SOME RESULTS ON ANTI-COMPETITIVE BEHAVIOR IN MULTI-UNIT ASCENDING PRICE AUCTIONS

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Anti-competitive behavior is a concern for economists since, if occurs, it is detrimental for the performance of market institutions in terms of both social efficiency and auctioneer's revenue. Traditionally, experimentalists investigated possibilities of anti-competitive behavior in (1) two-sided auction markets trading multiple units and (2) single-unit one-sided auctions (see Holt (1995) and Kagel (1995) for reviews, and also Cason's chapter in this volume). A number of recent experimental studies turned to one-sided multi-unit auctions. The interest is generated by both theoretical developments in auction theory, and by the growing use of multi-unit auction mechanisms in practice, such as government procurement and privatization programs and internet auctions.

Two frequently discussed kinds of anti-competitive behavior in multi-object auction markets are demand reduction and bidder collusion. Although the two are closely interrelated, distinction is often made along the following lines. Demand reduction occurs due to monopsony power of a buyer demanding multiple units of a homogeneous good in a uniform price auction. The buyer is essentially able to affect auction prices through reducing his or her demand. Coordination among buyers may not be necessary.[1] (Related earlier studies are market power experiments in two-sided auctions; e.g., Holt et al, 1986; Davis and Williams, 1991.) Bidder collusion involves explicit or implicit coordination among more than one bidders demanding single or multiple units of a homogeneous or heterogeneous goods, usually in an attempt to suppress price competition. (Earlier studies focus on successful or unsuccessful attempts of bidder collusion in single-unit auctions and double auction markets; e.g., Isaac and Walker, 1985; Isaac and Plott, 1981; Clauser and Plott, 1993).

Depending on the environment and institutional details, demand reduction and bidder collusion may occur under both ascending-price and sealed bid type markets. Here we focus on ascending auction institutions. Many researchers argue that, due to a richer action space and a superior information feedback that bidders get in the process of bidding in ascending auctions, these institutions have an advantage over the sealed bid procedures in solving complex allocation problems efficiently (such as allocation of airwave licenses; McAfee and McMillan, 1996). However, it is also well recognized that these very features of ascending auctions make them more susceptible to anti-competitive behavior (Milgrom, 1987; Cramton and Schwartz, 2000). The reason is two-fold. First, some anti-competitive outcomes may be supported as equilibria in the ascending auctions, but not in their sealed-bid analogs (Milgrom, 1987; Brusco and Lopomo, 1999). Second, in cases where the same outcome may result from equilibrium play in both

[•] I thank Jeremy Dulatre for research assistantship.

[1] In other cases, several bidders need to coordinate on a demand reduction equilibrium, and distinction between demand reduction and collusion becomes less pronounced; see, e.g., Grimm and Engelmann (2001) discussed below.

institutions, dynamic features of ascending auctions may allow bidders to learn their equilibrium strategies better.[2]

In this review we discuss whether experimental research on multi-unit auctions supports the above claims. The focus is on ascending price auctions; results on the sealed bids are mentioned only for comparison. Unless stated otherwise, we consider independent private value auctions.

Experiments on demand reduction

With the research extending from single-unit to multi-unit auctions, the first question was whether and when desirable efficiency properties of single-unit auctions generalize to multiple units. Vickrey (1961) provided an original theoretical insight that this is the case for the English and sealed bid uniform-price auctions as long as each bidder has use for at most one unit. McCabe et al. (1990) confirm, theoretically and experimentally, that with single-unit demands, the properties of English and Dutch clock auctions generalize to uniform-price multiple-unit institutions.[3]

Vickrey also made it clear that if bidders demand multiple units of the good, the strong incentive properties of single-unit English (and second price) auctions do not carry over to uniform-price multi-unit auctions: "It is not possible to consider a buyer wanting up to two units as merely an aggregation of two single-unit buyers: combining the two buyers into one introduces a built-in collusion and community of interest, and the bid offered for the second unit will be influenced by the possible effect of this bid on the price to be paid for the first, even under the first-rejected-bid method" (p. 27). This insight was later developed by theorists (Noussair, 1995; Ausubel and Cramton, 1996; Engelbert-Wiggans and Kahn, 1998) and tested by experimentalists, who confirmed that multi-unit uniform-price institutions create incentives for demand reduction. Uniform-price K-unit English clock (EC) and sealed bid (SB) auctions work as follows. In the EC auction, the price starts at zero and then increases by small increments; bidders report their quantities demanded at each price. The bidders are informed about the total demand at current price. The auction stops when there is no excess demand, and the uniform market-clearing price is then charged for every unit sold. In single-unit demand environments, each bidder has a dominant strategy to drop out of bidding once the price reaches his value; the outcome is therefore efficient with the price approximately equal to $(K+1)$st highest valuation. With multi-unit demands, however, there may be incentives for bidders to reduce their demands, i.e., to drop out of bidding on lower-valued units early in order to buy higher-valued units at lower prices. In the SB auction, each subject submits sealed bids for every unit they wish to buy; K highest bids win the auction at the price equal to the highest rejected bid (or the lowest accepted bid). Similarly to the EC institution, the equilibria in the SB auctions under single-unit demands result in efficient allocations, whereas under multi-unit demands, there may exist strategic incentives to

[2] Thus in single-unit auctions, ascending (English) and sealed bid second price auctions are strategically equivalent: it is a dominant strategy for bidders to bid according to their true value in both institutions. Yet, while observed behavior in English auctions closely conforms to the theory, overbidding is a persistent phenomenon in the second price auctions. A likely reason is that dynamic nature of the English auction makes the dominant strategy more transparent than in the second price auction (Davis and Holt, 1993; Kagel, 1995).

[3] See also Cox et al. (1984). McCabe et al. (1988) report that open outcry auctions for multiple units are not as well behaved as their English clock analogs due to "jump bidding." Isaac and James (2000) confirm that strong incentive properties of the sealed bid Vickrey auctions hold in combinatorial auctions with multiple heterogeneous units.

understate bidder willingness to pay for lower valued units, resulting in inefficiency and decreased seller revenue.[4]

Alsemgeest et al. (1998) were the first to observe the demand reduction phenomenon in the experimental laboratory.[5] They conducted multi-unit English clock (EC) auctions and sealed bid (SB) auctions with lowest-accepted-bid pricing, in both single-unit and two-unit demand environments, in markets with either six or three bidders. Alsemgeest et al. observed that whereas the outcomes of the EC under single-unit demands confirmed to the competitive prediction, there was a considerable amount of under-revelation under the two-unit demands: subjects attempted to influence prices by exiting the bidding process at prices below their valuations. Consequently, the EC generated less revenue under the two-unit demand than under the single-unit demand environment. Consistent with the theory, under-revelation most frequently occurred for the lower-valued unit in the two-unit demand environment. Interestingly, the authors observed no under-revelation in the two-unit demand environments in the SB auctions; the revenues and efficiencies in the SB were not significantly different between the single- and two-unit demand environments.[6]

Kagel and Levin (2001a) further study demand reduction in uniform price EC and SB auctions. They employed a design which freed the environment of strategic uncertainty regarding other bidders' behavior: In their two-unit auctions, a human subject with a flat demand for two units competed with a number of computer rivals with single-unit demands; the computer rivals were programmed to follow their dominant strategy of bidding according to their true value. The environment was chosen so that both EC and SB uniform price auctions yielded the same equilibrium prediction, with the human bidder bidding according to the true value on the first unit, and reducing demand to zero on the second unit. Kagel and Levin observe substantial demand reduction in both EC and SB auctions. However, similarly to earlier studies of single-unit auctions (Kagel et al. 1987; Kagel and Levin, 1993), they find that the behavior in the EC is closer to the equilibrium prediction than in the SB; see figure 1, sessions 3 and 5. Additional variations on the EC and SB were then considered to study how the features of the English auction help bidders better learn the equilibrium strategies. The outcomes of these treatments[7] allowed to conclude that "the closer conformity to equilibrium outcomes in the clock auctions results from both the information inherent in observing others' drop out prices and the ability of the clock to provide this information in a highly salient way" (p. 414).

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[4] We illustrate incentives for demand reduction with the following complete information example. Suppose that a bidder in the EC uniform-price auction demands two units, which he values at 70 each, and his only competitor demands one unit, which she values at 50. Two units are offered for sale. Assume the bidder demanding a single unit bids according to her valuation, which is her dominant strategy. If the bidder demanding two units bids for both units, the auction stops with his competitor dropping out at the price of 50, and the bidder gains 40 in profits. However, he can do better by dropping out of bidding for the second unit at the very start of the auction; the auction then stops at the price of zero, yielding this bidder the profit of 70.

[5] Miller and Plott (1985) studied multi-unit demand uniform and discriminative price sealed bid auctions. Under their design, there was no incentives for demand reduction for bidders.

[6] Theoretical properties of the sealed bid uniform price auctions under multi-unit demands were unknown at the time the study was conducted.

[7] "Outcomes in the clock auction with no feedback are essentially the same as in the sealed bid auctions… Sealed bid auctions with the second highest computer value announced begin to approach behavior in the clock auctions with feedback once the environment is structured so that the information inherent in announcing the computer's value is more salient" (p. 451).

[FIGURE 1 AROUND HERE: From Kagel and Levin (2001a), figs 3, 6 and 8.]

Kagel and Levin also compare the bidding behavior in the uniform price auction with the Ausubel, or dynamic Vickrey, auction (Ausubel, 1997) designed to eliminate the demand reduction incentives. The latter auction works similarly to the EC ascending price auction, except winning bidders in the Vickrey auction do not pay a common price, but the price at which they have "clinched" an item (see Ausubel for details). Thus a bidder in the dynamic Vickrey auction cannot affect the price he pays for one unit by misrepresenting demand for another unit. In equilibrium, the auction results in full demand revelation and full efficiency.

Kagel and Levin report that the dynamic Vickrey auction does eliminate demand reduction and thus improves efficiency as compared to uniform-price auctions (figure 1, session 9). However, they find that it raises less average revenue than the uniform price SB auctions, due to the bidders in the SB auction bidding less strategically than the theory predicts. They conclude that "there is a potential tradeoff between revenue and efficiency, unanticipated theoretically between the dynamic Vickrey auction and the uniform price sealed bid auction" (pp. 452-3).

In a related paper, Kagel and Levin (2001b) investigate demand reduction incentives in multi-unit demand uniform price EC and SB auctions in environments with synergies. They observe less demand reduction in the EC uniform price auctions in the environment with synergies than in the no-synergy environment, and also find that demand reduction decreases with an increased number of rivals. As in the previous study (Kagel and Levin, 2001a), the behavior is closer to the equilibrium play in the EC than in the SB auctions, but there is a large amount of out-of-equilibrium behavior under both institutions. The EC in these experiments not only generate less revenue than SB auctions, but they are also no more efficient.

Porter and Vragov (2000) compare Vickrey and uniform-price sealed bid (SB) with the English clock (EC) multi-unit auctions.[8] Unlike Kagel and Levin (2001a), they use a setting with two human bidders, each demanding two units, competing in a market with a total supply of two units. They also find that EC results in more demand reduction than other institutions. As an explanation, Porter and Vragov hypothesize that "the low information content in sealed bid auctions tempers the amount of demand reduction that actually occurs."

Grimm and Engelmann (2001) investigate a similar setting, where two human bidders with a flat demand for two units each compete in a market with a total supply of two units. They compare five different multi-unit auction formats, including uniform EC and SB auctions, Ausubel auction, as well as sealed-bid Vickrey and discriminative auctions. An interesting feature of Grimm and Engelmann is that in their setting, the uniform price EC and SB auctions are characterized by multiple equilibria, including the truthful revelation, or the "incentive compatible" (IC) equilibrium which prescribes bidding according to the true value on both units, as well as the full demand reduction (DR) equilibrium, which prescribes reducing bidders'

[8] Porter and Vragov also test the robustness of the findings of List and Lucking-Reiley (2000), who compared demand reduction in uniform price sealed bid and Vickrey auctions in a field internet experiment. Their results are largely consistent with List and Lucking-Reiley.

demands on the second unit down to zero.[9] Grimm and Engelmann report that three out of ten pairs in uniform EC auctions played almost the DR equilibrium strategy; in almost half of the cases bidders in the EC auctions acted in line with demand reduction incentives and dropped out of bidding on one unit immediately after the other bidder's drop-out. Given that bidders in these experiments played ten auctions only and did not have much time to learn to coordinate on DR equilibrium, the amount of demand reduction appears to be quite substantial. Slightly less demand reduction was observed in the uniform SB auction, with the bids often being noisier and further away from equilibrium than in the EC auctions. Grimm and Engelmann also report that Ausubel auctions exhibited more truthful bidding and higher efficiency than any other institutions considered, although some demand reduction was observed in the Ausubel auctions as well.

Manelli, Sefron and Wilner (2000) consider two mechanisms which, theoretically, are not subject to demand reduction incentives. They compare Vickrey and Ausubel mechanisms in a 3-unit supply environment with 3 bidders, each demanding 2 units, in both private value and common value component environment. With private values, sincere bidding is an equilibrium in both mechanisms, and they should both yield, in theory, the same revenue and efficient allocations. Manelli et al. report that neither mechanism conforms to the theoretical predictions. There was significant overbidding on the first unit in both Vickrey and Ausubel auctions (with more overbidding in Vickrey), and some underbidding (demand reduction) on the second unit in Vickrey auctions. Further, Ausubel auction exhibited another, unexpected, type of aggressive bidding. In the experiments, all bidders were allowed to demand up to three units, even though the third unit always had a value of zero. In Ausubel auctions bidders often bid for all three units until they secured the two units they desired; this sometimes led to a bidder acquiring all three units, leading to "too concentrated" allocations and therefore disturbing the efficiency. Manelli et al. note that while the amount of overbidding in Vickrey auctions was sensitive to small variations in the environment, aggressive over-demanding in Ausubel auctions persisted; in sum Vickrey auctions were always as efficient as Ausubel auctions, and yielded more or less revenue depending on the environment.

Kagel et al. (2001) also compare multi-unit sealed-bid Vickrey with Ausubel (dynamic Vickrey) auctions, but in an environment with no strategic uncertainty. Unlike Manelli et al., they report that the Ausubel auction with drop out information comes significantly closer to sincere bidding than other institutions. It is then useful to compare the results of Manelli et al. with others' findings on Ausubel auctions. Kagel and Levin (2001a) and Kagel et al. (2001) find that in environments where a single human subject competes with computer rivals, Ausubel auctions work well in terms of efficiency, outperforming other auction formats. Grimm and Engelmann also find that Ausubel auctions perform well in a setting where several human bidders interact but by design are precluded from overly aggressive bidding. On the other hand, Manelli et al. report that Ausubel auctions may suffer from efficiency losses caused by aggressive bidding,

[9] Note that playing the DR equilibrium requires certain coordination between the two bidders, hence this setting comes very close to studies of bidder collusion. The differences between such DR equilibria and collusive equilibria (to be discussed below) are small. One distinction is that in the EC multi-unit settings usually employed to study demand reduction, only one bidder demanding multiple units may be left active at some point of the game; he then has a monopsony power and faces the exact DR incentives as discussed at the beginning of this section. In the open outcry-type auctions which are typically used to study collusion, activity rule restrictions are absent, and hence market power may be sustained only through continuous coordination among bidders in the auction (see below).

which appears to be strategic in nature and therefore may be quite persistent. These results suggest that, at least in some environments, the presence of human rivals and strategic uncertainty associated with it may have significant effect on bidder behavior and therefore on performance characteristics of the Ausubel auction.

What have we learnt? First, demand reduction is a well-documented phenomenon in the lab. Second, multi-unit uniform price ascending clock auctions exhibit demand-reduction behavior closest to equilibrium predictions as compared to corresponding sealed-bid institutions. Thus in uniform price clock auctions, the dynamic nature of the institution helps bidders to learn their equilibrium strategies better. Third, it may not be a universal phenomenon that dynamic multi-unit auctions unambiguously result in outcomes closer to the theoretical predictions than their sealed-bid analogs. While the Ausubel (dynamic Vickrey) auction, designed to eliminate demand reduction incentives, performs well in some environments (as in Kagel and Levin and Grimm and Engelmann), it may become subject to new kinds of disequilibrium behavior in other settings (as in Manelli et al.), and lead to considerable efficiency losses.[10] These findings suggest that there is room for further research on multi-unit auction institutions that could eliminate demand-reduction incentives and improve efficiency.

Experiments on bidder collusion

Until recently, the evidence of outright bidder collusion in auctions under standard experimental procedures without communication was scarce (Kagel, 1995). Multi-unit ascending auctions present new opportunities for bidders to collude that are non-existent in single-unit auctions or even multi-unit sealed bid auctions.[11] Burns (1985) observed some collusion attempts in multi-unit sequential English auction with three bidders; yet collusion in her experiment was unstable and in the end all prices converged to competitive equilibrium. A number of recent studies report sustainable collusion in ascending auctions. The issues being addressed are: possibility of collusion under "standard" procedures; role of various institutional details or auction formats in preventing or facilitating collusion; and the role of communication. All studies discussed here consider collusion in open outcry ascending bid auctions, or their computerized analogs; collusion in experimental English clock auctions (often used to study demand reduction, as discussed above) has been rarely reported.[12]

Sherstyuk (1999, 2001) studies the role of bid improvement rules for safe-guarding against collusion in multi-unit ascending bid auctions. If bid improvement rules are absent in an ascending auction, then bidders may sustain supra-competitive pricing as equilibria by matching each other's low bids. Deviations are deterred by the threat to switch to competitive bidding, and in equilibrium objects are allocated to bidders randomly at a low price. Experimental design employed to test this prediction had three bidders in the market, each demanding a single unit, and a supply of two units. During the bidding process, the subjects were allowed to submit bids

[10] Manelli et al. go as far as writing: "Just as theoretical properties of single-unit auctions do not always carry over to multi-unit environments in a simple way, so too behavioral regularities observed in single-unit environments do not always carry over to the multi-unit environment. For example, the transparency of sincere bidding in private value English auctions, that results in efficient allocations in laboratory environments, does not appear to be a characteristic shared by its multi-unit analogue."
[11] Kawsnica (2000) studies bidder collusion in multi-unit sealed bid auctions with communication.
[12] Grimm and Engelmann (2001) is a notable exception; see footnote 9 above.

no lower than the outstanding bid in the market; when the bidding was over, the two objects were allocated to two highest bidders, with ties in the bids of acceptance broken randomly. Explicit communication among bidders was not allowed. Sherstyuk reports persistent and mostly stable tacit collusion in such auctions, with occasional competitive outbreaks, first in a setting where all bidders had equal and commonly known valuation for the good (1999), and later in private value settings (2001).[13] In contrast, the sealed bid sessions conducted under identical supply and demand conditions converged to the competitive equilibrium. In the ascending auctions, bidders actively used the bid matching possibilities to communicate their intention to collude and to achieve and sustain collusive outcomes; figure 2 presents an example of such "bid matching" auction. However, some collusion was also observed in the standard ascending price auctions with no bid matches allowed, relying on the repeated nature of the auction (2001). This indicates that institutional features of ascending auctions allow highly motivated bidders to find ways to achieve and sustain tacit collusion that are inaccessible in the sealed bid auctions; collusion may take various forms, with bidders splitting markets either within periods (using bid matching), or across periods (using bid rotation schemes).

[FIGURE 2 AROUND HERE: Based on Sherstyuk, 1999]

Kwasnica and Sherstyuk (2001) provide the first systematic evidence of bidder collusion in simultaneous ascending price auctions under "standard" procedures without communication.[14] There were two objects offered for sale in each auction period, and two or five of bidders, each demanding both objects. Each good was auctioned in a separate computerized ascending bid auction, with the auctions run simultaneously for both goods. Brusco and Lopomo (1999) show that there exist collusive equilibria in such auctions where bidders split the markets and secure objects to themselves, each in their "designated" market, at lower than competitive prices; such equilibria may be sustained even in the presence of large but common complementarities between objects. Kwasnica and Sherstyuk do observe a large amount of collusive behavior in two-bidder markets without complementarities and in the presence of moderate complementarities, especially among experienced bidders. Yet, markets with large complementarities were all competitive. As predicted by the theory, collusion never emerged in any of the five-person markets. Figure 3 illustrates the actual price dynamics in a 2-bidder market with no complementarities, 2-bidder market with large complementarity, and 5-bidder market with no complementarity.

[FIGURE 3 AROUND HERE: Based on Kwasnica and Sherstyuk, 2001.]

Kwasnica and Sherstyuk present an analysis of bidder behavior in these markets which sheds some light on how collusion was achieved and sustained. Two interesting features were characteristic to bidding in markets that resulted in low (collusive) prices. First, bidders in two-person markets often signaled to each other with their bids to decide on how to split markets.[15]

[13]McCabe et al. (1988) also noted that allowing for bid matches may lead to low price equilibria in some versions of multi-unit English auction. However, in their settings, the low price prediction was not supported by the experimental data (p. 57).

[14] The auction studied in this paper closely resembles the one used in practice by FCC to auction off airwave licenses.

[15] This is in line with theoretical predictions by Brusco and Lopomo.

Signaling involved either placing an opening bid in their preferred market first, or placing a strictly higher initial bid in the preferred market. Second, retaliation in the sense of bidding high, and often above own values, was used to punish non-collusive behavior of others.[16] Further (similarly to Sherstyuk, 2001), they provide evidence that bidders were able to adopt various collusive schemes to maximize their gains from collusion. In particular, in treatments with complementarities, the predominant collusive scheme was bid rotation across periods, rather than splitting markets within a period; the former scheme allowed bidders to capture the complementarity term.

Sherstyuk and Dulatre (2001) consider whether simultaneous ascending price auctions are more susceptible to collusion than sequential ones, as some theories predict. They study a setting with four bidders and four heterogeneous goods; explicit face-to-face communication was allowed between auction series to facilitate collusion. Curiously, Sherstyuk and Dulatre report that even with communication, in some markets collusion never emerged.[17] Further, collusive agreements took place more often in sequential than in simultaneous auctions. They conjecture that the reason was that sequential auctions were not as complex as the simultaneous ones, and advantages of collusion were easier to realize and learn under the former auction format. Sherstyuk and Dulatre further observe that the auction ending rules had a significant effect on bidder behavior. The "hard" closing rule led bidders in simultaneous auctions to focus on end-of -period bidding and possibly distracted the bidders' attention away from collusion. Collusion was somewhat more frequent under the soft closing rule.

Phillips et al. (2001) report on successful collusive practices in repeated sequential English auctions for homogeneous goods, in markets with two and six bidders.[18] Unlike in Sherstyuk and Dulatre, bidders in their design had identical downward sloping demands for the good, and the number of units offered for sale by the auctioneer was large enough to allow every bidder to buy most of their higher-valued units; thus the success of collusion may be due, to a large degree, to low competitive pressures from the market. An interesting finding they report is the absence of "high numbers effect" on collusion in auctions with communication (administered through email). Bidders in their six-person auctions were able to depress prices as effectively as in two-person auctions. A possible reason, Phillips et al. suggest, is that in the six-buyer markets a sharing arrangement where each took a turn winning was focal; whereas in two-buyer markets there were too many discussions on how much the subjects were earning, which complicated coordination between bidders. Phillips et al. also find that in two-buyer markets, knowing the quantity of goods for sale alone was as an effective collusion-facilitating device as communication.

In summary, the emerging experimental research on collusion in multi-unit ascending auctions clearly demonstrates that stable collusive outcomes can and do emerge under certain settings.

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[16] Kwasnica and Sherstyuk report that the about 20% of inexperienced bidders and over 30% of experienced bidders bid above their value at least twice during the experiment. In our knowledge, this is the first study where consistent overbidding is reported in private value ascending price pay-your-bid auctions.

[17] Archibald et al. (2001) report that collusion in some settings may be very hard to achieve except under a stringent set of procedures. They investigate posted-offer auctions in avoidable cost environments where collusion among firms is necessary to obtain efficiency.

[18] See also Menkhaus et al. (2001).

Yet, collusion proves to be difficult in other settings. Ascending open auctions appear to be more susceptible to collusion than sealed bids. Many interesting issues are under-explored or not yet explored. First, while all studies discussed here consider collusion in open outcry type auctions, in many cases the vulnerability of these institutions to collusion may be remedied by adopting an ascending English clock procedure instead. English clock auctions may make collusion among bidders much harder to achieve due to coordination problems.[19] Second, many other institutional aspects of ascending auctions that may affect collusion need further investigation, such as: "activity rules" in simultaneous auctions, information feedback to bidders, knowledge of quantity supplied, communication. Other interesting issues include effects of eliminating repeated interaction with the same group of bidders; comparison between homogeneous and heterogeneous goods markets; effects of numbers; equilibrium selection in settings with multiple (collusive and competitive) equilibria; and behavioral foundations of collusion. Finally, one might expect to see a closer connection between demand reduction and bidder collusion literature.

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[19] McCabe et al. (1988) and Banks et al. (2000) note that multi-unit English open-outcry-type auctions also suffer from other behavioral problems, such as "jump bids", or bid increases higher than the minimum required increment. Such "jump bidding" was observed even in single-unit-demand environments, and often resulted in efficiency losses. The problem is solved by disallowing bids from the floor – using the English clock.

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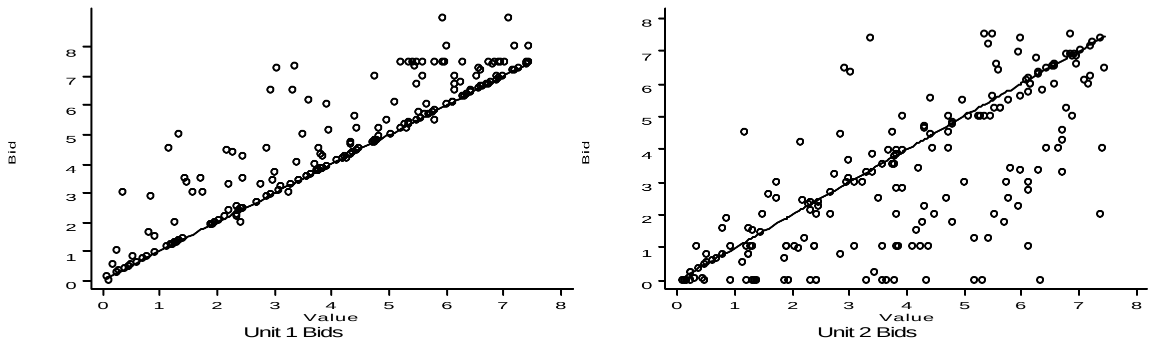
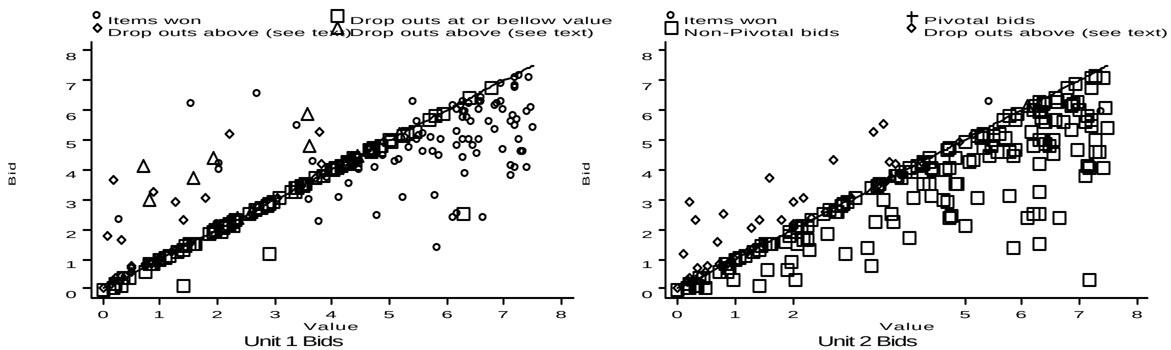
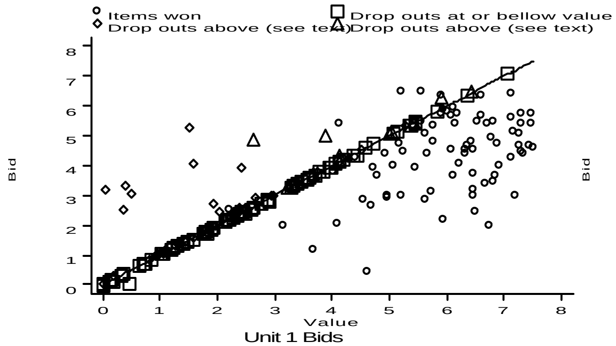
Figure 1: Human bidder behavior in auctions with 5 computerized rivals. Top: Uniform price sealed bid auction. Middle: uniform price clock auction. Bottom: Ausubel (dynamic Vickrey) auction. *Source:* Kagel and Levin (2001a), ©2001 The Econometric Society.

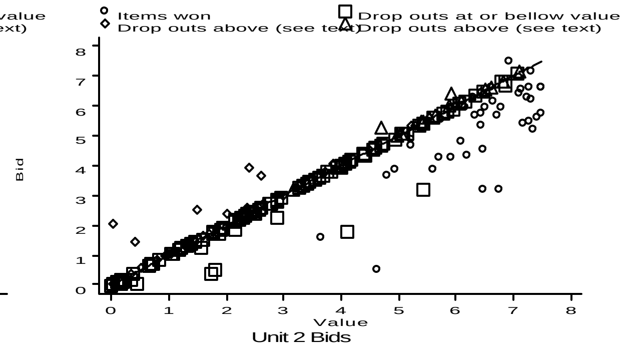


Session 3: Uniform Price Sealed Bid Auctions (n=5)



Session 5: Uniform Price Clock Auctions (n=5)





Session 9: Dynamic Vickrey/Ausubel Auctions (n=5)

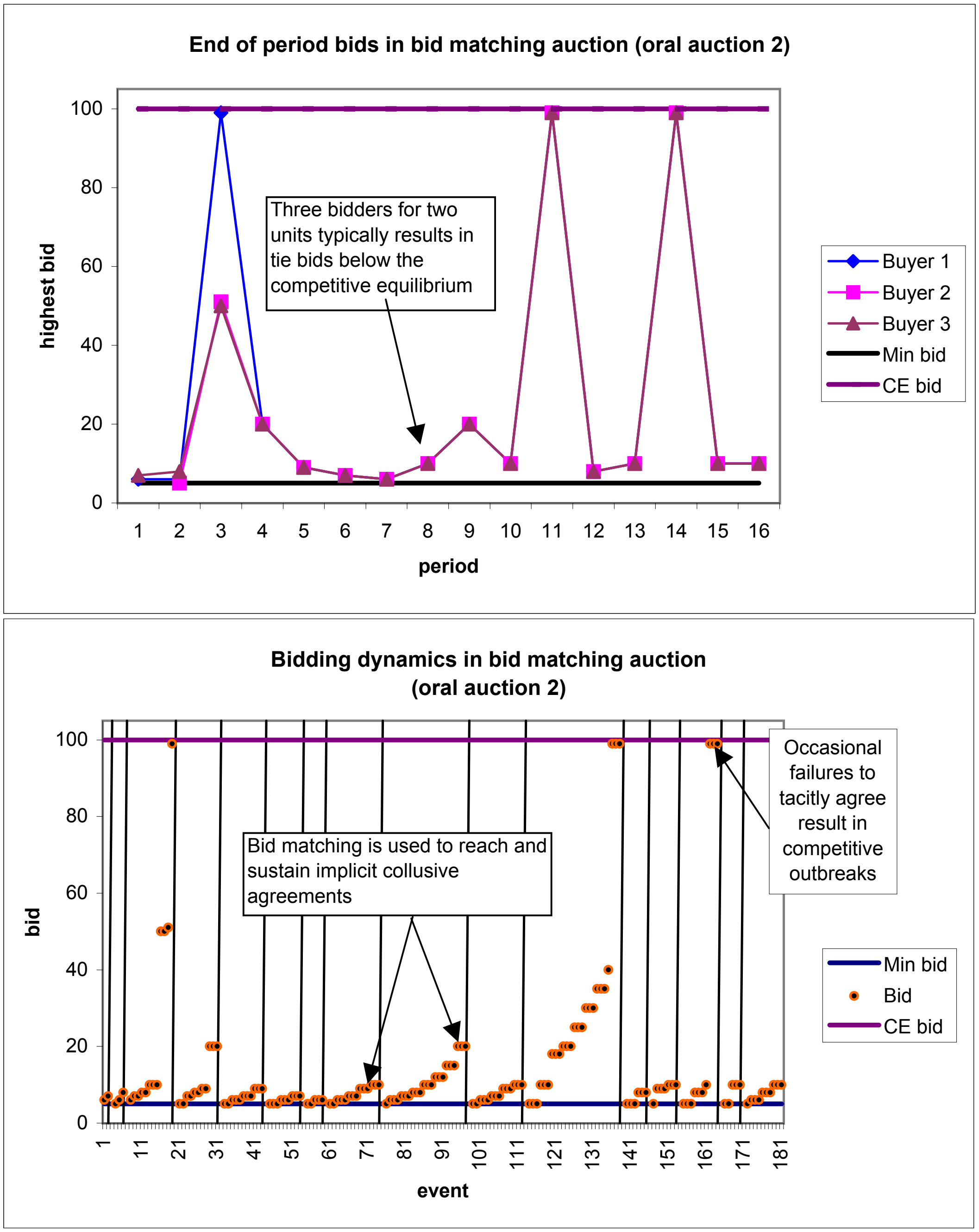


Figure 2: End-of-period bids (top) and bidding dynamics (bottom) in bid matching oral auction, session 2. In the absence of strict bid improvement rule, bidders used bid matches to suppress price competition. The prices averaged at 25.2 cents, compared with the competitive equilibrium prediction of 100 cents. Source: Constructed with data from Sherstyuk (1999).

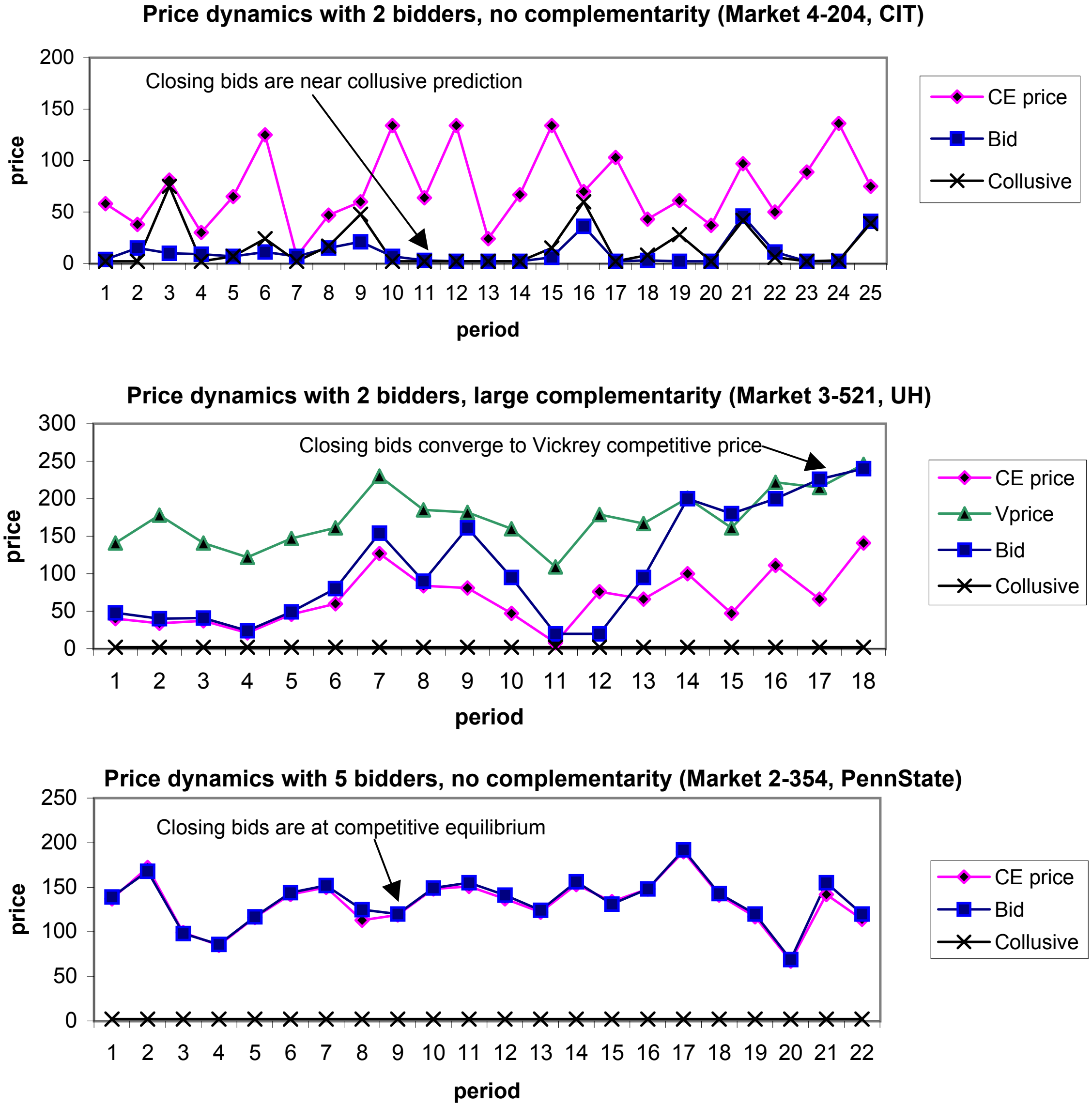


Figure 3: Price dynamics for two objects in a 2-bidder market with no complementarity (top), 2-bidder market with large complementarity (middle), and 5-bidder market with no complementarity (bottom). "Bid" -- actual price; "CE price" -- competitive equilibrium price without complementarity; "Vprice" -- competitive (Vickrey) price with complementarity; "Collusive" -- collusive equilibrium prediction. Source: Constructed with data from Kwasnica and Sherstyuk (2001).