the value than DUOs and TRIOs in SECOND, especially in R1 and R2. For the other comparisons, no significant differences and found.

Bid Over Value (%)	All	First	Second	R1	R2	R3	First			Second		
							R1	R2	R3	R1	R2	R3
SOLO	36.09%	4.70%	**66.67%**	33.59%	36.54%	40.00%	3.13%	5.88%	5.88%	**64.06%**	**66.04%**	72.22%
DUO	42.65%	2.90%	83.58%	42.19%	41.86%	44.83%	3.13%	0.00%	6.67%	81.25%	85.71%	85.71%
TRIO	43.48%	5.71%	82.35%	43.75%	48.89%	34.48%	3.13%	8.70%	6.67%	84.38%	90.91%	64.29%
Total	39.41%	4.51%	74.31%	38.28%	40.63%	39.84%	3.13%	5.21%	6.25%	73.44%	76.04%	73.44%

Table 4. Bid over value: pairwise differences in terms of size by right and mechanism

Table 5 analyses 'Overbid (Avg.)'. There are no differences found between SOLOs and DUOs, while SOLOs overbid less than TRIOs in R1 and R2, especially in Second. Both KPIs indicate that TRIOs show a riskier behavior than DUOs and SOLOs.

This bidding behavior has an obvious effect on the resource allocation and the payoffs conditional on winning. Table 6 shows the rights awarded to each group size. SOLOs (50% of professionals) win a little bit more (51.56%) than their expected proportional share, with the percentage raising from a low 37.50% for R1 to 53.13% for R2 and a high 64.06% in R3, with this pattern occurring in both First and Second mechanisms. For DUOs and TRIOs, the pattern is reversed and similar among both group sizes.

In terms of payoffs, Table 7 depicts 'Payoff conditional on winning < 0 (%)' and Table 8 the 'Payoff conditional on winning (Avg.)'. There are no significant differences found except for specific cases. For the last right at stake, R3, SOLOs and TRIOs are superior to DUOs in terms of negative payoffs and TRIOs are superior to SOLOs and DUOs in terms of average payoffs (specially driven by the results in Second-R3). Their riskier behavior pays off in this latter case since there are only two competitors for R3, with the winner, being the player with the highest bid, just paying not its bid but that of the loser.

Overbid (Avg.)	All	First	Second	R1	R2	R3	First			Second		
							R1	R2	R3	R1	R2	R3
SOLO	**13.88**	14.27	**13.51**	**16.92**	**12.78**	9.97	16.01	12.70	13.32	**17.82**	**12.86**	6.80
DUO	15.33	14.94	15.73	18.14	15.37	9.08	16.29	15.85	10.73	19.98	**14.85**	7.31
TRIO	17.01	14.64	19.45	20.33	19.96	5.10	16.88	14.53	10.03	23.78	25.64	-0.18
Total	14.97	14.52	15.43	18.07	15.04	8.66	16.30	13.86	11.94	19.85	16.22	5.39

Table 5. Overbid: pairwise differences in terms of size by right and mechanism

Wins (%)	All	First	Second	R1	R2	R3	First			Second		
							R1	R2	R3	R1	R2	R3
SOLO	**51.56%**	**55.21%**	47.92%	37.50%	**53.13%**	**64.06%**	40.63%	**53.13%**	**71.88%**	34.38%	**53.13%**	**56.25%**
DUO	24.48%	22.92%	**26.04%**	**32.81%**	21.88%	18.75%	**31.25%**	21.88%	15.63%	**34.38%**	21.88%	21.88%
TRIO	23.96%	21.88%	**26.04%**	**29.69%**	25.00%	17.19%	**28.13%**	25.00%	12.50%	**31.25%**	25.00%	21.88%
Total	192	96	96	64	64	64	32	32	32	32	32	32

Table 6. Wins (%): pairwise differences in terms of size by right and mechanism

Payoff Conditional Winning < 0 (%)	All	First	Second	R1	R2	R3	First			Second		
							R1	R2	R3	R1	R2	R3
SOLO	8.08%	3.77%	13.04%	12.50%	14.71%	**0.00%**	7.69%	5.88%	0.00%	18.18%	23.53%	0.00%
DUO	14.89%	4.55%	24.00%	14.29%	7.14%	25.00%	0.00%	0.00%	20.00%	27.27%	14.29%	28.57%
TRIO	17.39%	9.52%	24.00%	21.05%	25.00%	**0.00%**	0.00%	25.00%	0.00%	40.00%	25.00%	0.00%
Total	11.98%	5.21%	18.75%	15.63%	15.63%	4.69%	3.13%	9.38%	3.13%	28.13%	21.88%	6.25%

Table 7. Payoff Conditional on Winning < 0: pairwise differences in terms of size by right and mechanism

Payoff Conditional Winning (Avg.)	All	First	Second	R1	R2	R3	First			Second		
							R1	R2	R3	R1	R2	R3
SOLO	6.91	5.90	8.08	5.10	4.39	10.07	5.64	5.58	6.29	4.45	3.20	14.91
DUO	7.12	5.58	8.48	6.78	9.26	5.23	7.47	4.51	3.28	6.15	14.01	6.62
TRIO	8.13	5.32	10.50	2.99	6.34	**19.62**	7.07	3.15	5.73	-0.67	9.53	**27.55**
Total	7.26	5.70	8.82	5.02	5.94	10.81	6.61	4.74	5.75	3.43	7.15	15.86

Table 8. Payoff Conditional on Winning (Avg.): pairwise differences in terms of size by right and mechanism

In situ	All	First	Second	R1	R2	R3	First			Second		
							R1	R2	R3	R1	R2	R3
1. 'Bid Over Value (%)'			SOLO							solo	SOLO	
2. 'Overbid (Avg.)'	solo		solo	solo	solo					solo	solo	
3. '% Wins':	SOLO	SOLO		DUO	SOLO	SOLO	DUO	SOLO	SOLO	DUO	SOLO	SOLO
4. 'Payoffs when winning <0 (%)'.						solo						
5. 'Payoffs when winning (Avg.)'.						trio						trio

Table 9. Summary of comparisons with real professionals

Table 9 summarizes these results with the group size that dominates the other two highlighted in capital letters and in a colored background (black for SOLO, dark grey for DUO and light grey for TRIO). Those group sizes that dominate only one other group are also mentioned in regular letters. SOLOs bid lower and closer to Nash equilibrium than DUOs and TRIOs with no significant differences on average payoffs. SOLOs also won more rights. However, riskier TRIOs may capitalize on the lower bids of other players although the bids should always be below the assigned value.

The explanation is double fold but explained by the bidding behavior. SOLOs (and sometimes DUOs) bid lower and closer to equilibrium (less overbid) because they understand the game better and/or because they are more patient. The self-selection effect is at stakes, especially during the first two rights auctioned under the Second price mechanism (Palfrey & Pevnitskaya, 2008).

3.2. Simulation with Virtual Professionals

Since the previous results are based on 32 professional groups, and due to the difficulty of obtaining a larger sample to provide a full comparison across all levels of group sizes, we resort to non-parametric bootstrap simulations that use as input the bids observed during the in-situ experiments. What follows is the detailed analysis of the results after simulating 12,000 auctions while mixing the type of players in terms of their group size (SOLO, DUO or TRIO). The players during each auction were a random selection of the professionals that took part of the in-situ experiments. Each size was evenly represented among these 'virtual professionals.' The expectation was that the bidding results will be statistically equivalent to those of the in-situ game but the effect on resource allocation and payoffs might vary while mixing players of different size.

Table 10 shows the results after comparing the virtual professionals in terms of group size. Just by looking at the table, there is a clear indication of the ranking of group sizes in terms of bidding: SOLOs (13.93) overbid significantly less than DUOs (15.28) and TRIOs (16.99), with DUOs overbidding significantly less than TRIOs (these numbers and the whole set of detailed results are shown in Appendix 2). As expected, these results on overbid with 'virtual professionals' are obviously similar to those obtained with 'real professionals.' The numerical values for 'Bid over value' are also very similar but, in this case, and since the sample size is higher, the differences among group sizes are significant, once again, with SOLOs showing superior performance.

Simulation with Professionals							First			Second		
	All	First	Second	R1	R2	R3	R1	R2	R3	R1	R2	R3
1. 'Bid Over Value (%)'	SOLO	DUO	SOLO	SOLO	SOLO	TRIO		DUO		SOLO	SOLO	TRIO
2. 'Overbid (Avg.)'	SOLO	SOLO	SOLO	SOLO	SOLO	TRIO	SOLO	SOLO	TRIO	SOLO	SOLO	TRIO
3. '% Wins':				duo/ trio	DUO	SOLO	TRIO	DUO	SOLO	duo/ trio	TRIO	SOLO
4. 'Payoffs when winning <0 (%)'.	SOLO	solo/ duo	SOLO	SOLO	DUO	solo/ trio	TRIO	DUO	SOLO	SOLO	solo/ duo	solo/ trio
5. 'Payoffs when winning (Avg.)'.	SOLO	solo/ trio	SOLO	solo/ duo	solo/ duo	TRIO	TRIO	SOLO	solo/ trio	SOLO	DUO	solo/ trio

Table 10. Summary of comparisons with virtual professionals

On average, SOLOs (9.23) obtained better payoffs than DUOs (7.14) and DUOs than TRIOs (6.68), while the resources were evenly allocated over the three group sizes (32.93%, 33.90%, 33.17%, respectively). There are as expected minor variations whenever the combinations of mechanism and right are evaluated.

The resources were evenly allocated among the different sizes (32.9% wins by SOLOs, 33.9% by DUOs and 33.2% by TRIOs), about one third each, although the number of bids was higher for SOLOs (35.1% by SOLOs, 32.5% by DUOs and 32.4% by TRIOs).

In terms of payoffs, the results changed significantly for both KPIs, showing statistical differences while there were none found for the in-situ games. The ranking with respect to the percent of losses (SOLO better than DUO and DUO better than TRIO) stays the same although the totals significantly raised from 12.0% in real games to 15.7% in virtual games. SOLOs incurred in losses less often than DUOs and TRIOs (12.0%, 14.9% and 17.4%, respectively). Regarding average payoffs, the totals raised from 7.26 in real games to 7.67 in virtual games, with SOLOs obtaining higher payoffs (9.23, 7.14 and 6.68, respectively).

We dig deeper and seek an explanation in terms of mechanism and rights. The results confirm 'in situ' experiments in which SOLOs bid closer to Nash equilibrium than DUOs and DUOs than TRIOs, with few exceptions focused on R3 (when TRIOs excel). This bidding behavior had an implication on the percent of bids, with SOLOs reaching R3 more often (38.23% of bids) than DUOs (30.50%) or TRIOs (31.23%).

The results included in this section validate the simulation platform since the bidding behavior of the 'virtual professionals' is the same as that of the real professionals. As such, SOLOs bid lower than DUOs and DUOs than TRIOs. In terms of allocation of rights, there is an even distribution among the three types of professionals in terms of size, although SOLOs obtain R3 more often than R1 or R2. Concerning payoffs, SOLOs obtain higher payoffs on average, although for certain combinations of mechanisms and rights, riskier behaviors might pay off.

3.3. The Influence of Rational Behavior

Finally, we added 'rational player' to the games to compete against 'virtual players.' We included MACHINEs that always bid at equilibrium to see what their impact on resource allocation and payoffs of SOLOs, DUOs and TRIOs was. We expected that, while maintaining the same bidding behavior of 'virtual professionals', the payoffs when winning were larger for the MACHINEs as compared to 'virtual professionals', but the effect on the percentage of allocated resources to the 'virtual machines' was not clear.

To quantify the effect of rationality of different players, we run 16,000 auctions while mixing the type of players (virtual SOLOs, DUOs or TRIOs as well as rational MACHINEs). About 25% of the players will be of one of the four types.

Table 11 shows the results after comparing the 'virtual professionals' in terms of group size when machines are present. MACHINEs bid lower (obviously, they never overbid), and therefore did place more bids in the sequential game while reaching R3 more often (30.2% bids by 25% machines in the game). SOLOs as always bid lower than DUOs and DUOs than TRIOs, with the same bidding behavior as before. MACHINEs however won less than expected (just 18.4% of the rights) with the rest of rights evenly allocated among the virtual professionals (27.4%, 27.1%, 27.1%, respectively).

In terms of payoffs conditional on winning, MACHINEs obtained the highest results and never incurred in losses. With respect to 'virtual professionals', they won just between one half and one third of what MACHINEs obtain. The average totals raised once again for each group size, with SOLOs obtaining higher payoffs (9.34, 7.91 and 7.11, respectively).

The 'rational players' or MACHINEs bid lower and obtained better results. Their bids were even lower than those of SOLO professionals across mechanisms and rights. Therefore, their profits were higher, once again, whenever winning and obtaining a transmission right. Regarding 'virtual professionals', on average, SOLOs obtained better payoffs than DUOs and DUOs than TRIOs, while the resources are evenly allocated over the three group sizes. There are, as expected, minor variations whenever the combinations of mechanism and right are evaluated.

With respect to overbids, the differences among mechanisms and rights were significant, with more overbidding in Second (11.53) than in First (10.30) price auctions. The overbid was lower for later rights throughout group sizes, and specially in R3 of

Simulation with Machines							First			Second		
	All	First	Second	R1	R2	R3	R1	R2	R3	R1	R2	R3
1. 'Bid Over Value (%)'	SOLO	DUO	SOLO	SOLO	SOLO	TRIO		DUO		SOLO	SOLO	TRIO
2. 'Overbid (Avg.)'	SOLO	SOLO	SOLO	SOLO	SOLO	TRIO	solo/ duo	SOLO	TRIO	SOLO	SOLO	TRIO
3. '% Wins':	solo/ duo/ trio	SOLO		TRIO	DUO	SOLO	TRIO	DUO	SOLO	duo/ trio	TRIO	MACHINES
4. 'Payoffs when winning <0 (%)'.	SOLO	solo/ duo	SOLO	SOLO	DUO	SOLO	TRIO	DUO	SOLO	SOLO	DUO	solo/ trio
5. 'Payoffs when winning (Avg.)'.	SOLO	solo/ trio	SOLO	solo/ duo	SOLO	solo/ trio	TRIO	SOLO	solo/ trio	solo/ duo	DUO	solo/ trio

Table 11. Summary of comparisons including rational machines

Second, where the optimal bid should be equal to the value assigned to that right. TRIOs excel in Second-R3.

As for payoffs conditional on winning, MACHINEs won 21.80 on average, more than doubling the professionals. SOLOs obtained 9.34, with DUOs earning 7.91 and TRIOs only 7.11. On the other hand, SOLOs won more across mechanisms, with TRIOs following in second position in First and DUOs in Second. In terms of rights, the rankings varied somewhat, with SOLOs winning more in R3 (both First and Second) and in First-R2. DUOs were the winners in Second-R1 and Second-R2, and TRIOs in First-R1.

The astonishing results relates to the allocation of auctioned rights. Comparing rational MACHINEs versus professionals, out of the 48,000 rights that were awarded, professionals obtained 81.57% of the rights and MACHINEs just 18.43%, when 25% of the bidders were rational machines. Bidding low guarantees large positive payoffs, but only whenever winning.

There was also a big difference across rights: R1 (94% in First; 93% in Second) and R2 (81% in First; 84% in Second) were primarily won by professionals (75% of the players), whereas R3 was obtained by MACHINEs (25% of the players; 35% in First; 32% in Second). Moreover, SOLOs obtained more rights in R3 (31% in First; 27% in Second) than DUOs (17% in First; 21% in Second) or TRIOs (23% in First; 17% in Second) and less if R1 and R2 are added together (First: 55% for SOLOs; 65% for DUOs and 60% for TRIOs; Second: 52% for SOLOs; 60% for DUOs and 63% for TRIOs). Therefore, professionals were more allocative efficient than MACHINEs since they obtained more rights regardless of profits. Additionally, in terms of bidders' goals, it could be said that a bid is allocative efficient if the bidder gets the capacity resource (Muñoz & Encinar, 2019). Something different is the 'price' paid to get it. And of course, the worst situation is that in which the bidder does not obtain anything (although the payoff is consequently 0). Which type of bidder wins more frequently is a way to state which is more efficient in the allocation of the resource.

In summary, trying to win more often–to get the transmission rights or capacity resources as in the case of a sequential auction like our example of LNG–might be the reason why there is more overbid in general, and even more the larger the groups are. In fact, after the in-situ experiment, the professionals argued that they were thinking about getting the right and not only about maximizing profits. More overbid brings however the profits down. This trade-off between allocative efficiency and profits is a feature of sequential auctions. The simulation shows that in this kind of single-unit capacity auctions profits are higher whenever the overbidding is minimized, a behavior that corresponds to MACHINEs. Among 'virtual professionals' SOLO players perform better on average. A possible explanation is the elimination of extreme preferences for punishment through the coordination process in teams (Auerswald, Schmidt, Thum & Torsvik, 2018). This does not mean that certain DUOs or TRIOs may also play well or that in some cases riskier behaviors may pay off, especially on Second-R3. In this last case, the optimum bid is the value, so the profits are constant regardless of the group size and/or mix of competitors.

4. Concluding Remarks

Our results of the hybrid simulation approach show that not necessarily groups are superior to individuals. In particular, in our in-situ experiments, SOLO professionals bid lower and obtain higher profits than groups (DUOs and TRIOs) in sequential capacity auctions while there is a proportional allocation of rights among different group sizes. The level of difficulty or the self-selection effect, which varies with the different stages of the sequential game–as a function of the mechanism (First or Second price auctions) and the resources or rights remaining to be auctioned (3, 2, 1)–seems to be crucial to understand the superiority of SOLOs even among professionals. Contrary to most of the papers in the literature, in our experiments SOLO individuals outperform on average both DUOs and TRIOs. These results are however not entirely new. For example, Müller and Tan (2013) report that in one-shot markets they find no significant differences in the behavior of groups and individuals, and in repeated markets they find that the behavior of groups is further away from the subgame-perfect equilibrium of the stage game than that of individuals. For Meub and Proeger (2018) groups and individuals are equally biased by external factors, etc. Some authors however indicate that groups make less risky decisions (He & Villeval, 2017).

Our conclusions on group sizes are also backed up by the results obtained via non-parametric simulations based on in-situ data. The novel application of the coupling procedure has allowed for a substantial increase in the sample size as well as for performing virtual experiments that could have been difficult to run on a controlled environment.

Another interesting result is that, if the games are played to test the degree of rationality of the players regardless of size, 'rational machines' that bid optimally according to the theoretical Nash equilibrium were significantly better than 'virtual professionals' both in bidding and profits. In fact, the in-situ-based non-parametric simulations of auctions were run with different combinations of group sizes –'virtual professionals' (SOLO, DUO and/or TRIO) and 'rational' MACHINEs. However, the allocation of goods is not proportional anymore and MACHINEs win percentage-wise less units than 'virtual professionals.' This result raises an important question for further investigation as to whether 'too rational' behavior is the best strategy in unit-capacity auctions. Although bidding low is a guarantee of reasonable average payoff, bidding too low might be harmful in terms of allocation of resources to the rational player.

The main contribution of this paper is therefore that the size of the decision group does matter. Additionally, the 'degree of rationality' of the participants does also matter. Therefore, in LNG sequential auction markets, professionals should bid individually but using the theoretical knowledge of rational machines. The composition of over- and under-bidders in the population, controlling the personal skills and psychological traits, seems critical and should be the focus of future research, leading to the development of a behavioral bidding theory in markets with capacity constraints.

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Appendix 1: Instructions

You are going to participate in an experiment in which you will have to make decisions in groups, and you will be paid in cash at the end of the experiment. Each participant may obtain different amounts due partly to its own decisions, partly due to the decisions of others, and partly due to the luck of the draws. The experiment is computer-based and all the interactions among participants will be through the PC. It is important that you do not talk and that you do not try to communicate with other participants throughout the experiments.

We will start with a short period of instructions, in which you will be instructed on the rules of the experiment, and you will be taught on how to use the computers. It is very important that you pay close attention. If any questions arise, raise your hand and the answer will be given out loud for everyone. If any doubts strike your mind, raise your hand and I will help you with the computer.

At the end of the session, you will be paid according to just one of the 8 rounds that cover the experiment, chosen at random, plus an additional 2 euros as a participation reward. The payment will be performed on an individual basis and in private. You are not obliged to disclose whatever you have obtained.

The earnings during the experiment are measured in monetary units or tokens. According to your decisions you may win or lose tokens. At the end of the experiment, you will be paid in euros according to an exchange rate of 1 euro for every 4 tokens that you have earned during the round that has been selected at random.

The experiment will consist of 8 rounds of auctions. In each round, you will be randomly assigned to a group of 4 participants. You will not know the identity of the other 3 participants of your group. Since you are 12/16 participants, 3/4 groups will be formed in each round. Your reward depends exclusively on the decisions of the participants of your group and on the luck of the draws. Whatever happens on the other groups does not affect to your rewards, neither your behavior will affect the results on the other groups.

During each round, 3 goods will be auctioned among the 4 participants of each group sequentially, that is, one-at-a-time, and each participant will be allowed to buy just one of the three goods at stake. Therefore, at each round and for each group of 4 participants, 3 of the players will get one good and the fourth player will not get any. For each good at stake, only those participants that have not previously obtained a good may bid.

Let's now explain the rules of each round. At the beginning of each round, the PC will assign each participant to a group with other 3 participants, for each good being auctioned, the computer will assign a random valuation between 30 and 90 tokens. The interactive screen (Figure A1) will ask the participant to enter a bid, which must be positive and less than 150 tokens, and press the confirmation button.

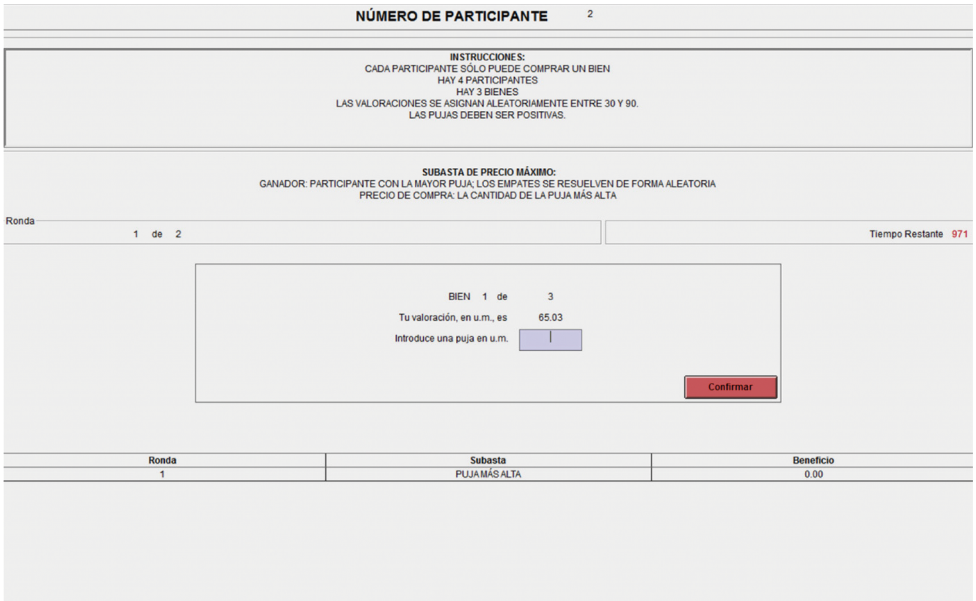

Figure A1.1. Placing a bid

We are facing a sealed-bid auction, since the bids are anonymous and secret, and there is a set period to time to submit the bid. That is why it is critical to remain in silence.

Before submitting the bid, it is convenient to read the information on the screen, to correctly identify the good being auctioned and to fully understand the rules:

- 4 participants in each group and 3 goods per round.
- The valuations are random between 30 and 90 tokens.
- The auction type currently under way: First Price and Second Price. The peculiarities of each of the two types will be explained later.
- The rest of the available information shown on the screen is:
- The round or period.
- The remaining time to submit a bid.
- The good that it is being auctioned out of the possible 3.
- The history of the experiment, indicating the profit obtained per round.

If a participant has previously obtained a good, the screen is different (Figure A2), just indicating the history, since the subject is not allowed to bid nor obtain a second good.

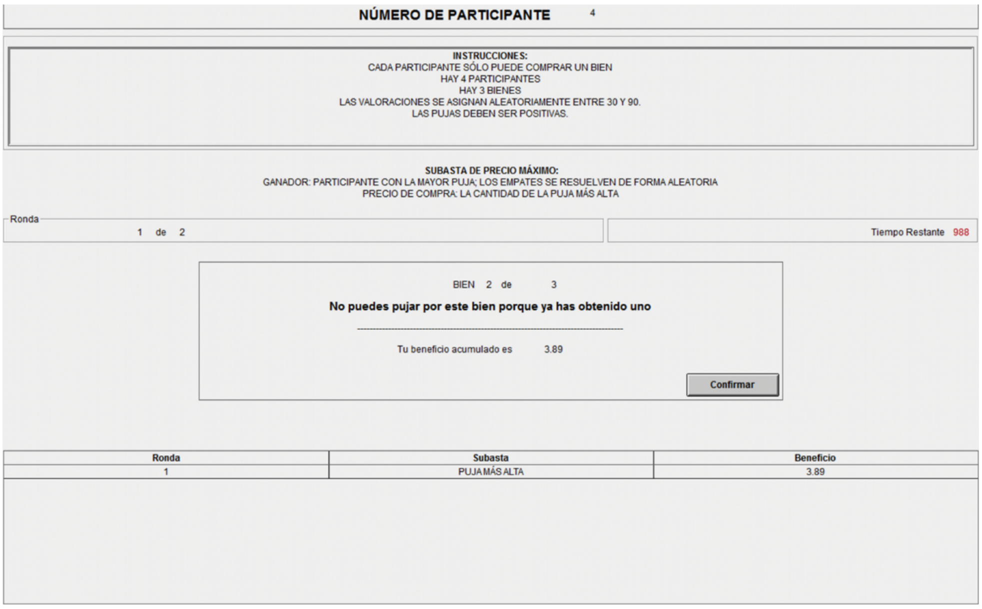

Figure A1.2. Not allowed to bid as a previous winner

When the participants confirm their bids or their profits, a wait screen will show up (Figure A3), screen that will disappear whenever each and every participant press the corresponding confirmation button.

Figure A1.3. Wait screen

When all the bids have been submitted, the computer will assign the good to the buyer or winner, whoever placed the highest bid. The price to pay in tokens will depend on the type of auction mechanism of the current round:

- Under First Price or Maximum Price, the Price coincides with the bid placed by the winner.
- Under Second Price or Vickrey, the Price corresponds not to one's own bid but to the second highest bid.

The profit obtained by the winner or buyer is equal then to the value minus the Price, being positive if the Price is lower than the valuation and negative if the price is above the valuation.

Following you will see simple screenshots with examples that may show up after the assignment of the good to the winner, screens that vary depending on the auction mechanism and the participant is the winner or not.

The first screenshot (Figure A4) will be seen by the winner of a First Price auction, and the profit is one's own valuation minus one's own bid.

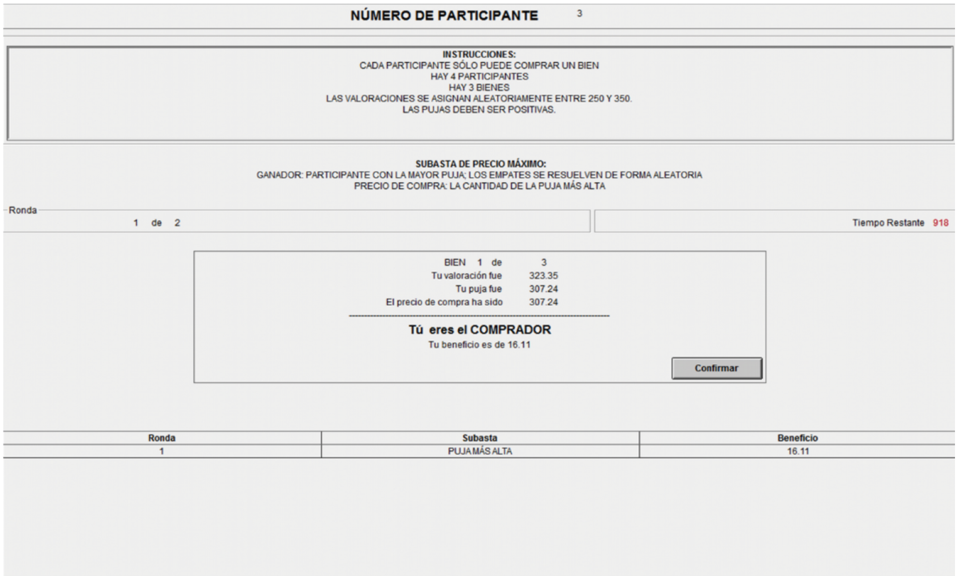

Figure A14. Winner of F

The second (Figure A5) corresponds to a non-winner in a First Price auction.

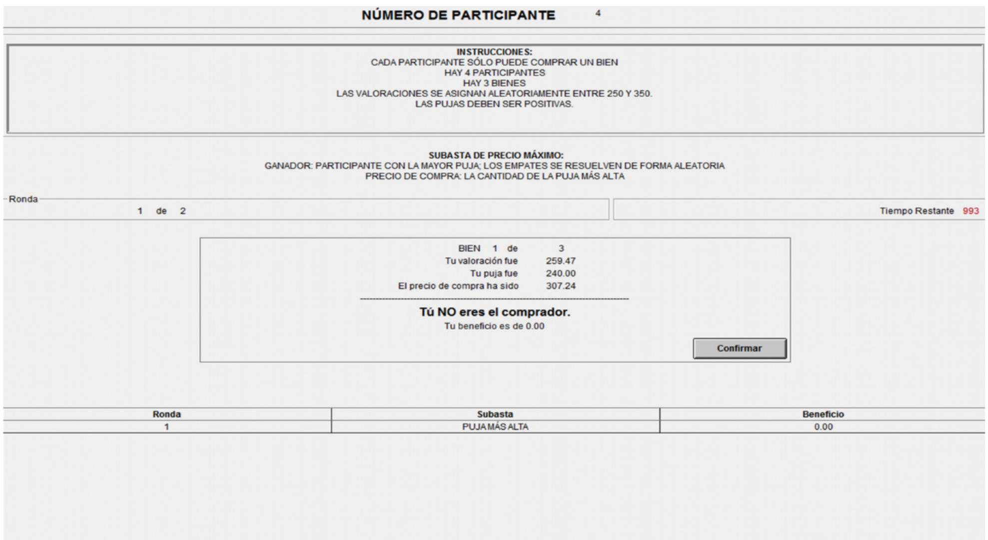

Figure A1.5. Non-winner of F

The third screen (Figure A6) corresponds to the winner of a Second Price auction, with its bid of 350 tokens and a Price to pay of 335 tokens, so the profit is, given the valuation of 347.59, of 12.59 tokens.

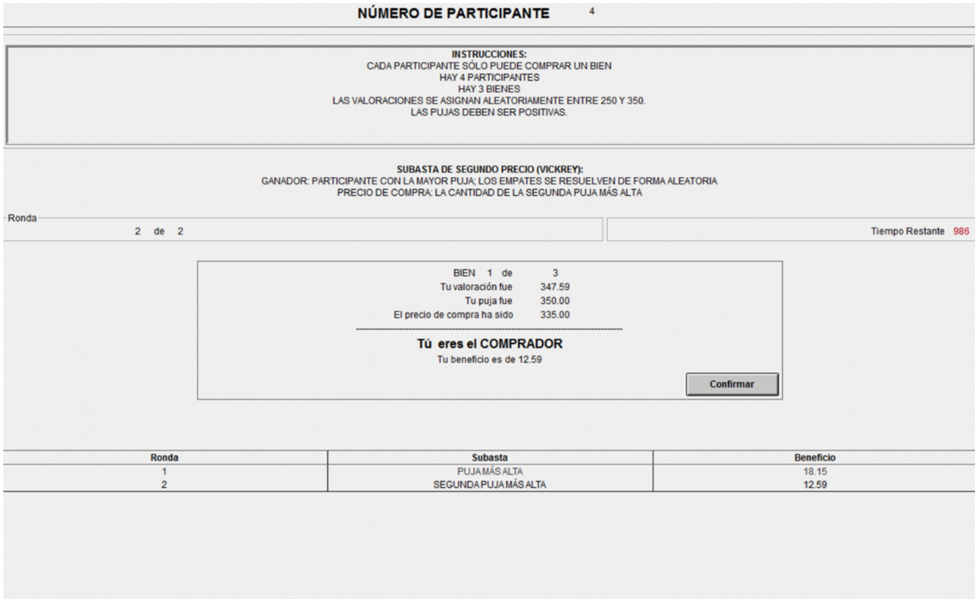

Figure A1.6. Winner of S

The fourth screenshot (Figure A7) corresponds to a non-winner of a Second Price auction, with a bid of 250, and a Price of 335 tokens.

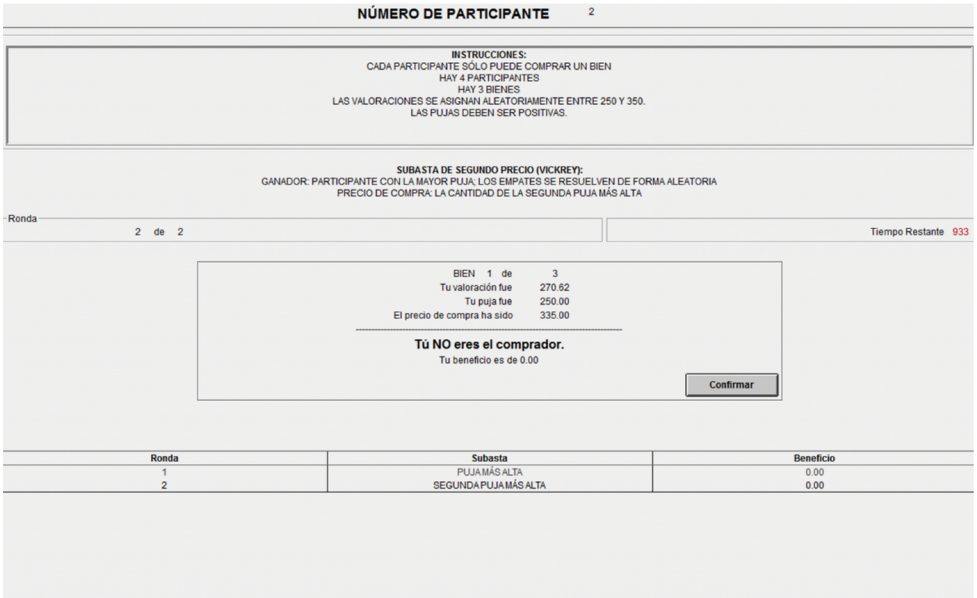

Figure A1.7. Non-winner of S

The last screen (Figure A8) shows the history of the profits for a participant that cannot bid.

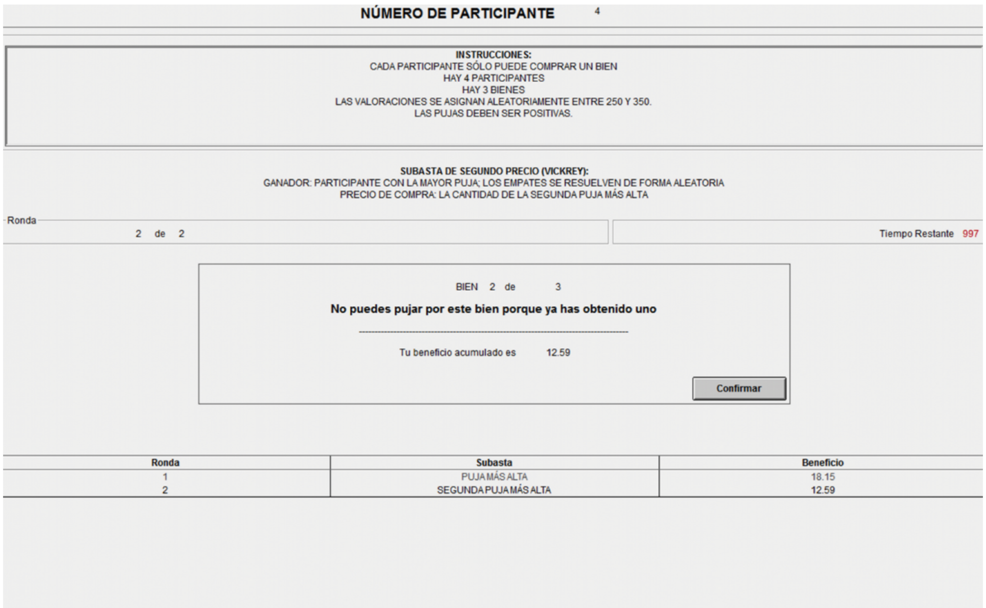

Figure A1.8. History of profits

Obviously, the numbers are fictitious since they are not within the allowable range for this experiment, since the valuations will be between 30 and 90 for everyone.

As a summary, each round is composed of the following stages:

- Assignment of participants to groups
- For each group:

  1. Auction for Good 1 of 3: Placement of 4 bids and assignment to the winner
  2. Auction for Good 2 of 3: Placement of 3 bids and assignment to the winner
  3. Auction for Good 3 of 3: Placement of 2 bids and assignment to the winner
  4. Presentation of profits in tokens after each good and auction

At the end of each round, the following screen (Figure A9) will appear, asking to wait for instructions:

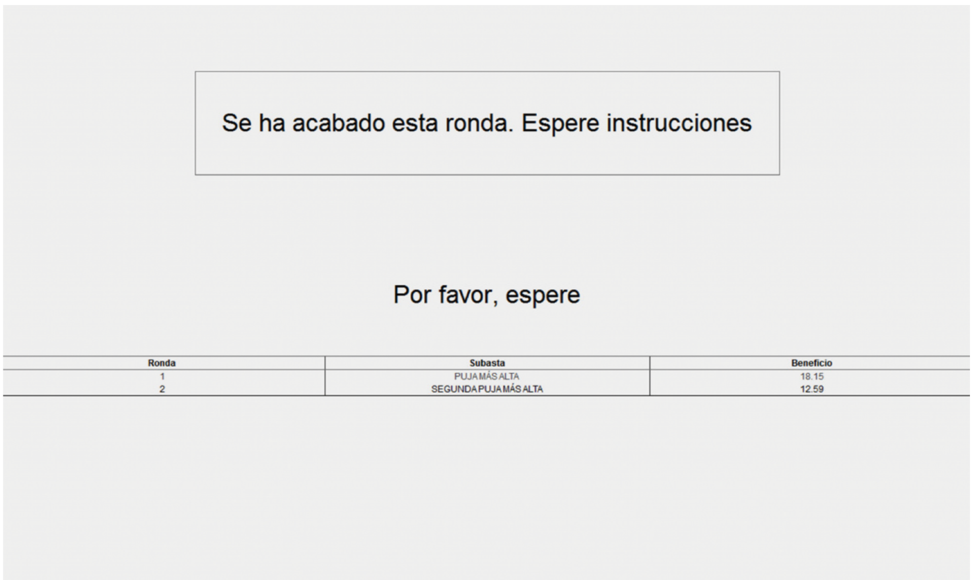

Figure A1.9. End of round

8 rounds will be played, the first 4 will be First Price/Second Price and the last 4 will be Second Price/First Price. A practice round will be performed first.

At the end of the experiment, after the 8 rounds, one round will be selected at random to convert the tokens obtained in that round in euros. Once the round is select, I will individually and secretly pay in euros at a conversion rate of 1 euro per 4 tokens. 2 additional euros will be payed to each individual to cover the participation.

We will now start the experiment. Please follow the instructions that I will dictate out loud.

Comprehension Quiz

1. How many rounds of FIRST PRICE auctions are there?

a) 1
b) 4
c) 8

2. How many rounds of SECOND PRICE auctions are there?

a) 1
b) 4
c) 8

3. In each round, how many participants are there in each group?

a) 1
b) 3
c) 4
d) 8

4. In each round, how many goods are auctioned in each group?

a) 1
b) 3
c) 4
d) 8

5. In each round, how are the goods auctioned?

a) All at once
b) Sequentially

6. If you win the first good in a given round, are you allowed to bid for the second good in that round?

a) Yes
b) No

7. If you do not win the first good in a given round, are you allowed to bid for the second good in that round?

a) Yes
b) No

8. If your valuation in a round is 234.56, your bid is 210.98, which is the highest bid, and the second highest bid is 200.00, what is your profit if the auction type is FIRST PRICE?

a) 234.56–210.98
b) 234.56–200.00
c) 210.98–200.00

Appendix 2: Detailed results of the experiments

	All	First	Second	R1	R2	R3	First			Second		
							R1	R2	R3	R1	R2	R3
Bids (%)												
SOLO	52.43%	51.74%	53.13%	50.00%	54.17%	54.69%	50.00%	53.13%	53.13%	50.00%	55.21%	56.25%
DUO	23.61%	23.96%	23.26%	25.00%	22.40%	22.66%	25.00%	22.92%	23.44%	25.00%	21.88%	21.88%
TRIO	23.96%	24.31%	23.61%	25.00%	23.44%	22.66%	25.00%	23.96%	23.44%	25.00%	22.92%	21.88%
TOTAL	576	288	288	256	192	128	128	96	64	128	96	64
Bid Over Value (%)												
SOLO	36.09%	4.70%	66.67%	33.59%	36.54%	40.00%	3.13%	5.88%	5.88%	64.06%	66.04%	72.22%
DUO	42.65%	2.90%	83.58%	42.19%	41.86%	44.83%	3.13%	0.00%	6.67%	81.25%	85.71%	85.71%
TRIO	43.48%	5.71%	82.35%	43.75%	48.89%	34.48%	3.13%	8.70%	6.67%	84.38%	90.91%	64.29%
Total	39.41%	4.51%	74.31%	38.28%	40.63%	39.84%	3.13%	5.21%	6.25%	73.44%	76.04%	73.44%
SOLO vs DUO	–	–	**SOLO**	–	–	–	–	–	–	–	**SOLO**	–
	0.1954	0.4990	0.0042	0.2488	0.5491	0.6589	1.0000	0.0742	0.9178	0.0601	0.0498	0.2595
SOLO vs TRIO	–	–	**SOLO**	–	–	–	–	–	–	**SOLO**	**SOLO**	–
	0.1432	0.7561	0.0088	0.1743	0.1615	0.6024	1.0000	0.6762	0.9178	0.0208	0.0054	0.5924
DUO vs TRIO*	–	–	–	–	–	–	–	–	–	–	–	–
	0.8895	0.4119	0.8493	0.8583	0.5069	0.4181	1.0000	0.1389	1.0000	0.7402	0.5957	0.1766
Overbid (Avg.)												
SOLO	13.88	14.27	13.51	16.92	12.78	9.97	16.01	12.70	13.32	17.82	12.86	6.80
DUO	15.33	14.94	15.73	18.14	15.37	9.08	16.29	15.85	10.73	19.98	14.85	7.31
TRIO	17.01	14.64	19.45	20.33	19.96	5.10	16.88	14.53	10.03	23.78	25.64	-0.18
Total	14.97	14.52	15.43	18.07	15.04	8.66	16.30	13.86	11.94	19.85	16.22	5.39
SOLO vs DUO	–	–	–	–	–	–	–	–	–	–	–	–
	0.1832	0.5837	0.2153	0.4482	0.0840	0.7121	0.8658	0.1055	0.4098	0.4259	0.3788	0.8843
SOLO vs TRIO	**SOLO**	–	**SOLO**	**SOLO**	**SOLO**	–	–	–	–	**SOLO**	**SOLO**	–
	0.0287	0.7404	0.0233	0.0317	0.0051	0.1465	0.6187	0.2911	0.1138	0.0175	0.0056	0.2568
DUO vs TRIO*	–	–	–	–	–	–	–	–	–	–	**DUO**	–
	0.2798	0.8242	0.1816	0.2403	0.0884	0.2482	0.7550	0.5235	0.8337	0.2169	0.0241	0.1973

Note: The highlighted value of group size is significant at 0.05 level using traditional hypothesis testing: differences on proportions or averages.

Table A2.1. Experimental game and the bidding behavior: pairwise differences in terms of size by right and mechanism

							First			Second		
	All	First	Second	R1	R2	R3	R1	R2	R3	R1	R2	R3
Wins (%)												
SOLO	**51.56%**	**55.21%**	47.92%	37.50%	**53.13%**	**64.06%**	40.63%	**53.13%**	**71.88%**	34.38%	**53.13%**	**56.25%**
DUO	24.48%	22.92%	**26.04%**	**32.81%**	21.88%	18.75%	**31.25%**	21.88%	15.63%	**34.38%**	21.88%	21.88%
TRIO	23.96%	21.88%	**26.04%**	**29.69%**	25.00%	17.19%	**28.13%**	25.00%	12.50%	**31.25%**	25.00%	21.88%
Total	192	96	96	64	64	64	32	32	32	32	32	32
Payoff Conditional Winning < 0 (%)												
SOLO	8.08%	3.77%	13.04%	12.50%	14.71%	0.00%	7.69%	5.88%	0.00%	18.18%	23.53%	0.00%
DUO	14.89%	4.55%	24.00%	14.29%	7.14%	25.00%	0.00%	0.00%	20.00%	27.27%	14.29%	28.57%
TRIO	17.39%	9.52%	24.00%	21.05%	25.00%	0.00%	0.00%	25.00%	0.00%	40.00%	25.00%	0.00%
Total	11.98%	5.21%	18.75%	15.63%	15.63%	4.69%	3.13%	9.38%	3.13%	28.13%	21.88%	6.25%
SOLO vs DUO	–	–	–	–	–	**SOLO**	–	–	–	–	–	–
	0.2459	0.8810	0.2675	0.8609	0.4100	0.0455	0.2980	0.3026	0.2636	0.6088	0.5812	0.0943
SOLO vs TRIO	–	–	–	–	–	–	–	–	–	–	–	–
	0.1347	0.4060	0.2675	0.4584	0.4069	1.0000	0.2980	0.2420	1.0000	0.2600	0.9365	1.0000
DUO vs TRIO*	–	–	–	–	–	**TRIO**	–	–	–	–	–	–
	0.7434	0.5230	1.0000	0.5752	0.1639	0.0455	1.0000	0.1025	0.2636	0.5347	0.5964	0.0943
Payoff Conditional Winning (Avg.)												
SOLO	6.91	5.90	8.08	5.10	4.39	10.07	5.64	5.58	6.29	4.45	3.20	14.91
DUO	7.12	5.58	8.48	6.78	9.26	5.23	7.47	4.51	3.28	6.15	14.01	6.62
TRIO	8.13	5.32	10.50	2.99	6.34	19.62	7.07	3.15	5.73	-0.67	9.53	27.55
Total	7.26	5.70	8.82	5.02	5.94	10.81	6.61	4.74	5.75	3.43	7.15	15.86
SOLO vs DUO	–	–	–	–	–	–	–	–	–	–	–	–
	0.8993	0.8309	0.8892	0.3795	0.1469	0.1271	0.4442	0.5133	0.4775	0.5709	0.0711	0.0817
SOLO vs TRIO	–	–	–	–	–	**TRIO**	–	–	–	–	–	**TRIO**
	0.6289	0.6650	0.5948	0.5486	0.6416	0.0210	0.4625	0.3721	0.7405	0.4109	0.4142	0.0053
DUO vs TRIO*	–	–	–	–	–	**TRIO**	–	–	–	–	–	**TRIO**
	0.7040	0.8845	0.6624	0.2903	0.5449	0.0020	0.8599	0.5783	0.5740	0.2758	0.6126	0.0000

Note: The highlighted value of group size is significant at 0.05 level using traditional hypothesis testing: differences on proportions or averages.

Table A2.2. Experimental game and payoffs conditional on winning: pairwise differences in terms of size by right and mechanism

							First			Second		
	All	First	Second	R1	R2	R3	R1	R2	R3	R1	R2	R3
Bids (%)												
SOLO	35.13%	35.17%	35.09%	33.15%	35.71%	38.23%	33.11%	35.81%	38.33%	33.18%	35.61%	38.13%
DUO	32.45%	31.91%	32.99%	33.44%	32.40%	30.55%	33.23%	32.33%	28.65%	33.65%	32.47%	32.44%
TRIO	32.42%	32.92%	31.92%	33.41%	31.89%	31.23%	33.66%	31.87%	33.03%	33.16%	31.92%	29.43%
Total	108,000	54,000	54,000	48,000	36,000	24,000	24,000	18,000	12,000	24,000	18,000	12,000
							First			Second		
	Total	First	Second	R1	R2	R3	R1	R2	R3	R1	R2	R3
Bid Over Value (%)												
SOLO	35.96%	4.97%	67.01%	33.88%	35.88%	39.64%	3.27%	5.93%	6.54%	64.43%	66.01%	72.92%
DUO	44.04%	2.70%	84.03%	42.61%	43.21%	48.51%	3.18%	0.00%	6.17%	81.54%	86.23%	85.90%
TRIO	43.50%	5.56%	82.64%	43.64%	49.89%	33.42%	3.21%	8.12%	6.66%	84.68%	91.59%	63.45%
Total	41.03%	4.44%	77.61%	40.06%	42.73%	40.41%	3.22%	4.71%	6.48%	76.90%	80.74%	74.34%
SOLO vs DUO	**SOLO**	**DUO**	**SOLO**	**SOLO**	**SOLO**	**SOLO**	–	**DUO**	–	**SOLO**	**SOLO**	**SOLO**
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7547	0.0000	0.4904	0.0000	0.0000	0.0000
SOLO vs TRIO	**SOLO**	**SOLO**	**SOLO**	**SOLO**	**SOLO**	**TRIO**	–	**SOLO**	–	**SOLO**	**SOLO**	**TRIO**
	0.0000	0.0104	0.0000	0.0000	0.0000	0.0000	0.8139	0.0000	0.8284	0.0000	0.0000	0.0000
DUO vs TRIO	–	**DUO**	**TRIO**	–	**DUO**	**TRIO**	–	**DUO**	–	**DUO**	**DUO**	**TRIO**
	0.1508	0.0000	0.0005	0.0615	0.0000	0.0000	0.9377	0.0000	0.3851	0.0000	0.0000	0.0000
Overbid (Avg.)												
SOLO	13.93	14.33	13.53	16.87	12.90	10.26	16.02	12.85	13.47	17.72	12.95	7.02
DUO	15.28	15.11	15.46	18.22	15.28	8.86	16.45	15.83	10.77	19.97	14.74	7.17
TRIO	16.99	14.58	19.48	20.24	20.30	4.97	16.86	14.51	10.04	23.68	26.09	-0.72
Total	15.36	14.66	16.06	18.45	16.03	8.18	16.44	14.34	11.56	20.45	17.73	4.79
SOLO vs DUO	**SOLO**	**SOLO**	**SOLO**	**SOLO**	**SOLO**	**DUO**	**SOLO**	**SOLO**	**DUO**	**SOLO**	**SOLO**	–
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0007	0.0000	0.0000	0.0000	0.0000	0.6073
SOLO vs TRIO	**SOLO**	**SOLO**	**SOLO**	**SOLO**	**SOLO**	**TRIO**	**SOLO**	**SOLO**	**TRIO**	**SOLO**	**SOLO**	**TRIO**
	0.0000	0.0018	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DUO vs TRIO	**DUO**	**TRIO**	**DUO**	**DUO**	**DUO**	**TRIO**	**DUO**	**TRIO**	**TRIO**	**DUO**	**DUO**	**TRIO**
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0000	0.0008	0.0000	0.0000	0.0000

Note: The highlighted value of group size is significant at 0.05 level using traditional hypothesis testing: differences on proportions or averages.

Table AII.3. Virtual professionals' and the bidding behavior: pairwise differences in terms of size by right and mechanism

							First			Second		
	All	First	Second	R1	R2	R3	R1	R2	R3	R1	R2	R3
Wins (%)												
SOLO	32.93%	33.49%	32.37%	25.46%	30.68%	**42.66%**	25.02%	30.77%	**44.68%**	25.90%	30.58%	**40.63%**
DUO	33.90%	33.90%	33.90%	**36.58%**	**36.11%**	29.02%	**35.95%**	**39.68%**	26.07%	**37.20%**	32.53%	31.97%
TRIO	33.17%	32.61%	33.73%	**37.97%**	33.22%	28.33%	**39.03%**	29.55%	29.25%	**36.90%**	**36.88%**	27.40%
Total	36,000	18,000	18,000	12,000	12,000	12,000	6,000	6,000	6,000	6,000	6,000	6,000
							First			Second		
	Total	First	Second	R1	R2	R3	R1	R2	R3	R1	R2	R3
Payoff Conditional Winning<0 (%)												
SOLO	12.04%	6.42%	17.85%	17.35%	13.07%	8.13%	8.79%	3.68%	6.98%	25.61%	22.51%	9.39%
DUO	14.69%	5.59%	23.80%	19.32%	9.39%	15.45%	6.07%	0.00%	13.43%	32.12%	20.85%	17.10%
TRIO	20.33%	9.25%	31.05%	24.58%	24.86%	9.33%	4.27%	15.17%	9.91%	46.07%	32.63%	8.70%
Total	15.69%	7.06%	24.32%	20.82%	15.66%	10.59%	6.05%	5.62%	9.52%	35.58%	25.70%	11.67%
SOLO vs DUO	**SOLO**	–	**SOLO**	**SOLO**	**DUO**	**SOLO**	**DUO**	**DUO**	**SOLO**	**SOLO**	–	**SOLO**
	0.0000	0.0539	0.0000	0.0298	0.0000	0.0000	0.0023	0.0000	0.0000	0.0000	0.2165	0.0000
SOLO vs TRIO	**SOLO**	**SOLO**	**SOLO**	**SOLO**	**SOLO**	–	**TRIO**	**SOLO**	**SOLO**	**SOLO**	**SOLO**	–
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0562	0.0000	0.0000	0.0007	0.0000	0.0000	0.4464
DUO vs TRIO	**DUO**	**DUO**	**DUO**	**DUO**	**DUO**	**TRIO**	**TRIO**	**DUO**	**TRIO**	**DUO**	**DUO**	**TRIO**
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0065	0.0000	0.0017	0.0000	0.0000	0.0000
Payoff Conditional Winning (Avg.)												
SOLO	9.23	5.49	13.09	5.54	7.46	12.70	4.56	6.51	5.31	6.49	8.42	20.82
DUO	7.14	4.17	10.10	5.39	7.21	9.25	5.11	4.99	1.65	5.66	9.91	15.45
TRIO	6.68	5.53	7.80	3.28	4.81	13.44	6.32	4.47	5.54	0.07	5.09	21.88
Total	7.67	5.06	10.29	4.63	6.49	11.91	5.44	5.30	4.42	3.81	7.67	19.39
SOLO vs DUO	**SOLO**	**SOLO**	**SOLO**	–	–	**SOLO**	**DUO**	**SOLO**	**SOLO**	**SOLO**	**DUO**	**SOLO**
	0.0000	0.0000	0.0000	0.5017	0.2433	0.0000	0.0008	0.0000	0.0000	0.0434	0.0003	0.0000
SOLO vs TRIO	**SOLO**	–	**SOLO**	**SOLO**	**SOLO**	**TRIO**	**TRIO**	**SOLO**	–	**SOLO**	**SOLO**	–
	0.0000	0.7022	0.0000	0.0000	0.0000	0.0366	0.0000	0.0000	0.1439	0.0000	0.0000	0.0878
DUO vs TRIO	**DUO**	**TRIO**	**DUO**	**DUO**	**DUO**	**TRIO**	**TRIO**	**DUO**	**TRIO**	**DUO**	**DUO**	**TRIO**
	0.0067	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0043	0.0000	0.0000	0.0000	0.0000

Note: The highlighted value of group size is significant at 0.05 level using traditional hypothesis testing: differences on proportions or averages.

Table A2.4. Experimental game and payoffs conditional on winning: pairwise differences in terms of size by right and mechanism

	All	First	Second	R1	R2	R3	First			Second		
							R1	R2	R3	R1	R2	R3
Bids (%)												
SOLO	24.82%	24.58%	25.06%	25.23%	24.96%	23.80%	25.22%	24.80%	22.99%	25.24%	25.12%	24.61%
DUO	22.41%	22.17%	22.65%	24.70%	22.19%	18.18%	24.64%	22.48%	16.77%	24.75%	21.90%	19.58%
TRIO	22.60%	22.81%	22.40%	25.00%	21.61%	19.30%	25.17%	21.38%	20.23%	24.83%	21.84%	18.38%
MACHINES	30.16%	30.44%	29.89%	25.08%	31.24%	38.72%	24.97%	31.34%	40.02%	25.19%	31.14%	37.43%
Total	144,000	72,000	72,000	64,000	48,000	32,000	32,000	24,000	16,000	32,000	24,000	16,000
Bid Over Value (%)												
SOLO	36.12%	4.78%	66.86%	33.89%	36.58%	40.11%	2.92%	6.38%	6.25%	64.82%	66.40%	71.74%
DUO	43.66%	2.74%	83.71%	42.37%	42.19%	49.83%	3.20%	0.00%	6.93%	81.39%	85.51%	86.56%
TRIO	43.60%	5.36%	82.55%	43.23%	50.12%	33.64%	3.23%	8.15%	6.24%	83.79%	91.20%	63.79%
MACHINES	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total	28.60%	3.01%	54.20%	29.82%	29.33%	25.10%	2.34%	3.33%	3.86%	57.30%	55.33%	46.33%
SOLO vs DUO	**SOLO**	**DUO**	**SOLO**	**SOLO**	**SOLO**	**SOLO**	–	**DUO**	–	**SOLO**	**SOLO**	**SOLO**
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3209	0.0000	0.2828	0.0000	0.0000	0.0000
SOLO vs TRIO	**SOLO**	**SOLO**	**SOLO**	**SOLO**	**SOLO**	**TRIO**	–	**SOLO**	–	**SOLO**	**SOLO**	**TRIO**
	0.0000	0.0149	0.0000	0.0000	0.0000	0.0000	0.2652	0.0004	0.9848	0.0000	0.0000	0.0000
DUO vs TRIO	–	**DUO**	**TRIO**	–	**DUO**	**TRIO**	–	**DUO**	–	**DUO**	**DUO**	**TRIO**
	0.8922	0.0000	0.0053	0.1233	0.0000	0.0000	0.9080	0.0000	0.2876	0.0001	0.0000	0.0000
Overbid (Avg.)												
SOLO	14.08	14.47	13.69	16.95	12.86	9.91	16.15	12.81	13.50	17.75	12.90	6.56
DUO	15.63	15.20	16.04	18.24	15.35	9.04	16.28	15.81	10.81	20.20	14.87	7.52
TRIO	17.32	14.76	19.93	20.24	20.00	5.28	16.82	14.39	10.21	23.70	25.49	-0.14
MACHINES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	10.91	10.30	11.53	13.84	10.94	5.02	12.32	9.81	6.98	15.36	12.07	3.06
SOLO vs DUO	**SOLO**	**SOLO**	**SOLO**	**SOLO**	**SOLO**	**DUO**	–	**SOLO**	**DUO**	**SOLO**	**SOLO**	**SOLO**
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2691	0.0000	0.0000	0.0000	0.0000	0.0015
SOLO vs TRIO	**SOLO**	**SOLO**	**SOLO**	**SOLO**	**SOLO**	**TRIO**	**SOLO**	**SOLO**	**TRIO**	**SOLO**	**SOLO**	**TRIO**
	0.0000	0.0007	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
DUO vs TRIO	**DUO**	**TRIO**	**DUO**	**DUO**	**DUO**	**TRIO**	**DUO**	**TRIO**	**TRIO**	**DUO**	**DUO**	**TRIO**
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0156	0.0000	0.0000	0.0000

Note: The highlighted value of group size is significant at 0.05 level using traditional hypothesis testing: differences on proportions or averages.

Table A2.5. Influence of machines and bidding: pairwise differences in terms of size by right and mechanism

							First			Second		
	All	First	Second	R1	R2	R3	R1	R2	R3	R1	R2	R3
Wins (%)												
SOLO	**27.39%**	**28.61%**	26.18%	26.02%	**27.29%**	**28.87%**	26.45%	**28.44%**	**30.94%**	25.59%	26.14%	**26.80%**
DUO	**27.07%**	**27.29%**	26.85%	**32.20%**	**30.23%**	18.78%	**31.13%**	**33.91%**	16.83%	33.28%	26.55%	20.73%
TRIO	**27.11%**	**27.58%**	26.64%	**35.18%**	26.21%	19.94%	**36.56%**	23.68%	22.51%	**33.79%**	**28.75%**	17.38%
MACHINES	18.43%	16.52%	20.34%	6.61%	16.27%	**32.41%**	5.86%	13.98%	29.73%	7.35%	18.56%	**35.10%**
Total	48,000	24,000	24,000	16,000	16,000	16,000	8,000	8,000	8,000	8,000	8,000	8,000
Payoff Conditional Winning<0 (%)												
SOLO	10.94%	5.71%	16.65%	13.93%	11.82%	7.40%	6.14%	4.48%	6.46%	21.98%	19.80%	8.49%
DUO	13.13%	5.28%	21.10%	16.58%	7.65%	16.05%	6.47%	0.00%	13.74%	26.03%	17.42%	17.91%
TRIO	18.22%	8.69%	28.09%	20.11%	22.22%	9.62%	4.58%	14.41%	9.33%	36.92%	28.65%	10.00%
MACHINES	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total	11.49%	5.47%	17.51%	16.04%	11.36%	7.07%	5.31%	4.69%	6.41%	26.76%	18.04%	7.73%
SOLO vs DUO	**SOLO**	–	**SOLO**	**SOLO**	**DUO**	**SOLO**	–	**DUO**	**SOLO**	**SOLO**	**DUO**	**SOLO**
	0.0000	0.2789	0.0000	0.0004	0.0000	0.0000	0.6536	0.0000	0.0000	0.0012	0.0472	0.0000
SOLO vs TRIO	**SOLO**	**SOLO**	**SOLO**	**SOLO**	**SOLO**	**SOLO**	**TRIO**	**SOLO**	**SOLO**	**SOLO**	**SOLO**	–
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006	0.0162	0.0000	0.0007	0.0000	0.0000	0.1326
DUO vs TRIO	**DUO**	**DUO**	**DUO**	**DUO**	**DUO**	**TRIO**	**TRIO**	**DUO**	**TRIO**	**DUO**	**DUO**	**TRIO**
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0026	0.0000	0.0001	0.0000	0.0000	0.0000
Payoff Conditional Winning (Avg.)												
SOLO	9.34	5.59	13.44	6.55	8.55	12.59	4.76	6.57	5.40	8.41	10.71	20.90
DUO	7.91	4.64	11.25	6.86	8.09	9.44	5.40	5.09	2.30	8.23	11.91	15.24
TRIO	7.11	5.64	8.63	4.86	6.17	12.30	6.41	4.68	5.39	3.19	7.40	21.25
MACHINES	21.80	22.28	21.41	25.14	23.36	20.34	27.21	25.38	19.86	23.49	21.84	20.75
Total	10.64	8.10	13.19	7.29	10.20	14.45	6.88	8.25	9.17	7.69	12.14	19.73
SOLO vs DUO	**SOLO**	**SOLO**	**SOLO**	–	**SOLO**	**SOLO**	**DUO**	**SOLO**	**SOLO**	–	**DUO**	**SOLO**
	0.0000	0.0000	0.0000	0.1272	0.0349	0.0000	0.0000	0.0000	0.0000	0.6260	0.0042	0.0000
SOLO vs TRIO	**SOLO**	–	**SOLO**	**SOLO**	**SOLO**	–	**TRIO**	**SOLO**	–	**SOLO**	**SOLO**	–
	0.0000	0.6072	0.0000	0.0000	0.0000	0.3957	0.0000	0.0000	0.9461	0.0000	0.0000	0.5810
DUO vs TRIO	**DUO**	**TRIO**	**DUO**	**DUO**	**DUO**	**TRIO**	**TRIO**	**DUO**	**TRIO**	**DUO**	**DUO**	**TRIO**
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0158	0.0000	0.0000	0.0000	0.0000

Note: The highlighted value of group size is significant at 0.05 level using traditional hypothesis testing: differences on proportions or averages.

Table A2.6. Influence of machines and payoffs: pairwise differences in terms of size by right and mechanism