Collusion and the choice of auction: An experimental study[1]

Jeroen Hinloopen[2] and Sander Onderstal[3]

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ABSTRACT:

We bring to the lab the theoretical result of Robinson (1985, RAND Journal of Economics 16: 141 - 145) that collusion is incentive compatible in the English auction (EN) and not in the first-price sealed-bid auction (FP) in the case of one-shot interaction. Our data partly confirm Robinson's prediction: in FP all cartels break down, but a majority of cartels breaks down in EN as well. However, more cartels form in EN than in FP and stable cartels in EN obtain the item for a price well below its value. In the case of repeated interaction, the two auctions no longer differ in terms of cartel stability but stable cartels are still better able to reduce the winning bid in EN than in FP.

KEYWORDS: Collusion; English auction; First-price sealed-bid auction; Laboratory experiments

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[2] Corresponding author. University of Amsterdam, FEB/ASE, Roetersstraat 11, 1018 WB Amsterdam, The Netherlands; `J.Hinloopen@uva.nl`.

[3] University of Amsterdam, FEB/ASE, Roetersstraat 11, 1018 WB Amsterdam, The Netherlands; `Onderstal@uva.nl`.

1. INTRODUCTION

In a seminal analysis, Robinson (1985) shows that a crucial difference between the oral or English auction (EN) and the first-price sealed-bid auction (FP) is that cartels are stable only in the former.[1] The intuition is that in EN, submitting a higher bid than that of the designated winner does not secure winning the auction because the designated winner can react to this defection by further raising the bid. In contrast, in FP, where all bidders submit a bid once, the designated winner cannot retaliate in case of defection. In this paper, we test the theoretical prediction of Robinson (1985) in the lab.

Robinson's (1985) theory has found its way into a consensus view that EN is more prone to collusion than FP (Phillips *et al*., 2003), a view that has trickled down into policy reports as well. For example, OECD (2006) gives auction designers the advice that "[w]here collusion is a significant threat, use sealed-bid rather than ascending bid (or "open") auctions." Perhaps surprisingly, the theory has not been tested in a controlled environment. Anecdotal evidence suggests that it is not universally true: both auction formats feature in prominent cartel cases, including FP in cartels for school milk tenders (Porter and Zona, 1999) and infrastructure procurement (Bajari and Ye, 2003), and EN in tobacco auctions (Phillips *et al*., 2003) and stamp auctions (Asker, 2010). Because of the illegal nature of cartels, it is difficult to find more systematic field evidence. Therefore, we rely on laboratory experiments to test Robinson's (1985) theory.

The workings of particular auction types are well-suited to be tested in a controlled environment because most auction formats can be implemented in the lab. This is particularly true because properly incentivized lab experiments can mimic real-life trading: "Laboratory markets are "real" markets in the sense that principles of economics apply there as well as elsewhere. Real people pursue real profits within the context of real rules. The simplicity of laboratory markets in comparison with naturally occurring markets must not be confused with questions about their reality as markets" (Plott, 1982, p. 1520, footnote omitted).[2] Improving our understanding of how auctions work is valuable for practical purposes if only because auctions

[1] In EN, the price is raised successively until one bidder remains who wins the object at the final price. In FP, each bidder independently submits a concealed bid. The winner is selected among the highest bidders and pays her bid.

[2] Indeed, it is quite common for auction designs to be tested in the lab before they are used in practice (see e.g. Cummings *et al*., 2004).

account for a substantial fraction of global trade, most notably in public procurement.[3] As a consequence, insights into the circumstances under which particular auction types are sensitive to collusion may be valuable for auction designers all over the world. Moreover, it so turns out that (auction) theories regularly fail in the lab (Kagel, 1995). An improved understanding of these failures could help to understand pricing patterns in practice. As we will discuss below in more detail, our experimental observations exhibit several patterns that were not predicted by Robinson's (1985) theory. Finally, the insights may be valuable for the design of license auctions. If the possibility to enter a market involves an auction (as with spectrum auctions), the auction protocol may affect entry cost and, subsequently, market structure and market conduct. For instance, increased entry costs make post entry collusion more likely (Offerman and Potters, 2006).

We are not the first to study collusion in experimental auctions. One robust insight from the literature to date is that tacit collusion is rare in single-unit auctions: if subjects deviate systematically from the one-shot Nash prediction, they bid more aggressively instead of less (Kagel, 1995).[4] Several experiments allow for explicit collusion in auctions.[5] These experiments almost universally rely on an experimental protocol where (1) bidders interact repeatedly in a series of auctions, (2) before bidding in the auctions, all bidders have the opportunity to communicate with each other for some fixed period of time, (3) bidders use free-form language to communicate, (4) cartels are all-inclusive, and (5) side-payments are not allowed. The main lessons from this literature are the following. First of all, on average, bidder profits are larger when they can communicate than when they cannot.[6] Second, not all groups find a way to collude successfully.[7] Third, successful collusive schemes typically involve market sharing

[3] OECD (2011) estimates OECD member countries to spend on average around 12% of their GDP on public procurement.

[4] Tacit collusion is sometimes observed in multi-unit auctions, in particular in settings where bidders can find ways to 'divide the market'. See Kwasnica and Sherstyuk (2013) for an overview.

[5] See, e.g., Isaac and Walker (1985), Phillips *et al*. (2003) and Sherstyuk and Dulatre (2008). Kagel and Levin (forthcoming) and Kwasnica and Sherstyuk (2013) present recent surveys of this literature.

[6] This finding fits well with the abundant experimental evidence that decision makers tend to benefit from pre-play communication in dilemma games, including the prisoner's dilemma (e.g., Dawes *et al*., 1977), public good games (e.g., Isaac *et al*. 1985), oligopoly games (e.g., Isaac *et al*., 1984, Hinloopen and Soetevent, 2008, Fonseca and Normann, 2012), and rent-seeking games (Kimbrough and Sheremeta, 2013).

[7] For example, Sherstyuk and Dulatre (2008) observe extensive heterogeneity among groups as far as collusion is concerned. Four (out of 15) groups did not discuss collusion at all. Those groups did not manage to coordinate on a collusive scheme. Nine (out of the remaining 11) groups coordinated on some form of collusive scheme, eight of which obtaining at least 80% of the maximum gains from trade.

agreements.[8] Fourth, in the case of multi-unit auctions, bidders are better able to sustain collusive agreements in ascending auctions than in sealed-bid auctions when interacting repeatedly.[9] It is still an open question how robust this finding is for single-object auctions in a one-shot setting, which is the environment studied by Robinson (1985).

Hu *et al*. (2011) is the only paper we are aware of that compares the collusive properties of EN and FP in a single-unit setting where subjects can form cartels. According to their design, before the auction, bidders can decide to form a cartel at a cost. If a cartel forms, the bidders in the cartel bid in a pre-auction knockout to determine who becomes the provisional auction winner and to establish the side-payments from her to the other bidders in the cartel. The experimental protocol enforces the agreement that (1) the designated bidder unconditionally divides her winning bid in the knockout among the other cartel members and (2) the designated winner is the only bidder in the cartel entering the auction. In contrast to what Robinson's (1985) result might suggest, Hu *et al*. (2011) find that at least as many cartels form in FP as in EN. However, this result may be driven by the binding nature of the cartel agreement, which contrasts with the assumptions made in Robinson (1985). Indeed, Hu *et al*.'s (2011) experimental design does not allow for a test of Robinson's (1985) prediction that cartels in EN are more stable than in FP because in their design all cartels are stable by construction. In our design cartel agreements are not binding.

We let subjects compete for a common value object in groups of three that are re-matched after every of 40 rounds. In any round, prior to the auction, a cartel forms if, and only if, all subjects agree to do so, after which a designated winner is randomly selected. All subjects are subsequently informed about this selection, and reminded about the cartel agreement, i.e., that only the designated winner submits a bid. The treatment variable is the type of auction. Our results partly confirm Robinson's (1985) prediction: in FP literally all cartels break down, but the majority of cartels break down in EN as well. Still, our findings offer strong support for Robinson's qualitative prediction that more cartels are stable in EN than in FP. In addition, more cartels form in EN than in FP. Stable cartels in EN are also quite successful in that they obtain

[8] Note that in a single-object context like ours, bidders do not have the possibility to 'share the market' among each other.

[9] As far as we know, Burtraw *et al*. (2009) is the only paper that makes a direct comparison between EN and FP in environments with pre-play communication. The authors conjecture that it is easier to collude in ascending auctions than in sealed-bid auction because in the former, bidders only have to coordinate their bids along one dimension (quantity), while in sealed-bid auctions they have to coordinate on two dimensions (quantity and price).

the item for a price well below its value. In both types of auctions, the winner in an unstable cartel pays a price close to the object's value.

We next test the robustness of our findings in a repeated-game setting. Theory suggests that cartels can be incentive compatible if the same players interact repeatedly (Friedman, 1971). Indeed, we observe that cartels become stable in both types of auctions, and that the winning cartel bid is reduced significantly compared to a one-shot setting. We also find that stable cartels are better able to reduce the winning bid in EN than in FP. However, the difference in cartel stability between the two types of auctions is no longer statistically significant.

The set-up of the remainder of this paper is as follows. We first review Robinson's (1985) theoretical predictions in Section 2. Section 3 presents our experimental procedures and design for the re-matching case. Section 4 contains the experimental results. In Section 5, we report our results for the repeated-game setting. Section 6 concludes.

2. THEORETICAL MODEL

This section summarizes Robinson's (1985) model and his main result. Robinson (1985) considers an auction (EN or FP) where one indivisible object is auctioned to one bidder out of a set of at least two risk-neutral bidders. A bidder's utility equals zero if she does not win the auction, and equals the difference between the value for the object and the winning bid if she wins. Before the auction, the bidders have formed an all-inclusive cartel in which they have credibly revealed their private information about their values for the object to each other. The model does not specify how the bidders revealed their private information in a credible way.[10] Now, suppose bidder h (the "designated winner") has the highest value V among all bidders. Assume that $V \geq R$, where R represents the seller's reserve price. Robinson (1985) specializes his result to two environments: the common value case and the private values case.[11] In our experiment, we implement a common value case where the object's value is common knowledge among the bidders. As a consequence, our experimental environment is a limiting case of both the common value model (where all bidders are completely informed about the object's value)

[10] Generally, side-payments between bidders are required for a pre-auction knockout to be incentive compatible. See, e.g., McAfee and McMillan (1992).

[11] In the independent private values model (Vickrey, 1961), each bidder is privately informed about her own value for the object, which does not depend on the values of the other bidders. In the common value model (e.g. Milgrom and Weber, 1982), the value is the same to all bidders. Before the start of the auction, they receive signals regarding this value which allows them to make independent estimates of the common value.

and the private values model (where all bidders attach the same value to the object).[12] Robinson (1985) derives the following propositions.

PROPOSITION 1 (Robinson, 1985). Consider the common value case. If all private information regarding the object's value is common knowledge, then: (i) EN has a Nash equilibrium where bidder h has a dropout price V and all other cartel members have dropout prices of R or do not enter a bid; (ii) FP has no Nash equilibrium in which any cartel members make positive profits.

PROPOSITION 2 (Robinson, 1985). Consider the independent private values case. If all bidders' values are common knowledge, then: (i) EN has a Nash equilibrium where bidder h has a dropout price V and all other cartel members have dropout prices of R or not do not enter a bid; (ii) FP has no Nash equilibrium in which bidder h bids below the second highest valuation.

The intuition behind these propositions is the following. In EN, bidder h plays a weakly dominant strategy by staying in the auction until the price reaches her value V. For the other bidders, bidding R or not entering the auction is a best response, so the proposed strategies constitute a Nash equilibrium. In FP, in the common value case, the only way for h to make a positive profit is to submit a bid below V and to win the object. However, this cannot be part of a Nash equilibrium because all other cartel members can strictly improve by bidding between bidder h's bid and V. Similarly, in the private values case, the cartel member having the second highest value could strictly improve if h bid below the second highest value in FP.

Observe that the findings are not sensitive to the exact type of English auction, be it an oral auction (where an auctioneer successively calls out increasing prices), a Japanese auction (where the price increases continuously up to the point where all but one bidder has indicated to be dropping out), or even a second-price sealed-bid auction (where the winning bidder is the one who submitted the highest dropout price and pays the second highest dropout price). In our experiment, we will use a version of the English auction where the bidders successively raise the price until only one bidder remains.

[12] Note that for this setting FP corresponds to a homogeneous goods Bertrand oligopoly, the only difference being that in case of a tie a product market is split evenly between the several suppliers whereas an auction winner would be selected by a random draw.

3. EXPERIMENTAL PROCEDURES AND DESIGN

The computerized experiment was conducted at the Center for Research in Experimental Economics and political Decision making (CREED) of the University of Amsterdam. Students were recruited by public announcement. In total 117 students from the University's entire undergraduate population participated in one of six sessions. The points that subjects earned were converted according to an exchange rate of 1 point = € 0.25. A show-up fee of € 7 was converted to 28 points for those subjects that entered the experiment. To make sure that all subjects understood the experiment, they had to correctly answer several test questions before the experiment started.[13] Average earnings were € 11.52 per subject while sessions took 60 to 90 minutes to complete.

At the start of each session, matching groups of nine subjects were formed randomly. Re-matching groups did not change during the sessions and communication between subjects (other than through their play) was not possible. All sessions consisted of 40 periods. At the start of each period subjects were matched randomly with two other subjects within the same matching group, against whom they could compete in the auction.[14] We had 54 [63] subjects compete in FP [EN], yielding six [seven] statistically independent observations.

Recall that Robinson's (1985) result relies on the assumption that the bidders share their private information before the auction. In our design, we by-pass the question as to how the bidders manage to credibly reveal their information to each other before the auction by implementing a common value setting: subjects compete for a single object with a common value of 10 points. As a consequence, Robinson's (1985) assumption is satisfied by construction.[15]

At the beginning of each period, each subject was asked if she wanted to "make an agreement". When, and only when, all group members pushed the 'yes' button (rather than the

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[13] Appendix A contains an English translation of the instructions.

[14] Subjects were re-matched such that they would not face the same opponent(s) in two consecutive periods. Subjects were informed about this conditional re-matching. Although (tacit) collusion is quite unlikely to be observed in groups with four or more subjects (see, e.g., Huck *et al*., 2004 and Fonseca and Normann, 2012), we introduced this conditional re-matching to eliminate any tendency towards (tacit) collusion due to repeated play that might affect a proper comparison between treatments. In section 5, we discuss additional sessions where subjects were not re-matched.

[15] Hu *et al.* (2011) used a pre-auction knockout to determine the designated winner in an independent private values environment. They found the pre-knockout auction's efficiency in both EN and FP to lie around 95% (where efficiency is defined as $(w\text{-}v)/(V\text{-}v)$ with w and v [V] denoting the winner's value and the lowest [highest] value among the bidders). This outcome is in contrast to Robinson's (1985) assumption that the designated winner is always the bidder with the highest value.

‘no’ button), a cartel formed.[16] As in Robinson (1985) we do not consider partial cartels.[17] Individual votes were not disclosed; subjects only learned whether or not “an agreement had been reached”. When a cartel had formed the computer randomly assigned a designated winner. According to the cartel agreement only the designated winner should submit a bid. All members of the cartel were reminded of this agreement once the designated winner was selected; designated losers received the message that “[a]ccording to the agreement you are not supposed to submit a bid”, while designated winners were informed that “[a]ccording to the agreement you are the only bidder who is supposed to submit a bid”. The cartel agreement was not binding though. This design feature corresponds to Robinson’s (1985) set-up whereby “[t]he cartel is assumed to select from among its members a “designated winner” (who should be the member with the highest valuation if they differ) and to recommend that he follow a particular bidding strategy while requesting other cartel members to be inactive in the bidding” (Robinson, 1985, p. 143).

We follow Hu *et al*. (2011) by imposing *ex ante* side-payments: designated winners pay automatically 2.5 points to both other cartel members (5 points in total) prior to the auction.[18;19] In laboratory experiments, a substantial fraction of the subjects tends to be inequity averse (e.g. Fehr and Schmidt (1999)). In the case of *ex ante* side-payments, inequity averse bidders have less reason to deviate from the cartel agreement because the pay-off differences between the winner and the losers are less pronounced than what they would be without side-payments. Moreover, entering the auction is likely to increase the pay-off difference. For instance, in EN, a stable cartel may yield 2.5 and 5 points for the designated losers and winner respectively. If a designated loser would enter the auction, she would earn nothing extra (because the designated

[16] This procedure has been introduced by Apesteguia *et al*. (2007), and was subsequently adopted by e.g. Hinloopen and Soetevent (2008), Hu *et al*. (2011), and Bigoni *et al*. (2012).

[17] See, e.g., Marshall and Marx (2007) and Bos and Harrington (2010) for a theoretical analysis of partial cartels. Clemens and Rau (2012) provide a first experimental test of partial cartel formation.

[18] We are not aware of any other auction experiment where side-payments between bidders was possible. As mentioned in the Introduction, in most experiments, side-payments were explicitly forbidden. Kimbrough and Sheremeta (2013) study side-payments between parties in a two-player rent-seeking contest. Before interacting in the contest, one party could offer the other money in order not to compete in the contest. Kimbrough and Sheremeta (2013) find that side-payments mitigate competition in the contest, even in a treatment where a party could still enter the contest after receiving a side-payment from the other. In particular, a substantial fraction of the parties that accepted side-payments from the other decided not to compete in the contest. This finding gives some support to our conjecture that designated losers may shy away from entering an auction after receiving side-payments for the designated winner.

[19] Asker (2010) gives a particularly striking example of a bidding ring of stamp dealers who organized no less than 1700 pre-auction knockouts in which the level of side-payments were decided.

winner will drive the price up to 10) while leaving the designated winner with a loss of 5 points. Without side-payments, stable cartels yield 10 and 0 points respectively for the designated winner and losers. If in this case a designated loser would enter the auction, both the designated winner and losers would earn nothing, thereby eliminating all inequity.[20] At the same time, *ex ante* side-payments do not affect the collusive properties of both EN and FP because they constitute a sunk cost. This result holds true even if *ex ante* side-payments affect the type of subjects who prefer to collude. For instance, *ex ante* side-payments may screen out loss-averse bidders. Because any winning cartel bid above 5 yields a net loss for the designated winner, loss averse subjects might shy away from cartel formation. Another possibility is that *ex ante* side-payments render cartel formation attractive for bidders with a low cumulative income as this may give them the opportunity to 'gamble for resurrection'.[21] Note that Robinson's (1985) results do not rely on (the absence of) loss-aversion or limited liability. So, our hypotheses regarding the stability of cartels are not affected even if *ex ante* side-payments might select a particular types of subjects. All in all, we do not believe the *ex ante* side-payments to systematically bias possible treatment effects. Still, to check for potential income effects, we have run a number of panel data regressions where we control for cumulative earnings (see Appendix C).

We implemented the following auction rules. In FP, in any of the 40 periods, each subject could submit a bid from the set {0, 1, …, 10} or could decide to abstain from bidding. The highest bidder won the auction of that period.[22] Ties were resolved randomly (nobody won the object when all group members decided not to submit a bid). The winner earned the difference between her bid and 10, the common value of the object. In EN, in any period the first auction round was almost the same as in FP, the only difference being that the highest bidder became the provisional winner. In subsequent auction rounds, subjects had to bid strictly higher than the current highest bid (whereby the provisional winner was excluded from bidding in that auction

[20] Our experimental data came reasonably close to these numbers. On average, in the case of deviation in FP [EN] designated losers earned 2.96 [2.68] while designated winners earned -4.66 [-3.73]. In a stable cartels in EN, the designated winner bought the object at an average price of about 3.4, resulting in a net payoff of 1.6, while designated losers would earn 2.5 by construction (we did not observe any stable cartels in FP). Arguably, the observed payoffs in a stable cartel are more equitable than the payoffs in an unstable cartel.

[21] Because designated winners paid the side-payments *ex ante*, subjects' cumulative earnings could end up below their show-up fee of 28 points. At the end of the experiment, we paid subjects the monetary equivalent of 28 points when their final cumulative earnings were below 28 points. As a consequence, subjects were not liable for losses as soon as their cumulative earnings would get below 28 points. In total, 15 subjects (out of 162 subjects that participated in the experiment, including the treatments with fixed matching) ended up below 28 points.

[22] The reserve price is therefore 0. A higher (or more sophisticated) reserve price could be expected to influence the collusive behavior in FP (see Thomas, 2005).

round) or leave the auction. A bidder left the auction when she was not the provisional winner in the previous auction round and when she chose not to submit a bid in the current auction round. Once a bidder had left the auction, she could not submit a bid in later auction rounds of that period. The provisional winner became the auction winner when both other group members had chosen not to submit a bid (anymore) or if she bid 10. The auction winner paid her highest bid, which she had submitted in the penultimate auction round.[23]

The auctions have the following equilibrium properties. In the case of a cartel, EN has a subgame-perfect Nash equilibrium where only the designated winner submits a bid. Specifically, the designated winner bids zero in the first round of the auction and always overbids any other bid by one bid increment until the price reaches 10. Even without forming a cartel, bidders can coordinate on a similar equilibrium by all bidding zero in the first round of the auction and letting the provisional winner play the role of designated winner. Of course, such collusive equilibria demand the designated losers to play a weakly dominant strategy: irrespective of the bidding strategies of others, they are always weakly better off by overbidding others up to a price of 9.[24] Note that EN has other equilibria too, for example a symmetric equilibrium where all bidders bid zero in the first round of the auction and subsequently raise the price up to 9 or 10 in steps of one bid increment. In contrast, FP does not have a subgame-perfect Nash equilibrium where both designated losers abstain from bidding. If both designated losers did so, the designated winner's best response would be to bid zero. But then a designated loser would be strictly better off by entering the auction and bidding 1. In fact, all bidders bidding 9 is the only Nash equilibrium of FP that does not involve the weakly dominated bid of 10.

4. Experimental Results

Figure 1 shows subjects' propensities to collude and to defect over time (where we mark a bidder as defecting from the cartel agreement if, and only if, she submits a bid in the auction while being a designated loser). Table 1 summarizes these data, which we list in Appendix B. To avoid possible learning and end-game effects, we restrict the statistical analyses to periods 6 through

[23] Our design precludes the seller to discriminate between buyers. In particular, we abstain from the possibility that the seller implements a mechanism whereby it becomes less profitable for buyers to collude (see Gruyer, 2009).

[24] Empirically, designated losers were slightly better off by deviating from the cartel agreement than sticking to it. In FP [EN] designated losers earned 2.96 [2.68] on average when deviating while they would have earned 2.5 if they had abstained from bidding, which is significantly less ($p = 0.01$ and $p = 0.00$ for FP and EN respectively)

35.[25] In line with Robinson (1985), we consider a cartel to be stable if, and only if, all bidders stick to the cartel agreement.

Figure 1: Cartel activity over time across auctions

Panel a: Propensity to collude (by subject) Panel b: Propensity to defect (by subject)

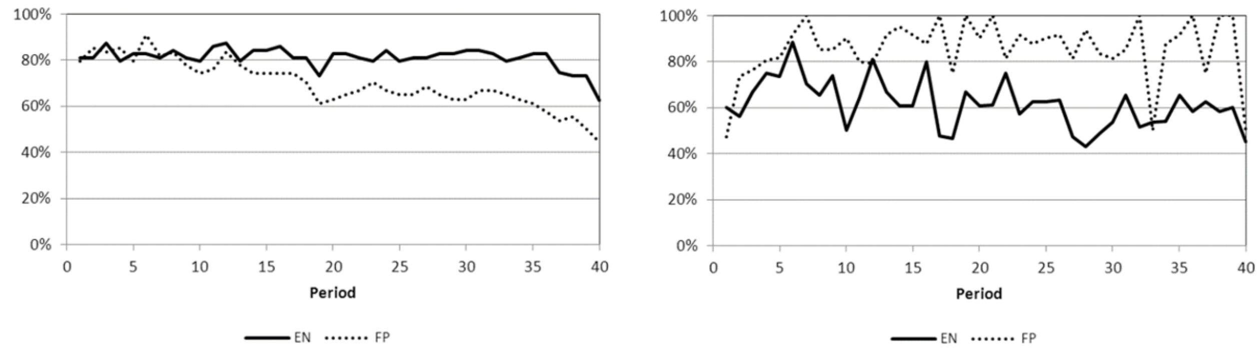


Table 1: Cartel activity across auctions[a]

	Propensity to collude (by subject)	Cartel formation	Propensity to defect (by subject)	Cartel breakdown
EN	0.82	0.57	0.61	0.87
	$\vee^{**}$	$\vee^{***}$	$\wedge^{***}$	$\wedge^{***}$
FP	0.70	0.34	0.89	1.00

[a] Significance levels are calculated with exact Wilcoxon rank-sum tests, counting each re-matching group as one independent observation; ***, ** and * indicate statistical significance at the 1%, 5% and 10% level, respectively; Propensity to collude (by subject) = probability that a subject replies 'yes' to the question 'do you want to form an agreement?'; Propensity to defect (by subject) = probability that a non-designated winner submits a bid; Cartel formation = Probability that all subjects in a group reply 'yes' to the question 'do you want to form an agreement?'; Cartel breakdown = probability that at least one non-designated winner in a cartel submits a bid.

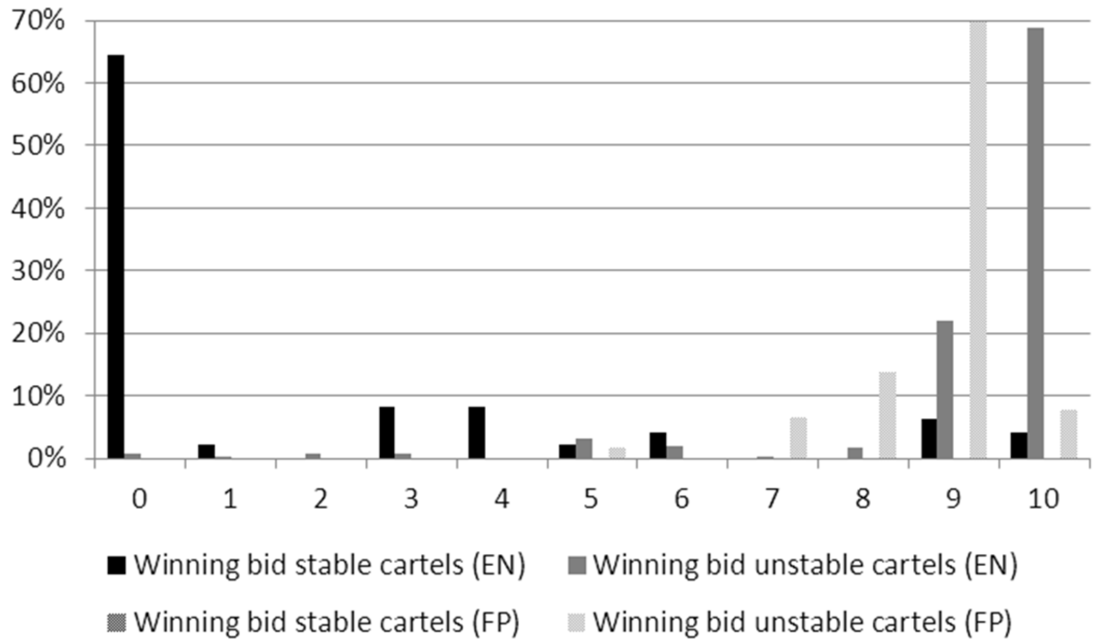
The data show that cartels are more likely to be formed in EN than in FP, and that in EN cartel defection is less likely than in FP. In fact, in FP literally none of the cartels is stable. The latter observation is perfectly in line with the theoretical result of Robinson (1985) that collusion is not incentive compatible in FP. At the same time there is only mild support for his prediction that in

[25] None of the reported results changes qualitatively if we include all periods. In our panel data regressions in Appendix C, we control for possible time trends over all 40 periods.

EN complying to the cartel agreement is incentive compatible: in EN only a small minority of cartels (13%) does not break down.[26]

Figure 2 shows the distribution of the winning cartel bids across auctions. Although our data indicate that EN is more conducive to (stable) cartel formation than FP, an auction designer may still prefer using FP over EN. The reason is that on the aggregate, FP produces virtually the same average revenue as EN but at a much lower variance. More specifically, the average revenue equals 8.96 in FP and 8.95 in EN. The difference is not statistically significant (p = 0.474). The average variance in revenue equals 0.23 in FP and 1.77 in EN, which is significantly different at the 5%-level (p = 0.015). The difference in variances between EN and FP is a direct consequence of the shape of the bid distribution of both cartels and non-cartels. For FP, these are single-peaked with a spike at 9, and contain very few bids below 7. The variance in EN is much higher because stable cartels typically pay 0 while non-cartels and unstable cartels drive the winning bid up to 9 or 10.[27]

Figure 2: Relative frequencies of the winning cartel bids



[26] Appendix C reports the results of panel regressions that accompanies the non-parametric comparisons in Table 1. These regressions control for income effects and end-game effects, and confirm all findings in Table 1, in spite of significant end-game effects and income effects.
[27] Clearly, we do not observe 'endogenous collusion' whereby group behavior evolves to charging the monopoly price without making an agreement (as in Brandts and Guillén, 2007).

To examine the underlying bidding strategies, we have summarized the bids of designated winners and designated losers in Table 2. Not surprisingly, the initial bid of the designated winner in EN does not differ (statistically) between stable and unstable cartels. Indeed, over time initial bids of designated winners are quite stable, as is the probability that the designated winner secures the item (see Figure 3). In line with the strategy suggested by Robinson (1985), in case of cartel defection a bidding war commences: in unstable cartels both the designated winner and designated losers have to continue bidding up to a price of at least 9 to secure the item.[28]

Table 2: Bids[a]

	Designated winner							
	FP			EN				
	Bid, winning		Bid, not winning	Initial bid		Final bid, wining		Final bid, not winning
Stable cartels				3.4	=	3.4		
				∨		$\wedge^{**}$		
Unstable cartels	8.9	$>^{***}$	6.2	1.8		9.5	$>^{***}$	6.2
	Designated losers							
	FP			EN				
	Bid, winning		Bid, not winning	Initial bid		Final bid, winning		Final bid, not winning
Unstable cartels	8.7	$>^{***}$	7.9	4.6		9.1	$>^{***}$	7.1

[a] Significance levels are calculated with exact Wilcoxon rank-sum tests, counting each matching group as one independent observation; ***, ** and * indicate statistical significance at the 1%, 5% and 10% level, respectively.

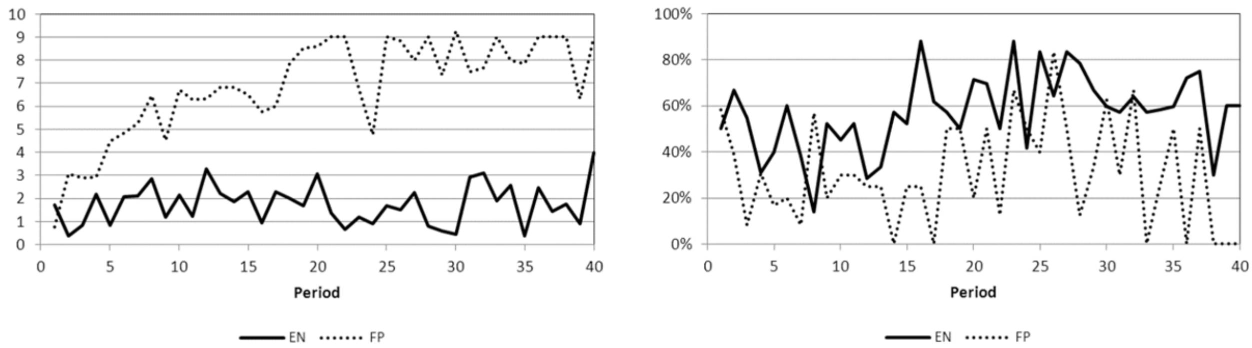
The winning bids in FP are close to the equilibrium predictions too. To secure the item a bid of about 9 has to be submitted. As a consequence, it hardly pays to form a cartel: all cartels break down, and on average cartels manage to reduce the winning bid from 9.1 to 8.7 only, a drop that is statistically significant though (p = 0.004). The pattern of increasing bids in FP in Figure 3

[28] Also the winning bid of the designated loser differs significantly from that of the designated winner in stable cartels (p = 0.064).

suggests that subjects learn in FP. In the early rounds designated winners submit low bids, much in line with the cartel agreement. However, by doing so, they have a low probability of securing the item. They respond by increasing their bids over time, which subsequently hover around 9 as of period 20.[29]

Figure 3: Designated winner's (initial) bids (panel a) and probabilities of securing the item (panel b), over time across auctions

Panel a Panel b



5. REPEATED INTERACTION

In the previous section, we observed that cartels are more likely to be stable in EN than in FP, but not as much as suggested by Robinson (1985); also in EN the majority of the cartels break down. Therefore, we next follow up on Robinson's remark that more cartels may become stable in either auction because "[p]otential cheaters may be deterred by the loss of long-run profits" (Robinson, 1985, p. 145). In four additional sessions, we examine the collusive properties of EN and FP in the case of repeated interaction.[30] At the beginning of each session groups of three

[29] In FP, the average winning cartel bid over periods 20 through 35 of designated winners and losers is 9.3 and 9.1 respectively. Still, the probability that the designated winner secures the item in FP is only 29%, which is significantly below the concomitant 59% in EN (p = 0.003). Further, Appendix C reports panel data regressions that examine bidding behavior over time in both auctions, correcting for end-game effects. These regressions show that in both auctions, the winning bids converge to at least 9 for non-cartels and unstable cartels, which corresponds to the one-shot Nash equilibrium in non-dominated strategies. For stable cartels in EN, winning bids tend to be higher than the equilibrium prediction of zero. However, note that the difference between the observed winning bid and the theoretical prediction of zero is not significant in a statistical sense.

[30] Indeed, in practice cartels often center around a set of bidders that interact repeatedly (Phillips *et al*., 2003). Note that repeating the auction does not affect the collusive properties of EN; cartels remain stable in equilibrium. However, from the theory of supergames (Friedman, 1971), it follows that stable cartels may form in FP too if the auction is repeated an infinite number of periods and if bidders are 'patient enough' (Aoyagi, 2007; see also Fabra, 2003). A stable cartel emerges in equilibrium if bidders play a grim strategy that tells the designated losers to abstain from bidding and the designated winner to bid zero in all periods up to the point that some bidder deviates. From then all, all bidders bid 9 or 10 in all subsequent periods.

subjects were formed that did not change over the course of the 40 periods.[31] All other aspects of the experimental procedures were unchanged. 24 [21] subjects participated in FP [EN] yielding eight [seven] independent observations.[32]

Tables 3 and 4 summarize the results on cartel activity. Compared to the case of re-matching, in FP cartels are more likely to be formed and cartels that form are less likely to break down, while only cartel stability is enhanced in EN. In addition, the two auctions no longer differ statistically in terms of cartel formation and cartel stability.[33]

Table 3: Cartel activity across treatments[a]

	FP		EN	
	Propensity to collude	Propensity to defect	Propensity to collude	Propensity to defect
Re-matching	0.70	0.89	0.82	0.62
	∧***	∨***	∧	∨***
Fixed matching	0.91	0.43	0.87	0.26

[a] Significance levels are calculated with exact Wilcoxon rank-sum tests, counting each (matching) group as one independent observation; ***, ** and * indicate statistical significance at the 1%, 5% and 10% level, respectively.

Table 4: Cartel activity across auctions, fixed matching[a]

	Propensity to collude (by subject)	Cartel formation	Propensity to defect (by subject)	Cartel breakdown
EN	0.87	0.72	0.26	0.46
	∧	∧	∧	∧
FP	0.91	0.76	0.43	0.58

[a] Significance levels are calculated with exact Wilcoxon rank-sum tests, counting each group as one independent observation; ***, ** and * indicate statistical significance at the 1%, 5% and 10% level, respectively.

[31] An alternative would have been to implement a random stopping rule. However, collusive play in a finitely repeated-game setting is typically observed until the last couple of periods (Selten and Stoecker, 1983). In our experiment we also observe end-game effects, and, again, use periods 6 through 35 only in the statistical analyses.

[32] Subjects earned € 24.82 on average in sessions that lasted, again, between 60 and 90 minutes.

[33] Again, panel regressions that also take potential income effects and end-game effects into account confirm the non-parametric comparisons in Table 4; see Appendix C.

Table 5: Bids, fixed matching[a]

	Designated winner							
	FP			EN				
	Bid, winning		Bid, not winning	Initial bid		Final bid, winning		Final bid, not winning
Stable cartels	2.4			0.0	=	0.0		
	^**			^		^**		
Unstable cartels	5.4	>**	2.5	2.2		5.9	>	4.3
	Designated losers							
	FP			EN				
	Bid, winning		Bid, not winning	Initial bid		Final bid, winning		Final bid, not winning
Unstable cartels	4.6	>	4.2	1.9		8.5	>**	3.5

[a] Significance levels are calculated with exact Wilcoxon rank-sum tests, counting each group as one independent observation; ***, ** and * indicate statistical significance at the 1%, 5% and 10% level, respectively.

Table 5 lists the average bids of designated winners and designated losers in case of fixed matching.[34] There are some marked differences compared to the re-matching case. In EN, the initial bids of both the designated winner and the designated losers are lower than in the case of re-matching ($p = 0.013$ and $p = 0.015$ respectively). In fact, stable cartels manage to obtain the item for the joint-profit maximizing price of zero. As a result, designated winners pay less in stable cartels than in the re-matching case. Similarly, the designated winner has to pay less than 3.4 to secure the item in unstable cartels ($p = 0.046$), and considerably less than 10. At the same time, designated losers have to pay the same, high price to be the auction winner ($p = 0.635$). Designated winners thus continue bidding in a pricing war until the provisional winning bid is at least 9, unless they themselves are the provisional winner. Designated losers, on the other hand, quit the bidding war earlier, which is also supported by the (statistically weakly) lower non-

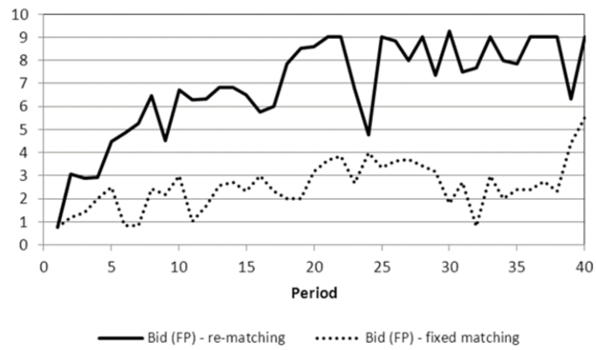
[34] The panel regressions in Appendix C show that over time for both auctions the winning bids move towards the theoretically optimal price of zero in case of stable cartels. Unstable cartels converge to winning bids below to the price of 9 that would result when bidders played the one-shot Nash equilibrium in non-dominated strategies.

winning final bid of designated losers (p = 0.063). One interpretation of this bidding pattern is that designated losers want to maintain the collective understanding of the cartel strategy because in any future period they could be the designated winner.

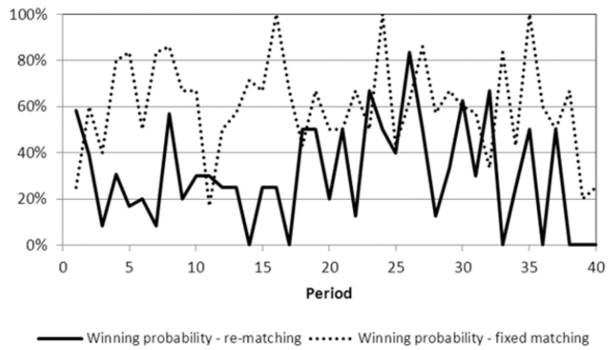
In FP with fixed matching, it is attractive to form a cartel in contrast to the re-matching case. Stable cartels now emerge, and designated winners of these cartels pay less than the winning bids of designated winners and losers in unstable cartels.[35] This suggests that the threat of future retaliation disciplines designated losers. As a result, designated winners are more confident that a low bid will secure them the item, which is indeed the case (see Figure 4).[36]

Figure 4: Designated winner's bids (panel a) and probabilities of securing the item (panel b) in FP, over time and across treatments

Panel a



Panel b



6. CONCLUSION

In his book on competition policy, Massimo Motta (2004) writes that "it is better to try to create an environment that discourages collusion in the first place than trying to prove unlawful behavior afterwards. A clear advantage of auction markets is that the environment can be affected directly, since the rules of the game are specified at the beginning by the auctioneer" (Motta, 2004, p. 192). Robinson's (1985) theoretical result that collusion is stable EN and not in FP would suggest that auction designers should follow the OECD's advice to use FP rather than EN in environments "where collusion is a significant threat". In this paper, we have tested

[35] Note that the winning bids of the designated winner and designated losers in unstable cartels do not differ (p = 1.000).

[36] The designated winners' bid with fixed matching is below that with re-matching (p = 0.002) while the probability of securing the item by the designated winner increases due to fixed matching (p = 0.010).

Robinson's (1985) theory. Our data partly confirm Robinson's (1985) prediction: some cartels are stable in EN while in FP all cartels break down. In addition, we observe that more cartels form in EN than in FP and stable cartels in EN obtain the item for a price well below its value.

However, our data also reveal several patterns that are not predicted by Robinson's (1985) theory. First of all, if observations from both cartels and non-cartels are taken together (which would apply if an auction designer is not able to distinguish between cartels and non-cartels), there appears to be no significant difference in average revenue between FP and EN. Second, we find that the price variability is much lower in FP than in EN. Risk-averse auction designers may therefore prefer FP over EN, which might be particularly relevant for governments designing license auctions and that are reluctant to accept the possibility of low revenues. Note that our result is in line with the general observation that the variance of revenue is higher in EN than in FP.[37] However, in our design information asymmetry, the usual suspect of price variability, does not play a role. In other words, our results identify the possibility to form a cartel as another potential driver of the difference in price variability between FP and EN. Third, in the case of repeated interaction, the two auctions no longer differ in terms of cartel stability. This might explain why also FP has featured in discovered cartels, because in practice it is quite common that the same set of bidders interact repeatedly. Finally, it takes subjects longer to 'learn' how to play in FP than in EN. In FP, we have observed a marked upward price trend while such trend was virtually absent in EN. To us, it is an open question why the auctions differ in this respect, but this observation indicates that an auction designer facing inexperienced bidders may prefer EN over FP. All in all, our findings suggest that unless the auction designer believes collusion to be a significant threat, the choice between EN and FP should primarily be led by considerations other than their respective collusive properties, such as the lower vulnerability to the winner's curse of EN or the lower price variability in FP.

We believe our experiment design to offer a conservative test of Robinson's (1985) theory. As Robinson (1985) notes, in EN cartels are only weakly incentive compatible: because the costs of entering the auction is zero, the designated losers are indifferent between entering the auction or not. In fact, for all bidders, abstaining from bidding is weakly dominated by entering the auction. Our design thus favors the alternative hypothesis that cartels are equally (un)stable in both auctions, which makes it less likely to observe treatment effects that depend on cartel

[37] See, e.g., Waehrer *et al*. (1998) for a theoretical result and Coppinger *et al*. (1980) for experimental support.

stability. Indeed, entry costs and *ex post* side payments would further stabilize cartel agreements in EN while not making cartel agreements incentive compatible in FP (Robinson, 1985, p. 144).[38] Future experimental research might provide further insights regarding the collusive properties of FP and EN. This includes the timing of side payments (*ex post* versus *ex ante*), the role of entry costs, and the assumption of all-inclusive cartels.

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[38] In practice, bidders typically incur at least some entry costs when entering a bid (Levin and Smith, 1994) and side-payments are mostly *ex post*: "[o]ften a bidding cartel will organize itself so that payments are only required from a cartel member who wins the object, with nonwinning cartel members receiving payments from the cartel" (Marshall and Marx, 2009, p. 885; see Asker, 2010, for an example of *ex post* side-payments).

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APPENDIX A: INSTRUCTIONS

The instructions are computerized. Subjects could read through the html-pages at their own pace. Below is a translation of the Dutch instructions for the English auction.

Welcome!

You are about to participate in an auction experiment. The experiment consists of **40 rounds** and each round consists of **2 steps**. Those steps are the same in each round and will be explained later in more detail.

In every round of the experiment, all participants will be randomly divided in **groups of 3** members. This will be done in such a way that participants will never be in the same group in two subsequent rounds; at the beginning of every round, you will be matched with two other participants than in the previous round.

Group members remain anonymous; you will not know with whom you are matched. Moreover, there will not be contact between separate groups during any round.

Earnings

In every round of the experiment, you can earn points. At the end of the experiment, points will be exchanged for Euros. The exchange rate will be

1 point = € 0.25

At the beginning of the experiment, you will receive a **starting capital** of **28 points**. At the end of every round, the points you will earn in this round will be added to your capital. If you earn a negative number of points in a round, these points will be subtracted from your capital.

In the remainder of these instructions, we will present an overview of the experiment followed by a further explanation of a single round. We will conclude with examples and test questions.

Overview of the experiment

You aim at buying a product in an **auction**, just like the other two members of your group. Only 1 item of the product is available in each round. In every round, you can bid in an auction.

In **step 1** of the experiment, you will get the opportunity to make an **agreement** with your group members about who will win the auction. An agreement will only be made if all group members desire to do so. An agreement is not binding, though.

In **step 2**, you and the other two group members will bid in the auction. You will earn points if you win the auction. If you win, the number of points that you earn in the auction will be equal to

10 – your winning bid

Now, an explanation of both steps follows.

Step 1: Agreement

In step 1 of every round, you will be asked the following question: “Would you like to make an agreement? If yes, press the YES button. If not, press the NO button.” You must answer YES or NO. The other two group members will have to make the same decision at the same time.

If all group members choose YES, an agreement will be made. The agreement will be that only one of the three group members will submit a bid. The others will not bid.

Chance determines who of the three group members will submit a bid according to the agreement. This agreement is not binding, though.

If one or more group members press the NO button, there will not be an agreement.

The group member the computer picks out to submit a bid, will pay the two other group members 2.5 points, so 5 points in total.

Step 2: The auction

The auction consists of several rounds. The winner of the auction obtains 10 points. You do not have to stick to an agreement (if any). This also holds true for the other two group members.

In every auction round, you can submit a bid by entering one of the following numbers:

0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

You can also indicate not to enter any number. If you decide to do so, you will step out of the auction and you cannot submit a bid in later rounds of the auction.

In every round of the auction, bidders can only choose a higher number than the currently highest bid. The bidder with the current highest bid is the **provisional winner** of the object. In the case of identical highest bids, chance determines who of the highest bidders will become the provisional winner.

In each round of the auction, the provisional winner cannot submit a bid. Only the other group members can do so.

The provisional winner will **win the auction** if the other group members decide not to enter a number. In that case, the winner will pay his highest bid (entered in the previous round). The earnings in the auction for the winner is then equal to

10 – winning bid

A bid of 10 guarantees that someone wins the auction, provided that none of the other bidders has also submitted a bid of 10. If several group members bid 10, chance determines who will win the auction.

If all group members decide not to submit a bid in the first round, nobody will win the object.

APPENDIX B: (MATCHING) GROUP AVERAGES OVER TIME

Re-matching				Fixed matching			
Propensity to collude		Propensity to defect		Propensity to collude		Propensity to defect	
EN	FP	EN	FP	EN	FP	EN	FP
0.81	0.80	0.60	0.58	0.71	1.00	0.00	0.38
0.81	0.85	0.56	0.94	0.86	0.88	0.38	0.20
0.87	0.83	0.67	1.00	0.71	0.88	0.25	0.50
0.79	0.85	0.75	1.00	0.76	0.88	0.13	0.40
0.83	0.80	0.73	1.00	0.86	0.92	0.00	0.25
0.83	0.91	0.88	1.00	0.90	0.92	0.10	0.33
0.81	0.81	0.70	1.00	0.81	0.92	0.00	0.33
0.84	0.83	0.65	1.00	0.95	0.96	0.42	0.29
0.81	0.78	0.74	1.00	0.90	0.92	0.20	0.33
0.79	0.74	0.50	1.00	0.86	0.92	0.40	0.42
0.86	0.76	0.64	1.00	0.76	0.92	0.13	0.42
0.87	0.83	0.81	1.00	0.86	0.92	0.25	0.50
0.79	0.78	0.67	1.00	0.86	0.96	0.10	0.43
0.84	0.74	0.61	1.00	0.95	0.96	0.33	0.43
0.84	0.74	0.61	1.00	0.86	0.92	0.20	0.42
0.86	0.74	0.80	1.00	0.86	0.92	0.50	0.42
0.81	0.74	0.48	1.00	0.86	0.92	0.25	0.33
0.81	0.70	0.46	1.00	0.81	0.96	0.20	0.36
0.73	0.61	0.67	1.00	0.90	0.92	0.25	0.42
0.83	0.63	0.61	1.00	0.81	0.92	0.20	0.50
0.83	0.65	0.61	1.00	0.81	0.92	0.13	0.58
0.81	0.67	0.75	1.00	0.81	0.92	0.13	0.42
0.79	0.70	0.57	1.00	0.86	0.92	0.10	0.42
0.84	0.67	0.63	1.00	0.90	0.92	0.20	0.50
0.79	0.65	0.63	1.00	0.90	0.96	0.17	0.50
0.81	0.65	0.63	1.00	0.86	1.00	0.10	0.38
0.81	0.69	0.47	1.00	0.86	0.96	0.13	0.21
0.83	0.65	0.43	1.00	0.95	0.96	0.08	0.50
0.83	0.63	0.49	1.00	0.90	0.88	0.17	0.33
0.84	0.63	0.54	1.00	0.86	0.88	0.20	0.40
0.84	0.67	0.65	1.00	0.90	0.96	0.00	0.29
0.83	0.67	0.51	1.00	0.90	0.92	0.08	0.42
0.79	0.65	0.54	1.00	0.95	0.92	0.08	0.17
0.81	0.63	0.54	1.00	0.90	0.96	0.25	0.43
0.83	0.61	0.65	1.00	0.86	0.88	0.20	0.20
0.83	0.57	0.58	1.00	0.90	0.88	0.17	0.30
0.75	0.54	0.63	1.00	0.95	0.83	0.17	0.50
0.73	0.56	0.58	1.00	0.95	0.79	0.25	0.50
0.73	0.50	0.60	1.00	0.95	0.83	0.33	1.00
0.63	0.44	0.45	1.00	0.86	0.71	0.40	1.00

APPENDIX C: PANEL REGRESSIONS

C1: COLLUSION AND DEFECTION PROPENSITIES

We estimate a random effects binomial logit model to explain the individual decision to collude or not, whereby we explicitly control for possible within-group correlations:

$$c_{jit}^{*X} = \beta_0 + \beta_1 CE_{jit-1}^X + \beta_2 DF_{jit}^X + \beta_3 CE_{jit-1}^X \times DF_{jit}^X + \beta_4 E_t(t-35) + \varepsilon_{jit}^X + u_i^X,$$
$$c_{jit}^X = 1 \Leftrightarrow c_{jit}^{*X} \geq 0,$$

$j = 1,2,3$, $i = 1,2,\ldots,n^X$, $t = 1,\ldots,40$, where n^X is the number of subjects in case of $X \in \{\text{re}-\text{matching, fixed matching}\}$, with $c_{jit}^X = 1 \Leftrightarrow$ subject j in group i is in favor of collusion in period t in case of X, CE_{jit}^X is the cumulative earnings (in euros) of subject j in group i at the end of period t in case of X, $DF_{jit}^X = 1 \Leftrightarrow$ the observation concerns FP, and $E_t = 1 \Leftrightarrow$ the observation concerns the final five rounds. The error terms ε_{jit}^X and u_i^X are iid according to a normal distribution with zero mean whereby u_i^X captures the panel structure of the data. A comparable regression applies for the decision to defect. The regression results are in Table C1.

Table C1: ML-estimates for the decision to collude and to defect[a]

	Propensity to collude		Propensity to defect	
	Re-matching	Fixed matching	Re-matching	Fixed matching
Constant	0.31*** (0.13)	0.48 (0.32)	0.06 (0.19)	-1.09** (0.44)
Cumulative earnings	0.09*** (0.01)	0.08*** (0.02)	0.03** (0.01)	0.00 (0.01)
FP	-1.22*** (0.19)	0.65 (0.40)	1.00** (0.40)	0.21 (0.58)
Cumulative earnings × FP	0.07*** (0.02)	-0.05*** (0.02)	-0.01 (0.03)	0.03 (0.02)
Final periods	-0.18*** (0.02)	-0.17 (0.04)	-0.06 (0.04)	0.22*** (0.05)
LR-test for random effects	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$

[a] Standard errors are within parentheses; ***, **, and * denote statistical significance at the 1%, 5%, and 10% respectively; standard errors are clustered at the group level.

C2: WINNING BIDS

We estimate a random effects model to examine convergence over time of the winning bids, whereby possible within-group correlation is controlled for:

$$b_{jit}^{X} = \beta_0 - \beta_1 T1_t^X + \beta_2 T2_t^X + \varepsilon_{jit}^X + u_i^X,$$

$j = 1, 2, 3$, $i = 1, 2, \ldots, n^X$, $t = 1, \ldots, 40$, where n^X is the number of subjects in case of X ∊ {re-matching and FP, fixed matching and FP, re-matching and EN with stable cartels, re-matching and EN with unstable cartels, fixed matching and EN with stable cartels, fixed matching and EN with unstable cartels}, where b_{jit}^X is the (winning) bid of subject j in group i in case of X, $T1_t^X = \max\{0, 35 - t\}$, and $T2_t^X = \max\{0, t - 35\}$. The error terms ε_{jit}^X and u_i^X are iid according to a normal distribution with zero mean whereby u_i^X captures the panel structure of the data. Note that inclusion of the latter two explanatory variables implies that the estimated value of β_0 corresponds to the value of the winning bid to which the bidding behavior converges in period 35. The regression results are in Table C2.

Table C2: ML-estimates of the winning bid[a]

	EN					
	Re-matching			Fixed matching		
	Non-cartels	Stable cartels	Unstable cartels	Non-cartels	Stable cartels	Unstable cartels
Constant	9.85***	3.02	9.50***	9.47***	0.00	6.25***
	(0.05)	(1.86)	(0.20)	(0.25)	(0.05)	(1.27)
Time trend periods 1-35	-0.01***	-0.02	0.02**	0.01	-0.00*	0.01
	(0.00)	(0.03)	(0.01)	(0.01)	(0.00)	(0.06)
Time trend periods 36-40	-0.02	0.21	-0.00	0.13	0.00	0.12
	(0.02)	(0.24)	(0.11)	(0.13)	(0.02)	(0.50)
	FP					
	Re-matching			Fixed matching		
	Non-cartels	Stable cartels	Unstable cartels	Non-cartels	Stable cartels	Unstable cartels
Constant	9.38***		10.24***	9.39***	1.91**	6.28***
	(0.08)		(0.23)	(0.19)	(0.97)	(0.63)
Time trend periods 1-35	-0.03***		0.10***	-0.01	-0.02*	0.11***
	(0.00)		(0.01)	(0.01)	(0.01)	(0.02)
Time trend periods 36-40	-0.07		-0.30***	0.01	1.01***	0.01
	(0.02)		(0.12)	(0.06)	(0.39)	(0.16)

[a] Standard errors are within parentheses; ***, **, and * denote statistical significance at the 1%, 5%, and 10% respectively; standard errors are clustered at the group level.