Collusion through Communication in Auctions

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Abstract

We study the extent to which communication can serve as a collusion device in one-shot first- and second-price sealed-bid auctions. In an array of laboratory experiments we vary the amount of interactions (communication and/or transfers without commitment) available to bidders. We find that communication alone leads to statistically significant but limited price drops. When, in addition, bidders can exchange transfers, revenues decline substantially, with over 70% of our experimental auctions culminating in the object being sold for approximately the minimal price. Furthermore, the effects of communication and transfers are similar across auction formats. We contrast these results with those generated in repeated auctions. By and large, repeated auctions yield lower collusion and lower efficiency levels.

Keywords: Auctions, Communication, Collusion, Experiments

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1 Introduction

1.1 Overview

Collusion has been a long-standing problem for auction design. Krishna (2002) reported that in the 1980s, collusion and auctions went hand-in-hand: 75% of US cartel cases involving collusion were auction-based. To date, approximately 30% of antitrust cases filed by the Department of Justice since 1994 involved bid-rigging in industries such as construction, antique sales, military supplies, utility procurement, etc.[1] The prevalence of collusion in auctions has led to a substantial body of theoretical work in the Economics literature. By and large, this literature has taken two approaches to explain the emergence of collusion: through repeated interactions between bidders, and through bidding that occurs over multiple objects (simultaneously or over time). Roughly speaking, both approaches allow bidders to devise joint schemes in which winning bidders alternate over time or over objects. Winning prices are low, because at each period, or for each object, only a select group of bidders is bidding competitively (see our literature review). Nonetheless, evidence suggests that some collusive behavior occurs in auctions or procurements that take place only once and involve a single object.[2] Several recent papers have therefore inspected theoretically the extent to which collusion can occur by a cartel that interacts once. The message emerging from this work is that the cartel needs substantial commitment instruments to be successful.

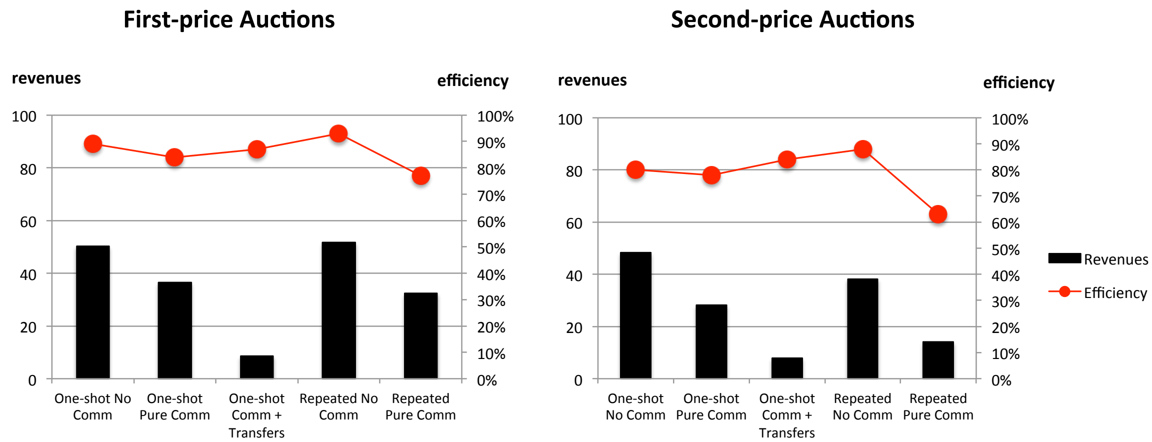
In this paper, we inspect the impacts of non-binding communication that precedes one-shot auctions. Since communication is often tacit and unobserved, and private values, available information, etc. are unknown, analyzing the impacts of communication with real-world auction data is difficult to carry out. Experiments are therefore particularly useful. We report results from an array of lab experiments that allow for communication in *one-shot*, sealed-bid auctions. We show the dramatic effects that communication can have on auction outcomes and bidders' behavior.

Specifically, we study experimentally first- and second-price independent private value auctions with two bidders, looking to buy a single unit of an object. Private values for the object are drawn uniformly between zero and a hundred experimental points (translated to \$1). We vary the amount of interaction available to bidders. For each auction format, we run three treatments. The first corresponds to auctions without communication (as in Cox, Roberson, and Smith, 1982, Dyer, Kagel, and Levin, 1989, Kagel and Levin, 1993, and

[1] According to the authors' tabulation, 438 cases out of 1423 antitrust cases involved bid-rigging, see: http://www.justice.gov/atr/cases/

[2] For instance, U.S. v. Metropolitan, U.S. v. A-A-A, U.S. v. Brinkley, and Finnegan v. Campeau. See our discussion below as well as Marshall and Marx (2007).

Figure 1: Revenues and efficiency levels



Harstad, 1991). In our second treatment, bidders can freely communicate with each other using an instant messaging screen after observing their private values and prior to bidding. In our third treatment, in addition to free-form communication, bidders can transfer money to one another after seeing their auction's results. This last treatment is motivated by the observation that, in reality, incidents of collusion are often accompanied by transfers: the department of Justice documents that transfers were explicitly mentioned in 148 of the reported 438 antitrust cases involving bid-rigging.

Our main results are as follows. Communication by itself leads to statistically significant but limited price drops in both auction formats. While in theory the availability of ex-post transfers should have no effect on outcomes (since there is no incentive to transfer money after the fact), the availability of transfers strongly impacts both auction bidders' behavior and, consequently, outcomes. *In over 70% of both first- and second-price auctions in which communication and transfers were available, the object's price is zero.* As a result, revenue is reduced under both auction formats, yielding *less than one fifth* of the revenues generated when all communication is banned under either auction format. In particular, contrary to the message of some of the theoretical literature on collusion in auctions (see, e.g., Marshall and Marx, 2007, 2012), both auction formats are equally prone to collusion. Furthermore, the availability of communication and/or transfers does not significantly affect efficiency levels, which remain high and comparable to the levels observed in the treatments without communication. The three left columns on each of the two panels of Figure 1 summarize these observations.

In terms of what subjects reveal during communication, the availability of transfers makes a substantial difference. Without transfers, subjects seldom share their private values or their intended bids. When they do, they frequently understate both their values and the bids they plan to submit. When transfers are available, misrepresentation diminishes significantly and truthful revelation of values and bids is part of the modal communication protocol.

We also see a persistent pattern of behavior at the transfer stage. When the ultimate price is high, indicating that bidders did not successfully collude, transfers are rare. However, when ultimate prices are close to zero, winning bidders submit an average of 44% of their surplus, with a modal transfer of 50%.[3] This suggests a coherent description of how subjects achieve collusive outcomes: they first share their values and then bid in a way that allows the high-value bidder to win the object at a low price (in the first-price auction, this means that both bidders submit a low bid; in the second-price auction, at least the losing bidder submits a low bid). The winning bidder then shares her surplus with the losing bidder, so long as the final price is low.

The behavior we observe also hints at why collusive outcomes are easier to achieve when transfers are available. Without transfers, losing bidders, who must submit low bids to generate a collusive outcome, do not gain from their behavior. The only beneficiary is the winning bidder. In contrast, transfers allow subjects to align their preferences.

Our observations are in line with multiple cases of known bid rigging. For instance, Pesendorfer (2000) studied bidding for school milk contracts in Florida and Texas during the 1980s. His data suggest that in Florida, the school milk cartel used side payments to compensate bidders for refraining from bidding competitively, which is effectively what we see in our experimental data. Transfers in the form of subcontracting arrangements are described in US vs. Inryco, Inc.[4], where the concrete construction firm Inryco subcontracted with its competitor Western following Western's submitting artificially high bids at certain procurements. While these examples may have involved some repeat interactions, collusion of the sort we observe occurs in one-shot settings as well. For example, in US vs. A-A-A Elec. Co.[5], contractors bidding for work at the Raleigh-Durham Airport discussed their bids prior to submitting them. They appointed A-A-A to be the lowest bidder; in this case, the winning bidder. After receiving final payment for the work, A-A-A made transfers to the other bidders. Much like in our experiments, these transfer payments were not finalized until after bidding outcomes had been published. Similarly, in US vs. Metropolitan Enterprises, Inc.[6], Broce Construction Company met with a group of other highway-paving companies before bidding for a number of Oklahoma repaving contracts. These companies agreed not

[3] As mentioned, in theory, we expect to see no transfers. Our observations are in line with similar violations detected in the dictator game, trust games, the centipede game, etc. (see Kagel and Roth, 1997).

[4] Unite States vs. Inryco, Inc., 642 F.2d 290 (1981).

[5] United States vs. A-A-A Elec. Co., Inc., 788 F.2d 242 (4th Cir., 1986).

[6] United States vs. Metropolitan Enterprises, Inc., 728 F.2d 444 (1984).

to bid against Broce, who became the winning bidder for the contracts. In compensation, Broce subcontracted with one of the companies that agreed not to counter-bid. For details of these cases and others, see Kovacic et al. (2006) and Marshall and Marx (2007).

Despite the documented examples of successful collusion in one-shot settings, as mentioned in the beginning, repeated interaction has been a leading explanation for the emergence of collusion. To compare the magnitude of collusion we see in our one-shot setting with that achievable through repeated interactions, we also ran an auxiliary set of experiments implementing analogous repeated auctions. For each auction format, we had two treatments: with and without communication preceding each round.

Figure 1 depicts the revenues and efficiency levels for these treatments as well. For either auction format, *repetition with or without communication does not lead to a greater scope for collusion than communication and transfers do in one-shot interactions.* This observation is particularly pronounced for first-price auctions, in which repetition and communication together generate significantly higher prices than those produced in the one-shot variant with communication and transfers. Furthermore, *collusive outcomes in our repeated auctions come together with a significant reduction in efficiency.* Indeed, communication allows subjects to alternate who wins the auction across periods, rather than condition on who wins the auction based on realized values. In contrast to the one-shot setting, repeated second-price auctions are somewhat more fragile to collusion than repeated first-price auctions.

To summarize, our results indicate the substantial scope for collusion that communication and transfers allow, even in one-shot settings. Together, they lead to the minimal feasible revenue with a substantial probability under both auction formats. Repetition, one of the common explanations for the emergence of collusion, is not more effective, even when agents can communicate, and generates lower efficiency levels.

1.2 Related Literature

The empirical literature documents many cases in which bidders in a variety of auction formats colluded (see, for instance, Hendricks and Porter, 1989 and Marshall and Marx, 2012 for reviews).

Following the prevalence of bid-rigging in auctions, a large body of theoretical work on collusion in auctions has emerged. Much of this work analyzes settings with repeated interactions, in which, roughly speaking, bidders can collude by devising schemes that split the auctions won over time (see Abreu, Pearce, and Stachetti, 1986, Athey and Bagwell, 2001, and Skryzspacz and Hopenhayn, 2004). Another approach considers multi-object auctions, in which collusive outcomes can emerge from bidders "splitting the market"; namely, bidders decide on which objects whom will bid on competitively (see, e.g., Kwasnica, 2002 and Brosco and Lopomo, 2002). Several papers study how communication affects the set of equilibrium outcomes in sealed bid one-shot auctions. McAfee and McMillan (1992) show that cartels can achieve full efficiency in first-price auctions with side transfers and pre-stage communication *and commitment*.[7] Without transfers, the best payoffs the cartel can achieve are generated by either non-cooperative bidding or bid rotation schemes, in which the winner is decided upon independently of her value. Graham and Marshall (1987) and Mailath and Zemsky (1991) generate similar insights for second-price auctions, the latter also allowing bidders to be heterogeneous. Marshall and Marx (2007) illustrate that some collusion mechanisms used by cartels to coordinate bids may lead to second-price auctions being more fragile to collusion than first-price auctions.[8] Without commitment, Lopomo, Marx, and Sun (2011) showed that, in first-price sealed-bid auctions, when there are two bidders and two possible values for the object, if the bid increment is sufficiently small, profitable collusion is not possible.

In terms of experimental work, our paper relates to the strand of experimental literature that studies behavior in one-shot sealed-bid auctions (see Kagel and Levin, 1993, Cox, Roberson, and Smith, 1992, and the surveys by Kagel, 1997 and Kagel and Levin, 2011). In our first treatment, we replicate these studies and observe similar results—bidders generally overbid relative to the theoretical predictions. Our main contribution, however, relates to the question of how cheap-talk communication affects behavior in one-shot sealed-bid auctions.[9]

Llorente-Saguer and Zultan (2017) study collusion in laboratory auctions by testing the model of Eso and Schummer (2004) and Rachmilevitch (2013). They allow one bidder, whose identity is determined prior to valuations being realized, to "bribe" the other. A bidder who accepts a bribe is *committed* to stay out of the auction. Bribes then serve as a signaling instrument. In their setting, outcomes under first- and second-price auctions are also similar. In addition, failed collusion attempts decrease efficiency, particularly in first-price auctions.

There is also experimental work considering a knockout auction as a mechanism for cartel members to determine which member will win the auction and what side payments will be made to other cartel members. Hu, Offerman, and Onderstal (2011) consider experimen-

[7]Kivetz and Tauman (2010) consider first-price auctions in which bidders' valuations are common knowledge among the bidders. They show that side payments between the highest-valuation bidders allow for effective collusion.

[8]Marshall and Marx (2009) show that details of ascending-bid or second-price auctions can, however, be modified to inhibit collusion.

[9]Isaac and Walker (1995) study the effects of face-to-face communication in a repeated first-price, private value, sealed-bid auction. They restricted the communication protocols by banning discussion of private values or side payments. Kagel (1995) studied collusion in first-price common value auctions with reserve prices, under similar restrictions on communication protocols. There is also some experimental work focusing on repeated auctions and multi-object auctions (see Section 4.1 in Kagel and Levin, 2011).

tal auctions in which: 1. collusion is costly; and 2. eligible bidders who join a cartel use a knockout auction as above. The experimental results show that the Amsterdam auction triggers less collusion than standard auctions. Noussair and Seres (2017) consider experimental second-price sealed-bid auctions in which bidders' valuations have private and common value components. In their experiments, subjects can choose whether to compete or form a cartel. Colluding bidders can communicate and make side payments using a knockout auction. The results show that a large majority of bidders join a cartel and that, unlike in our setting, collusion reduces efficiency.

There is a related experimental literature in industrial organization that considers the impacts of communication between market competitors on outcomes. For example, Fonseca and Normann (2012) illustrate the beneficial impact of communication on prices and profits for firms that participate in Bertrand competition. Moellers, Normann, and Snyder (2017) study experimental vertical markets with an upstream monopolist and competing downstream firms and also illustrate the important impact communication between firms has on profits. For a survey of related experiments in industrial organization, see Holt (1995).

In terms of design, our Communication and Transfers treatment is reminiscent of trust games in that losing bidders need to forgo the chance to win the object and submit a low bid providing their opponents large profits in the hope that money will be passed back to them. Our results are consistent with those observed in experimental trust games (see Berg, Dickhaut, and McCabe, 1995 and our discussion in Section 4.4.3).

Outside the realm of auctions and market competition, a growing experimental literature explores the effects of cheap-talk communication on strategic outcomes; see Crawford (1998) for a survey of some early literature, most of which placed strict restrictions on the messages sent. Recently, more studies have focused on free-form unrestricted communication rather than structured restricted communication. Unrestricted communication has been shown to affect strategic behavior of subjects in various environments, including hidden-action games (such as trust games) and hidden-information games as in Charness and Dufwenberg (2006, 2011), weak link games as in Brandts and Cooper (2007), bargaining as in Agranov and Tergiman (2014) and Baranski and Kagel (2015), collective action settings as in Goeree and Yariv (2011), and public good games as in Oprea, Charness, and Friedman (2015). One coherent message emerging from this body of work is that communication promotes coordination on Pareto superior outcomes. In all these settings, however, the outcomes observed with communication tend to benefit *all* participating individuals. In contrast, in the auction environment, a collusive outcome in which the object is won at a low price entails a huge asymmetry between players: only one bidder (the winner) benefits from driving the final prices down, while others do not gain from colluding. In particular, it is hard to extrapolate existing results to the auction environment.

2 Experimental Design

We use a sequence of first-price and second-price independent private-value auctions involving two bidders.[10] In all of our experimental auctions, each bidder seeks to buy a single unit of an object, the value of which is drawn independently from a uniform distribution over $[0, 100]$, where each experimental point corresponds to 1 cent. In all of our treatments, both bidders submit a bid. The winner of the object is the highest bidder, generating the value of the object to the winner (and no reward for the losing bidder of the auction). The price, paid only by the winner of the object, is given by the highest bid in the first-price auction and the lowest bid in the second-price auction; ties are broken randomly. Sessions varied in the amount and type of interaction that was available to bidders.

No Communication. In this treatment, subjects observe their private values and then asked to simultaneously submit their bids. These treatments replicate the classical experimental auctions a-la, e.g., Kagel and Levin (1993).

Pure Communication. In this treatment, subjects observe their private values and are then able to communicate via an instant messenger screen. When at least one bidder decides to stop communication (expressed by a clickable button on the experimental interface), both bidders are asked to simultaneously submit their bids.

Communication with Transfers. In this treatment, subjects observe their private values, are then able to communicate freely and, after communication comes to a halt, submit bids simultaneously (as in the Pure Communication treatment). Once bids are entered, the results of the auction are observed by both bidders. Then, each bidder can choose to make a transfer to the other bidder (greater or equal to zero). The ultimate payoff for each bidder is their auction payment plus their net transfers.

To summarize, the experiments employ a 2×3 design based on the variation in the auction format (first-price and second-price) and the type of interaction available between bidders. Each experimental session implemented one combination of auction format and interaction type. Six sessions were run for each treatment.[11] Most sessions entailed one practice round followed by 10 periods of actual play, and subjects were randomly paired

[10] The full instructions are available at:
http://people.hss.caltech.edu/~lyariv/papers/Collusion_Instructions.pdf

[11] For one treatment, an additional session was run, but due to some slow subjects, the number of rounds was low. This session produced indistinguishable results from our other sessions. However, since for much of our analysis we focus on rounds 6 and on, we excluded this session from our data.

in each period.[12] In three out of six sessions of each of the six treatments we elicited risk attitudes using the Gneezy and Potters (1997) methodology.[13] Namely, at the end of each of these sessions, we asked subjects to allocate 100 points (translating into $2) between a safe investment, which had a unit return (i.e., returning point for point), and a risky investment, which with probability 50% returned 2.5 points for each point invested and with probability 50% produced no returns for the investment. Any amount earned from this task was added to the overall earnings in the session. Table 1 summarizes our design details.

In several additional sessions, we employed a complete strangers protocol, in which subjects were never paired more than once with another subject. While such sessions require more subjects, they allow us to eliminate repeated game effects altogether. These sessions generated data that is statistically indistinguishable from that generated by sessions in which bidders were randomly matched with one another in each round. Their analysis is relegated to the Online Appendix (see Section 2 there).

Table 1: Experimental Design

Auction Format	Available Interaction	Num of Subjects
First-price	No Communication	60
	Pure Communication	66
	Communication with Transfers	66
Second-price	No Communication	66
	Pure Communication	66
	Communication with Transfers	64

Remarks: For each treatment, there were six sessions, three of which included a risk elicitation.

The experiments were conducted at the Experimental Social Sciences Laboratory (ESSL) at University of California at Irvine. Overall, 388 subjects participated. The average payoff per subject was $22, including a $12 show-up fee.

There are a few points to note regarding our design choices. First, we allowed subjects to communicate freely rather than offer them a restricted set of messages, which would have arguably made the analysis simpler. Our decision was due to several reasons: while laboratory auctions certainly have artificial features that do not perfectly match real auctions, we did want to make the communication as organic as possible. In fact, the endogenous

[12]In several sessions we allowed subjects to participate in 15 rounds. However, due to time constraints, most of the sessions were run with 10 rounds only.

[13]This method is among the more popular ones to elicit risk attitudes of subjects in laboratory experiments (see survey of Charness, Gneezy, and Imas, 2013).

communication protocols were something we wanted to inspect. As will be seen, different treatments led to different communication protocols that would have been hard for us to predict (and thereby design an appropriate set of restricted messages). In addition, we were concerned that by restricting communication protocols we would guide subjects toward particular patterns of behavior, thereby introducing a form of experimenter demand.

Second, we study auctions with only two bidders. Many auctions entail a fairly small number of bidders. For instance, the eBay analytics team reported to us that in 2013, 27% of auctions with multiple bidders had only two bidders participating (and 77% had five or fewer bidders).[14] We believe the analysis of two-bidder auctions is a natural first step to studying collusion through communication: they are simple in that any negotiation is only between two individuals and communication is a two-way interaction. We view the study of auctions with more bidders as an interesting direction for the future.

Third, our design of the treatment allowing for transfers takes a very special form. In particular, we did not allow subjects more sophisticated contractual mechanisms, namely ones that would allow them to commit to, possibly contingent, transfers. In a way, the transfer instruments we provide are fairly weak (theoretically, they should have no impact at all), and yet, as we will see, they have a dramatic impact on outcomes. We suspect that more elaborate transfer instruments may enable even greater levels of collusion.

Last, we study sealed-bid first- and second-price auctions as opposed to English and Dutch auctions. Sealed-bid auctions are prevalent in applications and are simpler to implement in the lab with communication since there is a natural point in time for communication to occur. Studying the effects of communication on English and Dutch auctions, as well as other auction formats, is also left for the future.

3 Theoretical Predictions

In our setting, absent communication, the first-price auction admits a unique equilibrium in which each bidder submits half her valuation (see Lebrun, 2004 and Maskin and Riley, 2003). In the second-price auction, there is a unique symmetric equilibrium, which entails strategies that are not weakly dominated, where each bidder bids precisely her value (see Fudenberg and Tirole, 1991). Nonetheless, in the second-price auction, there exist multiple asymmetric equilibria (for instance, one bidder bidding 100 and the other 0, regardless of their private

[14] Hong and Shum (2002) also report a small number of bidders in general highway, construction, and grading and paving procurement auctions and Grether, Porter, and Shum (2015) report a small number of bidders (with averages ranging between $2 - 5$) in used automobile auctions.

values, is an equilibrium).[15] It is important to note that when symmetric equilibria are played in the first- and second-price auctions, the resulting mappings between bidders' valuations to allocation of the object (i.e., the probability that either bid wins the object) coincide. Furthermore, in both auctions the bidder with a valuation of 0 expects 0 payoffs. In this case, the Revenue Equivalence Theorem applies and the first- and second-price auctions are expected to generate identical revenues, given by 100/3.

With communication, the extant literature does not provide a full characterization of equilibria in our auctions. In terms of first-price auctions, Lopomo, Marx, and Sun (2011) may be the closest. Their results illustrate that with two bidders, binary valuations, and finite possible bids with vanishing increments, communication does not allow bidders to achieve greater returns than in the non-cooperative case with no communication. Most of the literature on one-shot collusion in auctions, however, relies on some level of commitment across cartel members. Nonetheless, as we describe in the literature review, the underlying message—with the caveat of differing assumptions—is that private-value sealed-bid second-price auctions are more fragile to collusion than first-price auctions.

In the Online Appendix, we illustrate that, in fact, in our setting, the set of communication equilibrium outcomes of the second-price auction contains that of the first-price auctions. Furthermore, while in our second-price auctions there is an equilibrium generating 0 price even without communication, that is not the case for our first-price auctions, and equilibrium prices are bounded from below.[16]

In general, however, adding communication naturally enlarges the set of equilibrium outcomes. In relation to our design, the goal is to see whether particular outcomes will be consistently selected.

As mentioned above, the availability of transfers does not impact the set of equilibrium predictions. Indeed, any best response corresponding to the game augmented with transfers would entail zero transfers.

To summarize, there are three insights that are relevant to our design. *First*, without communication, both auction formats entail unique equilibrium predictions when bidders use weakly dominant strategies, and these equilibria are symmetric; The second-price auction entails multiple asymmetric equilibria if the domination restriction is dropped. *Second*, with communication, second-price auctions generate more equilibrium outcomes than first-price auctions. In particular, full collusion, associated with 0 revenue, is possible under the second-price auction but not under the first-price auction. *Last*, transfers have no impact

[15]For three or more bidders, Blume and Heidhues (2004) characterize the full set of equilibria in second-price auctions without communication.

[16]While our focus here is on two-bidder auctions for reasons discussed above, the theoretical results derived in the Online Appendix extend directly to auctions with a larger number of bidders.

on outcomes in either auction format and outcomes are predicted to be identical to those in auctions with communication, but without transfers. Furthermore, no positive transfers are passed in any subgame-perfect equilibrium.

4 Results

4.1 Approach to Data Analysis

In this section we discuss our approach to data analysis and the statistical tests we use. The Online Appendix contains many robustness checks relevant to any restrictions we impose here.

First, we focus on rounds 6 through 10 in order to avoid noise due to learning. There are no statistically significant round effects starting from round 6 (see Section 6 in the Online Appendix).[17]

Second, we often allow for perturbations of two experimental points in our classifications. Specifically, we call an outcome *efficient* if the winning bidder's value is at least as high as the losing bidder's value minus two experimental points. We use the term *minimal price* to refer to a price below or equal to two experimental points. We call a transfer *substantial* if the amount transferred strictly greater than two experimental points. Finally, we use the same perturbation allowance to define collusive outcomes as well as to classify subjects' announcements regarding their values and bids in the communication stage as truthful, overstated, and understated. In Section 4 of the Online Appendix we show that results remain virtually identical when we consider a smaller perturbation of one experimental point.

Finally, while risk can, in principle, play an important role in bidding behavior, it has no statistically significant effect on neither behavior nor outcomes in our data (see Section 5 in the Online Appendix). We therefore report results without explicitly controlling for elicited risk.

To compare average outcomes between two groups (be that two treatments, two auctions, or two parts of the experiment), we use regression analysis. Namely, we run a random-effects GLS regression in which we regress the variable of interest, e.g. an indicator of whether an outcome is efficient or collusive, on a constant and an indicator for one of the two considered groups. We cluster standard errors by session. We report that there is a statistically significant difference between outcomes in these two groups if the estimated

[17] We also find no differences in outcomes and behavior observed in sessions that lasted longer than 10 rounds. These results are available from the authors upon request.

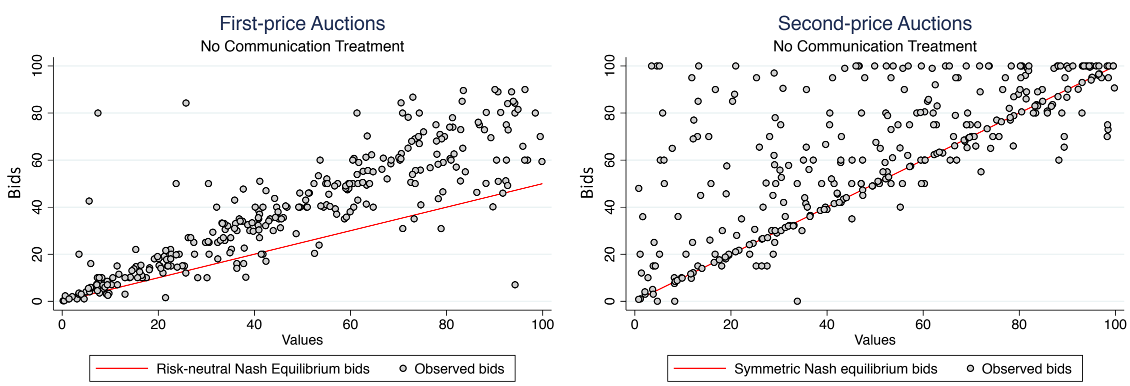
coefficient on the group indicator dummy variable is significantly different from zero at the 5% level.

To compare median outcomes between two groups we use the Wilcoxon rank-sum test and report results at the 5% significance level. Finally, to compare two distributions (for example, those of prices), we use the Kolmogorov-Smirnov test of equality of distributions and report results at the 5% significance level.

4.2 No Communication

Our sessions without communication display results that are in line with the classical observations regarding bidding behavior in experimental auctions (see Cox, Roberson, and Smith, 1982; Dyer, Kagel, and Levin, 1989; Kagel and Levin, 1993; and Harstad, 1991). This is illustrated in Figure 2, which depicts bidding behavior in each auction format.

Figure 2: Bidding Patterns in Auctions Without Communication



In our first-price auctions (left panel), the unique equilibrium for risk-neutral bidders, entails bidders submitting half of their valuation as their bid (see Lebrun, 2004 and Maskin and Riley, 2003). The equilibrium bidding function is indicated by a solid line in the figure. As can be seen, bidders often over-bid relative to the equilibrium prescriptions. Nonetheless, bids are more often than not lower than private valuations. In our second-price auctions (right panel), the solid line indicates the unique symmetric equilibrium in weakly dominant strategies, in which bidders bid precisely their values (see Fudenberg and Tirole, 1991). While some of the observed bids are close to this equilibrium behavior, over 50% of bids are above private valuations, consistent with the substantial amount of over-bidding commonly observed in such experimental auctions.

In terms of efficiency, we calculate the frequency with which the highest-value bidder wins the object. In our first-price auctions, the mean efficiency is 89% while in our second-price auctions, the mean efficiency is 80%.[18] These figures are significantly different from each other at the 5% level ($p = 0.026$) and mirror efficiency levels documented in the extant auction literature (see Cox, Roberson, and Smith, 1982 and Kagel and Levin, 1993).

4.3 The Emergence of Collusion

The extent to which our experimental subjects established successful collusion can be seen through the resulting price distributions. Figure 3 depicts the cumulative distribution of prices across our treatments. In both auction formats, price distributions are ranked in terms of first-order stochastic dominance.[19] In particular, the introduction of pure communication generates a relatively modest shift in price distributions, especially in our second-price auctions. The addition of transfers, however, decreases prices dramatically and the vast majority of auctions culminate in a minimal price. These observations stand in sharp contrast to the theoretical predictions described in Section 3—we see no statistically significant differences in the scope of collusion between our two auction platforms and transfers allow for very low prices to emerge under both.

To quantify these effects, we define collusive outcomes as the ones that generate minimal prices, and, consequently, minimal revenues for the auctioneer. Without communication, less than 2% of all outcomes in both first- and second-price auctions are collusive. The frequency of collusive outcomes remains low when bidders can communicate with each other: less than 14% of all first-price auctions and less than 23% of all second-price auctions reach collusive outcomes. However, when communication and transfers are available, *successful collusion is achieved in* 71% *of all first-price and* 79% *of all second-price auctions.*

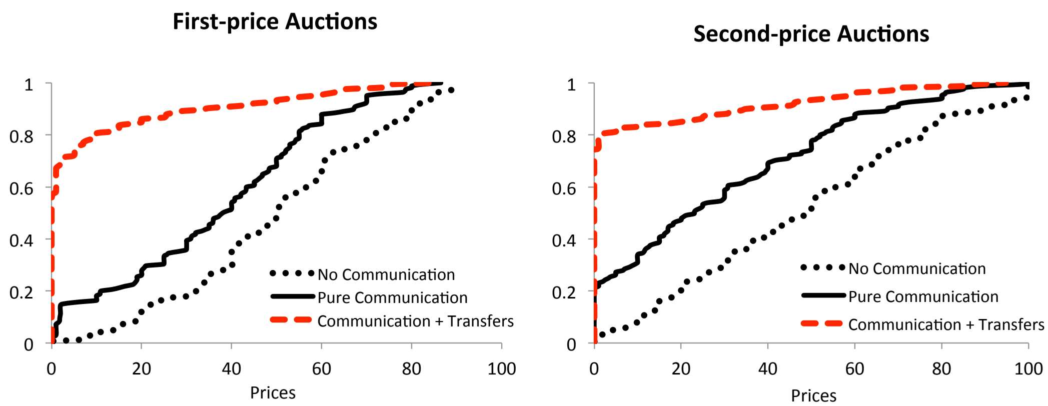
These differences in price distributions translate directly to the auctioneer's revenues, as revenues effectively correspond to average prices in our treatments. In our first-price auctions, revenues are 50.2, 36.5, and 8.7 for the No Communication, Pure Communication, and Communication with Transfers treatments, respectively. In our second-price auctions, revenues are 48.3, 28.3, and 8.0 for the No Communication, Pure Communication, and Communication with Transfers treatments, respectively.[20] Across our treatments, there is

[18]Clustering by session, robust standard errors for the efficiency levels are 0.03 for both the first- and the second-price auctions without communication.

[19]The Kolmogorov-Smirnov test of equality of distributions confirms that price distributions between any two treatments are significantly different at the 5% level in both auction formats ($p < 0.001$ in all six pairwise comparisons).

[20]Clustering by session, robust standard errors for the first-price auction revenues are 3.1, 2.2, and 1.7 for the No Communication, Pure Communication, and Communication with Transfers treatments, respectively. For our second-price auction revenues, they are 2.9, 4.0, and 2.0 for the No Communication, Pure

Figure 3: Cumulative Distribution of Prices Across Treatments



a revenue equivalence—the revenues under both auction formats are statistically indistinguishable in all treatments. Importantly, the availability of communication *and* transfers yields statistically significant reductions in revenues under both auction formats, generating *less than one third* of the revenues generated when all communication is banned under either auction format.

In terms of efficiency, sessions with communication with or without transfers generate efficiency levels similar to those observed in sessions without communication in both auction formats. In our first-price auctions, generated efficiencies are 84% and 87% for the Pure Communication and Communication with Transfers treatments, respectively. Similarly, in our second-price auctions, generated efficiencies are 78% and 84% for the Pure Communication and Communication with Transfers treatments, respectively.[21] No pair of values is significantly different at the standard 5% level.[22]

In theory, the availability of transfers should not impact outcomes. Indeed, bidders cannot commit to a transfer and a bidder maximizing her profits would never make a positive transfer, see Section 3. Nonetheless, we see a fairly negligible volume of collusive outcomes when only communication is available, and a considerable volume of collusive outcomes when

Communication, and Communication with Transfers treatments, respectively.

[21] Clustering by session, robust standard errors for the first-price auction efficiencies are 0.04 and 0.03 for the Pure Communication and Communication with Transfers treatments, respectively. For our second-price auction efficiencies, they are 0.05 and 0.04 for the Pure Communication and Communication with Transfers treatments, respectively.

[22] For the comparison between efficiency levels in our first- and second-price auctions with pure communication, we obtain $p = 0.318$. For the comparison between efficiency levels in our first- and second-price auctions with communication and transfers, we obtain $p = 0.654$. Similarly, for the comparison between efficiency levels in our first-price auctions with pure communication and our first-price auctions with communication with transfers we obtain $p = 0.668$. The analogous comparison across treatments pertaining to our second-price auctions yields $p = 0.376$.

transfers are available in addition to communication, *even when focusing on the last round of sessions*. In what follows, we focus exclusively on the Communication with Transfers treatment. Our primary goal is to investigate the mechanism underlying successful collusion in that treatment.[23]

4.4 Collusion in Communication with Transfers Treatments

In this section, we first identify the strategies used by our subjects and the main determinants of prices. We then proceed to analyzing communication protocols and the tendency of subjects to misrepresent their values and bids during pre-auction discussions. We conclude by documenting subjects' behavior at the transfer stage.

4.4.1 Determinants of Prices

In order to get a sense of the behavior underlying the outcomes generated when both communication and transfers are available, we first analyze the strategies suggested during the communication phase and the extent to which they are followed when bids are submitted.

To assure a low price in an auction, at least one of the bidders should submit a low bid (in a first-price auction, both bidders need to submit a low bid for the price to be low). There is one leading collusive strategy that appears in the analysis of the communication stage.[24] This strategy profile, which we term the *reveal-collude* strategy, consists of the bidders revealing their values and submitting bids that assure the object is given to the high-value bidder at a low price, defined as lower than two points. In first-price auctions, this implies both bidders submitting a low bid; In second-price auctions, this implies the losing bidder submitting a low bid and the winning bidder submitting any bid that is higher.

Table 2 describes the rates at which this strategy was discussed as well as the rates at which it was used. This strategy is sensitive to deviations by the bidder who is to bid the lowest bid. Indeed, bidders have an incentive to mis-report their values in order to change the identity of the winning bidder. Furthermore, in first-price auctions, a bidder may attempt to out-bid her opponent, while still submitting a low bid to achieve a low ultimate price. Strategic responses as such may both lead to an observed price that is below our threshold of two, despite a deviation from the agreed-upon strategy profile. In order to assess the prevalence of such strategic deviations, we look at the frequency of efficient outcomes when seemingly collusive outcomes were observed. An efficient outcome suggests that the higher-value bidder received the object for a low price; An inefficient outcome suggests that the

[23] Detailed analysis of our Pure Communication treatment appears in Section 2 of the Online Appendix.

[24] Protocols were analyzed by three research assistants, who were not privy to the research questions posed in this paper. Their classifications exhibited high correlations, see the Online Appendix.

Table 2: Strategies Discussed and Used in Communication with Transfers treatments

	First-price	Second-price
Discuss Reveal-collude	84.8%	85.6%
Discuss and Use Reveal-collude	68.5%	67.5%
Achieved Efficient Outcome	66.1%	61.3%
Achieved Inefficient Outcome	2.4%	6.3%

Remarks: Discuss Reveal-collude: bidders announce their values and discuss colluding in a way leads the bidder with a higher announced value to win the object. Discuss and Use Reveal-collude: bidders discuss the reveal-collude strategy and the bidder with the higher announced value submits the higher bid, which is lower than 2.

lower-value bidder received the object at a low price, either due to mis-reporting of her value or due to out-bidding her opponent. As is evident, we see a fairly small fraction of inefficient outcomes when the reveal-collude strategy is carried out. This indicates the limited scope of strategic manipulation that subjects exercised in this environment. In what follows, we inspect bidders' behavior in more detail, both during communication and in the auctions themselves.

Table 3 presents the results of a Tobit regression analysis of how different features of the communication protocols impact prices when bidders interact prior to bidding (errors clustered by session). At the aggregate level, in either auction format, when agents talk during the communication phase, prices drop in a statistically significant manner. The topics discussed during communication matter. Discussion of values, bids, or transfers impacts prices statistically significantly and substantially. We note, however, that discussion of bids is highly correlated with discussion of transfers (0.68 in first-price auctions and 0.73 in second-price auctions). Given that their effects on prices are rather similar, it is difficult to isolate which of the two plays a more important role in the determination of the ultimate auction price. We return to a more elaborate analysis of how transfers are set by our subjects in Section 4.4.3.

4.4.2 Analysis of Communication

Figure 4 illustrates that the availability of transfers changes the way bidders communicate with each other. In this figure, we depict the fraction of subjects who did not talk, talked and overstated their values or bids, revealed truthfully their values or bids, or understated their values or bids. We treat each subject in each round (of a particular auction format) as

Table 3: Tobit Estimates Explaining Ultimate Prices in Communication With Transfers Treatments

	First-price Auctions				
	Regression 1	Regression 2	Regression 3	Regression 4	Regression 5
Equilibrium Prediction	0.20** (0.08)	0.13 (0.08)	0.23** (0.10)	0.20** (0.06)	0.19* (0.07)
Indicator if Bidders Talk	-39.98** (7.71)				
Indicator if Bidders Discuss Values		-36.40** (12.19)			
Indicator if Bidders Discuss Bids			-29.17** (4.47)		
Indicator if Bidders Discuss Reveal-collude				-29.65** (6.00)	
Indicator if Bidders Discuss Transfers					-26.50** (5.94)
Constant	38.75** (9.17)	36.77** (11.50)	23.07** (4.74)	26.05** (6.07)	22.49** (5.90)
# of obs	165	153	153	153	153
# of sessions	6	6	6	6	6
Pseudo R^2	0.0484	0.0226	0.0793	0.0487	0.0558
	Second-price Auctions				
	Regression 1	Regression 2	Regression 3	Regression 4	Regression 5
Equilibrium Prediction	0.046** (0.14)	0.53** (0.18)	0.40** (0.23)	0.44** (0.18)	0.43** (0.17)
Indicator if Bidders Talk	-46.78** (20.51)				
Indicator if Bidders Discuss Values		-68.01** (13.96)			
Indicator if Bidders Discuss Bids			-40.66** (14.99)		
Indicator if Bidders Discuss Reveal-collude				-55.20** (11.89)	
Indicator if Bidders Discuss Transfers					-42.68** (10.79)
Constant	15.00 (16.42)	32.63** (6.15)	5.41 (14.82)	20.69** (10.29)	6.36 (12.34)
# of obs	160	153	151	154	154
# of sessions	6	6	6	6	6
Pseudo R^2	0.0218	0.0414	0.0477	0.0752	0.0591

Remarks: We run Tobit regressions in which we regress the observed price on the equilibrium price predicted by the risk-neutral Nash equilibrium, as well as indicators capturing conversations between bidders. Robust standard errors are clustered at the session level. Reveal-collude is the strategy in which bidders announce their values and discuss colluding in a way that a bidder with a higher announced value bids higher than the other one. Flip-a-coin is the strategy in which bidders agree to put the same bid.

one observation.[25] When only communication is available, in the majority of auctions subjects do not talk about any relevant aspect of the auction, i.e. neither bidder in the group discusses values, bids, or strategy. In contrast, discussions of bids and values are very common in our treatment with transfers under both auction formats. Indeed, subjects talk about their values in 87% of the cases and about their bids in 73% of the cases in our first-price auctions (and discussion of values precedes that of bids about 90% of the time). In our second-price auctions, they discuss values in 87% of the cases and bids in 54% of the cases (and the order in which values and bids are discussed appears approximately random). Furthermore, while in the Pure Communication treatment, conditional on talking, most of the revealed values are reported truthfully but bids are misrepresented, this is not the case in the Communication with Transfers treatment, in which most of the reports are truthful. Conditional on reporting values, reports are truthful 66% of the time in our first-price auctions and 69% of the time in our second-price auctions. Similarly, conditional on reporting one's intended bid, subjects follow through with their intention 92% of the time in our first-price auctions and 83% of the time in our second-price auctions.

These observations are in line with the high levels of efficiency we observe throughout our treatments. Without effective communication, bidders use monotonic bidding functions—individuals with higher valuations bid higher. When communication is effective, bidders choose bids that allow the higher bidder to win the auction. The fact that the efficiency levels we observe are approximately 80% rather than 100% is an artifact of the noisiness of our experimental data and consistent with the levels observed in various other experiments of auctions without communication, as referenced before.

4.4.3 The Impacts of Transfers

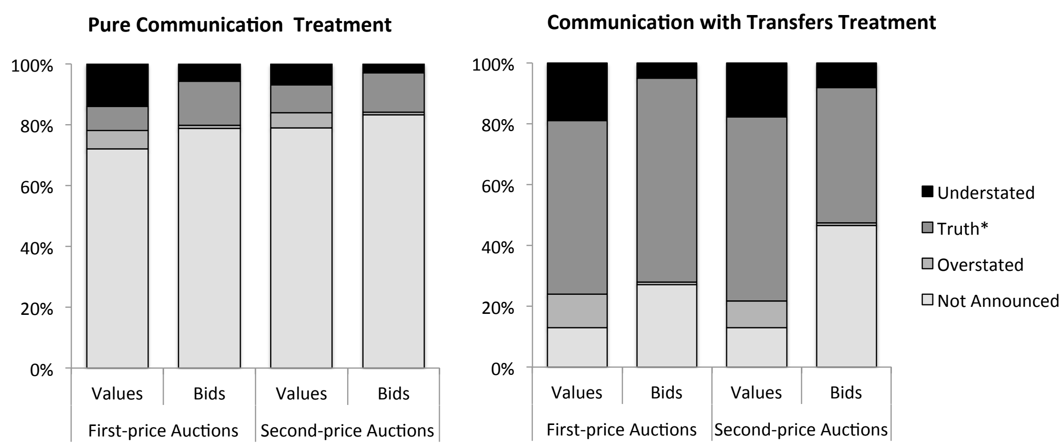
Our treatment with both communication and transfers was very effective in allowing subjects to collude in both auction formats despite the fact that subjects could not commit to the transfers passed and were randomly matched with one another to prevent effective commitment through repeated play.[26]

Transfers rarely originate from the loser of the object to its winner; This occurred in fewer than 5% of cases under both auction formats. Winners, on the other hand, transfer more than 2 points to their losing opponents at a frequency of 65% in our first-price auctions and

[25] Values and bids were communicated as numbers or verbally ("low", "high", etc.). The three research assistants that analyzed the communication protocols were instructed to interpret "low"and its synonyms as corresponding to $0-33$, "moderate"and its synonyms to $34-66$, and "high"and its synonyms to $67-100$.

[26] In Table 3 and 4 of the Online Appendix, we present additional analysis that indicates this is also true in the very last rounds of our sessions, as well as in the sessions in which a complete-strangers matching protocol was used, in which subjects knew they would never encounter the same partner more than once.

Figure 4: Frequency of Communication Across Treatments



Remarks: Values and Bids refer to both numerical and verbal descriptions of values and bids. For each category, we classify announced values and bids relative to the actual values and bids. The value (bid) is understated if the announced value (bid) is below the actual value (bid) minus 2 experimental points. The value (bid) is overstated if the announced value (bid) is above the actual value (bid) plus 2 experimental points. Finally, if the announced value (bid) is between the actual value (bid),minus 2 and the actual value (bid) plus 2, then it is classified as Truth. Verbal announcements were of the form "low," "moderate," and "high," which we interpret as 0-33, 33-67, and 67-100, respectively. We used the average announcements of these ranges to classify announcements as those that are overstated, those that are understated, and those that are truthful.

63% in our second-price auctions. The frequency of transfers depends on how the auction culminates: transfers are very frequent if the ultimate price is minimal (the frequency of substantial transfers in our first-price auctions is 85% while it is 77% in our second-price auctions).[27] However, if the price above minimal, then substantial transfers are rare (17% in our first-price auctions and 6% in our second-price auctions).[28]

[27]As mentioned in the literature review, our setting is reminiscent of trust games. As a comparison, Berg, Dickhaut, and McCabe (1995) studied trust games in which the first player had $10 to allocate and any amount passed on to the second player was multiplied by 3. Of 28 pairs in which some money was transferred, in 12 cases (or 43%) money was transferred back, in line with our figures.

[28]High frequencies of positive transfers from the winning bidders to the losing bidders remain prevalent even in the very last round of the experiment. In the last round of our first-price auctions winners transferred substantial amounts to their losing counterpart in 72% of cases, while this happened in 87% of cases in which the price was minimal. Similarly, in the very last round of our second-price auctions, in 66% of the auctions winning bidders transferred substantial amounts to the losing bidders, while this fraction becomes 71% once we condition on the price of the object being minimal. These data reinforce the claim that our observations are not driven by wrong perceptions of repeated play, since subjects knew when the last round of the experiment was taking place.

Table 4: Probit Estimates Explaining when Transfers Occur

	First-price	**Second-price**
Winning Bidder's Value	0.02** (0.005)	0.01** (0.006)
Losing Bidder's Value	-0.003 (0.004)	-0.007 (0.007)
Price	-0.05** (0.01)	-0.08** (0.02)
Indicator if Efficient Outcome	1.24** (0.53)	0.94** (0.34)
Indicator if Winning Bidder Lied in the Past about Values or Bids	-0.47** (0.24)	-0.65** (0.27)
Constant	-0.91* (0.48)	-0.28 (0.38)
# of obs	165	160
# of sessions	6	6
Pseudo R-square	0.3986	0.4146

Remarks: Estimates are from the Probit regressions with a dependent variable that takes the value of 1 if the winning bidder transferred a substantial amount (more than 2 experimental points) to the losing bidder and zero otherwise. Robust standard errors are clustered at the session level. ** (*) indicates significance at the 5% (10%) level.

Table 4 reports results from a Probit regression in which whether or not substantial transfers were passed is explained by the winning and losing bidders' values, the ultimate price in the auction (a proxy for whether a collusive outcome emerged), an indicator that takes a value of 1 if the auction culminated in an efficient outcome, and an indicator that takes a value of 1 if the winning bidder had lied in the previous auctions about his or her values or bids. The last variable is designed to capture a "type" of bidder that is more inclined to act in a self-interested manner.

As can be seen, the winning bidder's value and the final price have a statistically significant impact on whether transfers occur, with price having a larger effect than the winning bidder's value.[29] The losing bidder's value has no statistically significant effect on whether or not transfers occur, while efficient outcomes are associated with a significantly higher likelihood of transfers being passed. Note that collusive outcomes require some coordination achieved through communication and efficiency is a proxy for whether values are revealed truthfully. Nonetheless, the winning bidder's truthfulness in prior rounds, which could serve as a proxy for her "type," does not seem to play an important role in the occurrence of transfers. We do see some difference between the two auction formats in terms of the impact of final prices: they exhibit a larger effect in our second-price auctions.

Conditional on making a substantial transfer, the amount transferred averages at 44%

[29] Using the winning bidder's surplus instead of value and final price, leads to similar conclusions—a higher surplus is linked with a greater likelihood of transfers occurring. These results are reported in Table 5 in the Online Appendix.

of the surplus in both auction formats. However, the modal fraction of surplus transferred is 50% – in 62% of our first-price auctions and 67% of our second-price auctions half of the surplus was transferred. In line with our observations above, the amount transferred does not depend on the losing bidder's value.

These observations suggest a consistent pattern of behavior as follows. Subjects share some (mostly truthful) information regarding their values during communication. They then submit bids that assure a fairly low price and realize approximately the maximal surplus for the bidders given their values. Last, they share the surplus at roughly equal proportions. As mentioned in the introduction, the outcomes of such protocols mimic what has happened in multiple collusion cases in the US, in which one bidder was designated as the winning bidder during communication prior to the auction, and later compensated the losing bidders: the case of school milk cartels documented in Pesendorfer (2000), US vs. Inryco, Inc., US vs. A-A-A Elec. Co., and US vs. Metropolitan Enterprises, Inc.

4.4.4 Norms of Transfers and Other-regarding Preferences

Norms of Transfers The behavior we observe may raise a suspicion that subjects operate under a norm that prescribes an equal division of the surplus regardless of the profile of bids (in the spirit of Andreoni and Bernheim, 2009). As it turns out, under both auction formats, were such a norm in place, the behavior patterns we observe in our data are consistent with equilibrium play.

Suppose players act according to the following protocol. In the communication stage, both reveal their value. Then, the low-value bidder submits a bid of 0 and the high-value bidder submits a bid of 0.01 (the smallest possible bid greater than 0). If both state the same value, both submit 0. This protocol is incentive compatible under both auction formats. Indeed, both individuals have an incentive for the highest-value bidder to win the object at the lowest possible price since the surplus divided, and consequently their payoffs, are highest in that case. Furthermore, there is no incentive to out-bid at the bidding stage. This protocol echoes what we see in much of our data – subjects utilizing the communication phase to implement the reveal-collude strategy and then splitting the surplus of the winning bidder.[30]

This profile of actions would no longer be an equilibrium if the prevailing norm were to split the surplus unequally between the winning and losing bidders. Indeed, suppose the winning bidder was to keep a fraction $\alpha > 1/2$ of the surplus and transfer a fraction $1 - \alpha$.

[30]Notice that there could be a multiplicity of equilibria. In particular, in second-price auctions, winning bidders could submit arbitrary positive bids. Indeed, we see a substantial variance of high bids in our second-price auctions. These equilibria, which are equivalent with respect to outcomes, are welfare maximizing.

In this case, winning the object entails an advantage since a greater fraction of the surplus is then kept. This tilts individual incentives – they may prefer to win the object themselves even if it generates a slightly lower surplus. In fact, the above protocol does not constitute part of an equilibrium any longer. It can be shown that a bidder with a private value of v would benefit from mis-reporting a value of $\frac{\alpha}{1-\alpha}v > v$ at the communication stage.[31] In that respect, while norms of transfers are in line with much of our data, these conclusions are fragile to the precise norms in place.

Other-regarding Preferences and Reciprocity The behavior we observe could, in principle, be an artifact of preferences rather than behavioral heuristics. In particular, one may worry that some of the generous transfers we observe in our experiments are an artifact of a form of other-regarding preferences that are often observed in laboratory settings (see, e.g., Fehr and Schmidt, 1999, Bolton and Ockenfels, 2000, and work that followed). Certainly, such other-regarding preferences cannot be overwhelmingly strong in our experimental setting. If they were, we would expect, for instance, that subjects submit zero bids in second-price auctions without communication in order to allow their opponent to gain the object at a low cost. Still, subjects may be putting some weight on their opponents' outcomes, in addition to their own. In their simplest form, models of other-regarding preferences pose utilities that are composed of two *linear* terms: one corresponding to one's own monetary outcomes and one corresponding to others' outcomes (this is the essence of the Fehr and Schmidt, 1999 model). Formally, suppose the surplus is s, Fehr and Schmidt (1999) would suggest a utility from transferring t to the other bidder of:

$$\begin{aligned} U(s;t) &= s - t - \alpha \max\{t-(s-t),0\} - \beta \max\{(s-t)-t,0\} = \\ &= s - t - \alpha \max\{2t-s,0\} - \beta \max\{s-2t,0\} = \\ &= \begin{cases} (1+\alpha)s - (1+2\alpha)t & t \geq s/2 \\ (1-\beta)s - (1-2\beta)t & t < s/2 \end{cases}, \end{aligned}$$

where $\alpha \geq \beta$ and $\beta \in [0,1)$. It follows that if $\beta \leq 1/2$,

$$\begin{aligned} \max_{t\in[0,s]} U(s;t) &= \max\{(1+\alpha)s - (1+2\alpha)s/2, (1-\beta)s\} = \\ &= \max\{s/2, (1-\beta)s\} = (1-\beta)s \end{aligned}$$

[31] This would be true even if all bidders were risk averse. Intuitively, reporting the valuation truthfully generates a random outcome that depends on the other bidder's valuation. In contrast, exaggerating one's valuation and reporting the maximal possible valuation produces a nearly certain outcome. Therefore, truth-telling would be harder to sustain when bidders are risk averse.

and the optimal transfer is $t = 0$.

If $\beta > 1/2$, however, utility is maximized at $t = s/2$. Nonetheless, this prediction has two issues. First, it suggests that transfers are either minimal (for winning bidders with $\beta \leq 1/2$) or half the surplus (for winning bidders with $\beta > 1/2$), which is inconsistent with our data. Second, data from other experiments (see Table 1 in Fehr and Schmidt, 1999, as well as Roth, 1995), suggest that a substantial fraction of the population is characterized by $\beta < 1/2$—Fehr and Schmidt (1999) base some of their analysis on a distribution that places 60% on $\beta \in \{0, 0.25\}$. This would imply a significant fraction of winning bidders that transfer minimal amounts, which is again inconsistent with what we see in our data.

There are many ways to introduce non-linearities to the basic model that accounts for both one's own and others' outcomes. In order to illustrate the impacts of non-linearities, we consider a class of utilities as follows. The utility for a winning bidder with surplus $s = v - p$ from transferring t to the other bidder is given by:

$$\begin{aligned} U_i &= \alpha(s-t) - (1-\alpha) f\left((s-t) - t\right) = \\ &= \alpha(s-t) - (1-\alpha) f\left(s - 2t\right), \end{aligned}$$

where $\alpha \in (0, 1)$ is a weight parameter that indicates how much bidder i cares about her own payoff relative to the variation of payoffs within the pair. We assume that the inequality cost function f is symmetric, $f(x) = f(-x)$, twice continuously differentiable, increasing in the distance between payoffs, $f'(x) * sgn(x) > 0$, and convex, $f''(x) > 0$ for all x.

Consider a winning bidder in our auctions who has an object value of v that she has gained for the price of p. If she maximizes her utility as above with respect to the transfer t, it must be that:

$$s - 2t = v - p - 2t = \left(f'\right)^{-1}\left(\frac{\alpha}{2\left(1-\alpha\right)}\right).$$

In other words, the net profits of the winning and the losing bidders should differ by a constant, the size of which depends on the weight put on one's own monetary outcomes relative to the egalitarian utility component. We stress that this solution does not depend on the auction format nor on what has transpired in the auction (namely, the ultimate price of the object). However, in our data, the difference between the surpluses of the two bidders exhibit a large variance and does not appear constant, even when conditioning on the minimal price being achieved.[32] Naturally, one could consider even more general functional

[32]Indeed, in our first-price auctions, the average difference between the surplus of the two bidders is 19 with a standard deviation of 25 and values varied between -10 and 92. Similarly, in our second-price auctions the average difference is 14 with a standard deviation of 31 and values varied between -95 and 98. Even when focusing only on auctions that resulted in the minimal price, the difference in surpluses varies significantly

forms, incomplete information on the weight α (in which case bids also serve as signals on the private parameter α), etc. We leave such elaborations for future work. But simple models of other-regarding preferences, which are the common ones used in the literature, do not explain our observations.

4.5 Repeated Auctions

Since much of the literature studying collusion in auctions has focused on repeated interactions as a driving channel, we ran several auxiliary sessions to compare the magnitude of collusion documented in our one-shot setting with that achieved in repeated auctions.

4.5.1 Design of Auxiliary Sessions

In each of our auxiliary sessions, subjects were initially randomly paired. They then proceeded to play a repeated game in which each stage mimicked our one-shot setting. That is, subjects were informed of their private values, submitted simultaneously their bids, and were informed of the outcome of the auction. The repeated game terminated with a 10% probability in each period. This probability was chosen so that the expected number of rounds played will be 10, the number of rounds in the sessions of our one-shot treatments. With a 10% termination probability, there is a fully collusive equilibrium under both the first- and second-price repeated auction in which, on path, prices are 0.

In order to assure we observe the behavior of subjects for at least 10 rounds, subjects all played the first 10 rounds (regardless of whether the game had terminated or not). If the game terminated within the first 10 rounds, we informed subjects that was the case and this marked the end of the session. Subjects were then paid for all periods in which the game was active.[33] If the game had not terminated, subjects continued playing as long as the game was active. However, after round 10, we informed subjects in each round whether the game had come to an end or not.

We ran two sessions as above, one corresponding to the first-price auction (with 24 subjects, yielding 12 independent pairs) and one corresponding to the second-price auction (with 30 subjects, yielding 15 independent pairs). In addition, we ran analogous sessions in which, in every round, subjects could communicate freely as in our benchmark sessions after observing their private values and before submitting their bids. We ran one session as such for the first-price auction (with 26 subjects, yielding 13 independent pairs) and one for the second-price auction (with 30 subjects, yielding 15 independent pairs).

from auction to auction with standard deviations of similar size (26 in both auction formats).

[33]For instance, if the game terminated after period 5, subjects were paid for the first 5 periods only.

In what follows, unless otherwise mentioned, we focus on rounds 6-10, so that results are comparable with those pertaining to our one-shot setting.

4.5.2 Collusion and Efficiency in Repeated Auctions

We start comparing repeated and one-shot auctions by looking at the distribution of prices and frequency of collusion. With respect to prices, Figure 5 depicts the cumulative distributions of prices across all our treatments. As can be seen, *repeated interaction, with or without communication, does not enlarge the scope of collusion relative to our one-shot treatment with communication and transfers.* In fact, in our repeated first-price auctions, the distribution of prices with or without communication first order stochastically dominates the price distribution we observe in our one-shot treatment with communication and transfers; Even when allowing for communication, the minimal price is achieved in only 45% of our repeated auctions, as compared with 78% in our one-shot first-price auctions with communication and transfers. In our repeated second-price auctions, the price distribution when communication is available is first order stochastically dominated by that corresponding to the case in which communication was not available, and virtually coincides with the distribution of prices in our one-shot second-price auction with communication and transfers; When allowing for communication, the minimal price was achieved in 69% of our repeated auctions, as compared with 68% in our one-shot second-price auctions.[34] This leads to an interesting distinction between our one-shot auctions and our repeated ones: unlike our one-shot auctions, repeated first- and second-price auctions generate outcomes whose differences are statistically significant.

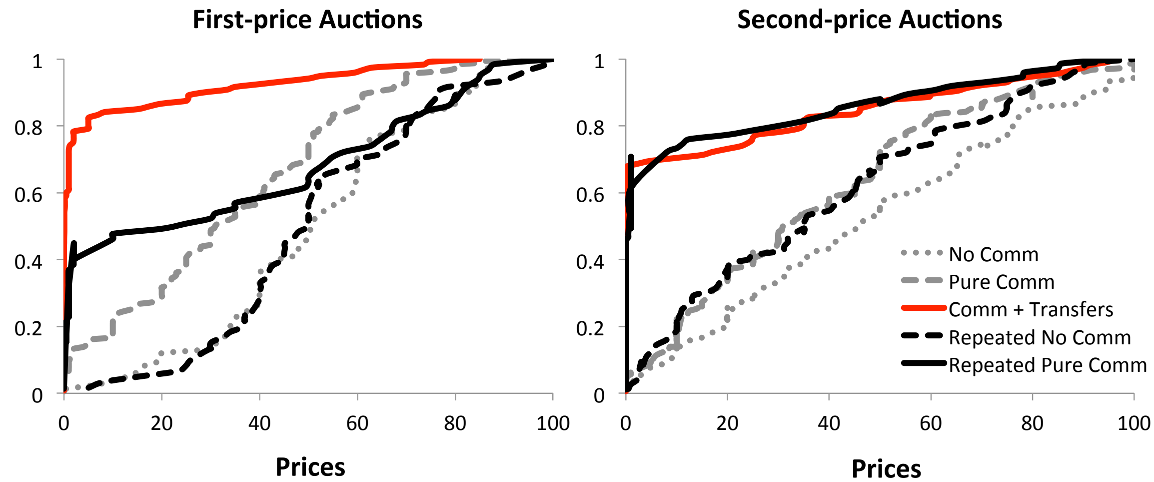
Collusive outcomes in our repeated auctions go hand-in-hand with a reduction in efficiency. With communication, our repeated first-price auctions culminate in efficient outcomes 77% of the time, while our repeated second-price auctions achieve efficient outcomes only 63% of the time.[35]

These efficiency levels are consistent with the fraction of collusive outcomes being gener-

[34] Specifically, in our repeated first-price auctions without communication, the average revenues are 51.7 with the robust standard errors of 4.3, while in our repeated first-price auctions with communication, the average revenues are 32.5 with the robust standard errors of 8.8. For the repeated second-price auctions with and without communication, the average revenues are 38.3 and 14.2 with robust standard errors of 3.8 and 5.0, respectively. A series of Wilcoxon rank-sum tests confirm that median prices observed in our repeated first-price auctions are significantly higher than those observed in our one-shot first-price auctions with communication and transfers at the 5% level. For our second-price auctions, when communication is allowed, the two price distributions are statistically indistinguishable.

[35] Clustering by pairs of subjects that were matched throughout the experiment, robust standard errors for efficiency levels in our repeated first-price auctions with and without communication are 0.06 and 0.03, respectively. Similarly, robust standard errors for efficiency levels in our repeated second-price auctions with and without communication are 0.06 and 0.03, respectively.

Figure 5: Cumulative Distributions of Prices Across Treatments



ated by simple strategies in the repeated game that lead to winning bidders alternating or being randomly determined. Turning to behavior, define a *run* as a maximal block of rounds in which one bidder wins consecutively. We define the *number of switches* in a session to be the number of times the identity of the winning bidder changed in consecutive rounds; This is the number of runs minus 1. For example, if one bidder wins the auction throughout a session of 10 rounds, there would be only one run and no switches; If bidders alternate who wins across rounds, the maximal number of 10 runs and 9 switches would be observed. The number of switches is then a proxy for the extent to which subjects alternate between who is the winning bidder. If the winning bidder's identity were random (as would be the case if outcomes were fully efficient), the expected number of runs would be 5.5 leading to 4.5 expected switches.[36]

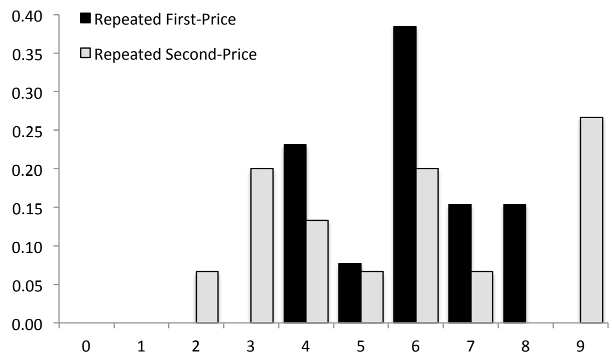
Figure 6 depicts the distribution of the number of switches of winning bidders in our different repeated auctions. The average number of switches is 5.9 in our repeated first-price auctions and 5.7 in our repeated second-price auctions and we see a statistically significant fraction of groups exhibiting 8 or 9 switches.[37] These data suggest that at least some of the collusive outcomes we observe in our repeated auctions do, in fact, arise from subjects attempting to alternate between who wins the auction. An analysis of communication proto-

[36]Indeed, denote by Z_t for $t = 2, ..., 10$ an indicator that takes the value of 1 if the winner in round t is different than the winner in round $t-1$. Notice that $\mathbb{E}(Z_t) = 1/2$. The number of runs is then $1 + \sum_{t=2}^{n} \mathbb{E}(Z_t) = 5.5$ and the number of switches is $\sum_{t=2}^{n} \mathbb{E}(Z_t) = 4.5$.

[37]The probability of 9 switches when winners are determined randomly is $\frac{1}{2}^9$, lower than 0.2%. The probability of 8 switches when winners are determined randomly is $9 \cdot \frac{1}{2}^9$, lower than 2%.

cols in our repeated auctions illustrates that much of the relevant communication that took place revolved around an alternating strategy profile. Since such alternating strategies imply that the identity of the winning bidder is not associated with bidders' relative valuation of the object, a reduction in efficiency follows.

Figure 6: Distribution of Number of Switches of Winning Bidders



5 Conclusions

In this paper we report results from a sequence of experiments testing the impacts of communication and transfers on auction outcomes in the first- and second-price one-shot auctions. The main message is that while collusion is rare when bidders can communicate with each other without transfers, communication coupled with transfers allows for a substantial amount of collusion, even in one-shot settings. The patterns we observe when collusion is most effective are in line with multiple documented cases of bid rigging: bidders communicate to designate who is to win the object and the winning bidder then transfers some of the surplus to losing bidders.

Repetition, which has been one of the prevailing explanations for the emergence of collusion in the literature, does not appear to allow greater scope for collusion, even when combined with communication between rounds. Repetition, however, leads to a statistically significant reduction in efficiency that communication and transfers in one-shot settings do not.

The frequency of collusive outcomes is similar across auction formats, so neither is immune to collusive behavior. In both auction formats, subjects use similar strategies to reach collusive outcomes. They share with each other (mostly truthfully) their values during the communication stage in order to ensure that highest-valuation bidder wins the object at the minimal price. They then share the surplus at roughly equal proportions. Overall, the paper suggests that communication can serve an important component of the emergence of collusion.

From a theoretical perspective, our data features several aspects that are not in line with theoretical predictions. Without communication, we observe consistent over-bidding, which has been noted by many authors before us. With communication and transfers, the results are similarly in conflict with the guidance theory provides. Importantly, ex-post transfers seem to have a substantial impact on outcomes, even absent any commitment instruments. These observations suggest that enriching the basic theoretical model used for behavior in the auctions we study may be warranted.

There are several natural directions for extending our results: allowing for more than two bidders, introducing explicit anti-collusion measures to our design[38], or providing various commitment instruments pertaining to transfers. We view these as interesting avenues for future research.

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