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Testing for the occurrence of Shill-bidding (in internet auctions)

Abstract
After the emergence of Internet auction sites, both anecdotal evidence and the conviction of a number of shill-bidders document that the problem of shill-bidding in real-world auctions does exist. This finding is consistent with the economic theory of auctions, because sellers do have a motivation to shill-bid. Shill-bidding is harmful because it redistributes surplus in auctions, worsens the information asymmetry between the seller and the bidders, and raises the possibility of a winner's curse and of ex post inefficiency. This paper reviews four econometric procedures testing for the presence of latent shill-bidding, based on the arrival or return rate of bids, the revenue comparisons, the relation between the minimum bid and the secret reserve, and the behavior of bidders and sellers in relation to events outside of the auction of interest. The paper also discusses competing procedures suggested in the literature that identify 'blatantly irrational' bidding under various behavioral assumptions.

Keywords: shill bidding, auction, eBay, cheating, detection

1. Introduction

After the emergence of Internet auction sites, stories about unfair behavior of auction sellers started circulating. Both anecdotal evidence and the conviction of a number of shill-bidders in recent years document that the problem of shill-bidding in 'real-world' auctions exists (Simpson 2000, Lamy 2006). This finding is consistent with the economic theory, as the sellers do have an incentive to participate in bidding for their own auctioned product – namely, to raise the expected revenue from the auction. While they face the risk of winning their product back, and thus realizing revenue of zero, some of this risk is traded off for the chance to increase the final price paid by the winning bidder.

This paper adds to the recent literature on the characteristics, and principally the bidding strategies in auctions. I study illicit shill-bidding and propose four major distinct approaches to testing for its presence in an auction environment or in a particular auction.

This topic is important for three reasons (besides the fact that shill-bidding is illegal):

i) Shill-bidding is likely to redistribute the winner's surplus in an auction to the seller.
ii) In common value auctions, it accentuates the *winner's curse* that is difficult for bidders to account for. Shill-bidding confuses bidders about the good's true value (for instance, Hlasny 2002).
iii) Shill-bidding introduces the possibility of ex-post inefficiency, specifically, the chance that the seller wins his good back even though another bidder values it more (see Chakraborty & Kosmopoulou 2004, Kauffman & Wood 2003a, 2003b and 2005, Bag et al. 2000, or Wang et al. 2001, for more discussion of the consequences of shill-bidding).

Even though this paper focuses on online auctions, shill-bidding is not limited to the Internet environment. The theory and historical evidence suggest that shill-bidding has existed long before (and likely for as long as auctions have been conducted). However, Internet auctions are especially susceptible to shill-bidding due to the non-transparency of online trading (e.g., ease of hiding relevant private information) and the resulting asymmetry of information between the seller and the bidders (Kauffman & Wood 2003a, 2003b).

In what follows, I describe four major approaches to detecting shill-bidding in auctions. Each of the methods results in a statistical test of the null hypothesis of no shill-bidding. As most econometric tests, these tests rely on a comparison of two states with different *a priori* probabilities of shill-bidding (refer to Sections 8.4 and 8.6), and evaluate the significance of the difference between these states. Unfortunately, the results of the proposed tests are rarely crystal-clear, and are sometimes contingent on a number of behavioral assumptions, a consequence of dealing with human behavior. Many factors

enter into auction participants' actions and the shill-bidder has a natural incentive to conceal his scheme. The results of these tests will usually not pinpoint which action was illicit, but they will tell us what confidence we can place on the absence of shill-bidding at a given auction or auction environment.[1]

I review the theoretical foundations on which these methods are grounded and cite the literature responsible for these methods. Finally, I discuss the validity, robustness and applicability of the proposed tests, and suggest on what scale they are sensible to implement. For each test there is a minimum number of auctions that can be jointly tested for the presence of shill-bidding. The tests may be invalid on individual-auction level, due to high auction-specific variation in parameters and outcomes. The conclusions of these tests include:

i) Evaluation of particular accusations of shill-bidding.
ii) Determination of the effects of a particular auction policy on the likelihood of shill-bidding.
iii) Estimation of the welfare effects of shill-bidding at an auction environment.
iv) Evaluation of the selection outcome of a particular policy – what audience or type of products an auction site draws due to a particular policy. This evaluation is important for auction sites, because it allows them to target specific agents or types of behavior, by modifying the bidding rules.

The next section summarizes the general setting of auctions I will be considering. Since bidding rules differ across auction environments, the next section will also delineate the main points of their divergence and the implications for shill-bidding and testing for it. The auction rules and their heterogeneity are one of the grounds for testing that I subsequently propose. Obviously, the tests are based on the 'detectable' differences between auctions where shill-bidding occurs, and where it does not. Each method takes advantage of a particular dichotomy between the incentives and strategies of: bidders

[1] One could use the results of these tests to estimate the mean price inflation due to the higher rate of shill-bidding in one group, or the discouragement of bidders, but this issue is not discussed in this paper.

versus sellers; different types of bidders including shill-bidders; or sellers who shill-bid versus sellers who do not.

The following five sections put forward several criteria that can be used to test for the presence of shill-bidding in auctions, and particularly in online auctions. Each section outlines the auction setting in which the test is valid (and sensible) and discusses how the test can be applied and what conclusions can be drawn from its results.

2. Auction environments

Online auctions differ in many dimensions. Many of the differences influence the bidders' and the sellers' behavior and strategy space in various ways (Wolfstetter 1999). Comparing the agents' behavior across environments can be used to answer interesting economic and sociological questions. In what follows, I use the term 'auction environment' in the general sense. Rather than to specific auction houses, it refers to the set of auction rules (e.g., fees, timing rules, information availability, penalty for the detection of shill-bidding) and conditions (e.g., time of the day and day of the week when an auction ends, duration of an auction, item auctioned off) that make a group of auctions (even at different auction sites) likely to yield similar bidder and seller strategies and outcomes.

One auction-specific difference concerns the character of the auctioned goods and the relationships among values that bidders place on them. As the vast literature in auction theory documents, bidders' strategies differ according to whether their values are interrelated, and what information about the good is revealed to them. Auctions can thus be sorted according to where the auctioned goods can be placed in the spectrum from purely common value- to purely private value- types (Milgrom & Weber 1982). In private-value auctions bidders' signals about their valuation of the auctioned good are independent of each other, and bidders do not need to know the valuation of other bidders. In common-value auctions, however, knowing the signals or bids of other bidders helps each bidder determine the true value of the auctioned good. It is thus desirable for a

bidder to observe the bids of other bidders, and keep secret his own bid, less other bidders would update their own bids upward.

Major dichotomy among auction sites concerns the timing of events: Some auction sites (e.g., eBay) have a fixed time schedule, under which the auction automatically ends when the time runs out. Others (e.g., Yahoo) have a system similar to traditional ascending auctions where bidders always have time to respond to other bidders' bids (Ariely et al. 2001). Once the scheduled time runs out, time is automatically added as long as someone bids. This distinction is important because it affects the amount of information available to all bidders in the face of uncertainty over other bidders' signals, and thus also over other bidders' optimal strategies in extracting surplus from the auction[2]. In the limit, it distinguishes the ascending from the second-price auctions, and consequently influences the optimal behavior of agents (for instance, Wolfstetter 1999). In common-value auctions the additional information changes each bidder's valuation, and thus necessarily their bid. Refer to Bajari & Hortacsu (2001), Roth & Ockenfels (2000, 2002) and Ockenfels & Roth (2001) for the implications of different timing rules.

Other variations in auction rules influence the behavior of auction participants across auction sites. The type of fee schedule, for instance, determines the sellers' cost of setting minimum bids and secret reserve prices, the net revenue from an auction, and thus the incentives to shill-bid. The bidder registration procedures can build obstacles to setting up multiple identities and can indirectly increase the chance of shill-bidder's detection. The availability of tools such as secret reserve prices, minimum bids and buyout options obviously alters bidders' as well as sellers' action-spaces, and may represent substitutes for shill-bidding (refer to Section 6). The ability to select one's nickname and earn a history of positive feedback affects the seller's reputation and penalty from the detection of a deviation. The actual penalty for detected shill-bidding can involve temporary or permanent suspension or even criminal charges. Indeed there are auctions and auction environments where shill-bidding is more plausible than in others. Sections 8.4 through 8.6 describe how individual auctions or auction

[2] The seller's strategy is also affected, since the expected duration of the auction changes with the timing rule, and so do presumably the willingness of bidders to bid in late stages of an auction, the number of bids, and the consequences of the seller's shill-bidding.

environments could be split according to the risk of the occurrence of shill-bidding based on circumstances of the auctions, the properties of the items auctioned, the auction rules and fees, the observable characteristics of the sellers etc.

3. Data

Before delineating each of the tests of the existence of latent shill-bidding, it is necessary to review the data available in the Internet auctions, because quality of this data is a primary determinant of the feasibility of any tests. All data is available for download from online auction sites, either manually or using a custom-built data collection software, which allows a researcher to automatically collect detailed information about thousands of auctions in a very short time. Such data can include:

i) The number and the identities (or nicknames) of all active bidders and sellers.
ii) The bidding experience and history of all participants (e.g., their feedback), as a snapshot or as changing over time.
iii) The characteristics of the auctioned product (its quality and features, shipping cost, shipping time, as well as the amount of information provided[3]).
iv) The timing and the levels of all placed bids.
v) The existence of minimum bids, secret reserves or buyout options.

Furthermore, for each auction site one can record the bidder registration procedures and requirements (such as presentation of a valid credit card number), auction fee schedule and the evidence of endorsement of a no-shill-bidding policy. (For a discussion of auctioneer's action space, see Chakraborty & Kosmopoulou 2004, or Wang et al. 2001.)

For each auctioned object it is possible to obtain a retail or resale value at other auctions or online outlets. For commercial auction participants it is possible to track

[3] Items sold 'as is' or with major information concealed receive few bids, suggesting a 'lemons market' or risk aversion among bidders.

down information on their specialization, their past, ongoing and future auctions, and their experience and perceived quality.

In addition, it is possible to follow the exact bidding or selling history for a particular agent for a period of time and even across auctions. Researcher can thus check whether a seller (who has accidentally won his object back due to aggressive shill-bidding) resells the same object repeatedly. Discussion of this option is postponed till Section 8.

One limitation of the Internet data is that it generally does not reveal the number of all potential bidders who self-selected out of bidding. Only those participants who place bids (or visit the webpage with auction details) are recorded. Researcher generally cannot estimate how often (potential) bidders check on the standing of an auction (e.g., the current price or the status of their bid).[4] Even though some pages with descriptions of auctioned goods have counters of hits, these measure the public interest in the particular auction (or eagerness of bidders) very imprecisely. As a result, the number of potential bidders is unknown, which is particularly unfortunate in an environment with endogenous entry (Bajari & Hortacsu 2001).

4. Arrival or return rate of bids

Motives idiosyncratic to a certain group of auction participants provide a good way to test for shill-bidding. While regular bidders try to *win* the auction at the *lowest* possible price, the shill-bidder strives to *lose* the auction at the *highest* price.[5] Clear dichotomy between bidders' and shill-bidders' strategies in the common value auctions (and in certain cases also in private value auctions, as noted in Roth & Ockenfels 2000) is in the timing of the arrival of bids. While bidders want to avoid revealing their *signals* about the true value of the auctioned good to other bidders for the fear of updating opponents' valuations and

[4] Indeed, bidders using automatic proxy agents (i.e., 'snipping' software) may not visit the webpage even once.
[5] This assumes, of course, that the reached price is above his reservation value. No matter whether the seller or another bidder wins the auction, the seller must pay all fees associated with the final price.

consequently being outbid, the shill-bidder has the opposite objective. As theory and empirical evidence suggest, bidders want to postpone bidding until their opponents are unable to react to their bids (Bajari & Hortacsu 2001, Ockenfels & Roth 2001, Roth & Ockenfels 2000 and 2002). The shill-bidder, on the other hand, wants to bid up the price earlier in the auction, to signal that the good is valuable and to give bidders a chance to outbid him. By bidding frequently and relatively early in the auction, the shill-bidder tries to raise the chance of being outbid and to trigger price wars (see Roth & Ockenfels 2000) and frequent upward revisions of bidders' valuations, in order to raise the final price. This strategy and the responses of other bidders are consistent with full rationality. Under uncertainty, even when participants suspect that there may be a shill-bidder among them, they cannot rule out that the suspicious behavior resulted from a bidder's excitement or a 'trembling hand', rather than from shill-bidding. Their optimal bidding strategy can therefore account for the plausibility of shill-bidding, weighted by the probability (perhaps very small) that what was occurring was indeed shill-bidding.[6] In common-values auctions, the shill-bidder's bid provides information about the seller's signal of the item's true value. In that case other bidders may update their bids even if the presence of shill-bidding is publicly known.

The testable conjecture is then that the arrival of bids has a greater left tail in time in the presence of shill-bidding than in its absence. If we can derive a bid arrival or return function for a set of auctions with given characteristics, testing the significance of a skew is a possibility.[7] Roth & Ockenfels (2000) report that the distribution of bids until the end of an auction follows closely a power law, which can be characterized by a single exponent (provided that we do not restrict the number of bids in an interval of time) estimated by nonlinear least squares or maximum likelihood methods. This exponent can be compared across samples of benchmark and suspected auctions, to determine the statistical significance of their difference, under the null hypothesis of equivalence of the distributions. The Pearson's chi-square or the Kolmogorov-Smirnov test can then

[6] Hlasny (2002) distinguishes three scenarios – no shill-bidding, secret shill-bidding where bidders do not suspect it, and open shill-bidding where sellers have the right to shill-bid and all bidders are aware of this.
[7] As a simple test, one could compute the proportion of bids occurring within particular time intervals until the end of the auction.

evaluate the fit of the predicted distribution under the benchmark case to the distribution of actual bid arrivals observed in the suspected auctions (Goldstein et al. 2004). An important limitation is, of course, the presence of randomness and of auction-specific shocks that allow the level of skew in different auctions to naturally vary. While this test may perform well in comparisons of (similar[8]) large sets of auctions, where one set differs from another in the *a priori* likelihood of shill-bidding (refer to Sections 8.4 through 8.6), it would not produce good results in evaluations of individual auctions.

Another test based on the timing dichotomy takes advantage of the fact that a shill-bidder strives to leave bidders as much time as possible to respond to his bid, and therefore bids immediately upon being outbid.[9,10] This hypothesis, consistent with the theory, results in a test. The test compares the realized timing of bids in an auction with the hypothesized (random) return rate obtained from observing the timing in a large sample of similar auctions. Significant evidence of the presence of 'pairs' of bids in an auction is an indication of shill-bidding. In addition to the above-mentioned test of the power-law arrival rate of bids, which can effectively test for deviations of the distribution of bids from the benchmark hypothesis, we can use more tailored tests to detect differences in the second through the fourth moments around the estimated bid arrival times.

Depending on the amount of structure we want to impose on the data, we can evaluate the overall distribution of all bids, or we can attempt to specify rules for distinguishing regular bids and the shill bids. In the first case, we note that the presence of shill-bidding is expected to affect the variance and skew in the arrival rate of bids even if the mean arrival rate does not change distinguishably. The chi-square test evaluates whether the variances of the bid arrival rate across two samples differ statistically significantly. We may also attempt to distinguish regular bids from the shill bids, and

[8] Further in the paper, 'similar' will refer to auctions with similar expected number of bidders, seller's bidding history, expected price, time left on the clock, presence of a secret reserve, or other characteristics that can be controlled for by the econometrician with a large sample.
[9] He trades off the risk of being exposed, due to following this strategy, with the benefit of the additional time that he gives bidders to respond to his bid. As a result, his optimal return rate (or bid-placing rate) is still above the return rate of other bidders.
[10] However, note that the total number of bidders and bids may not be higher than without shill-bidding, as some bidders or bids may be discouraged by the lower expected surplus from winning in the auction.

split the data into clusters. We can do this by inspecting the bidding histories and manually marking the suspected bids (based on their distance from other bids, by the identity of the particular bidder etc.) or by using the statistical agglomerative clustering based on the distance of individual bids (normalized by the mean arrival rate at the times of the bids given by the power law distribution). Upon manual selection of all suspected bids, we compare the mean time lags 1) between these bids and the preceding bids; 2) between these bids and the next bids, and 3) among all other bids. Manual selection is, however, time consuming in a large sample and can be called into question. Letting the bid arrival times self-select into clusters statistically is a more robust method that works particularly well in large samples. The number of clusters of bids (endogenous or econometrician-selected) is generated by joining individual observations (using the Ward's method or the k-means clustering, respectively) to minimize a measure of distance of observations within clusters, and maximize their distance among clusters (Everitt et al. 2001). In distinguishing shill-bids from regular bids, these methods analyze the variance of the arrival times, and essentially test for the existence of a bimodal distribution of the bid arrivals. A high prevalence of pairs of bids in the data, unsupported by the benchmark distribution of the arrivals, indicates that a subset of bids is distributed according to a different underlying principle than the rest of bids.

One remarkable characteristic of these tests is that they do not require that the shill-bidder have a single identity. The timing of events can be measured for individual participants or for all participants jointly. These tests rely solely on economic theory and on the statistical likelihood of the arrival of all bids, and take the shill-bidder's incentive to remain clandestine into account. They allow the identities of all bidders to be absolutely arbitrary. Even if the seller's identity appears among the bidders, these tests do not necessarily report shill-bidding.

Although consistent with the theory, the above two tests are unfortunately also consistent with a 'hot-headed bidder' hypothesis: Some bidders may drive up the price from the start of an auction, because they derive utility from having their names listed as the top bidders, because of irrational fears of being outbid or other demonstrated

misunderstanding of the system, or for another reason (see Wang et al. 2001).[11] Both of the above tests assume this behavior away. More importantly, they also require that there be no unobserved systematic heterogeneity, other than the occurrence of shill-bidding, causing the irregularities in the timing of bids.[12] In comparisons of similar auctions, given that bidders and sellers have identical timing motives across auctions, this assumption is plausible.

5. Revenue comparisons

This perhaps obvious method of testing for the presence of shill-bidding is also based on auction theory. It is easy to prove that if we assume exogenous bidder participation, private value auctions achieve no lower final price with shill-bidding than in the absence thereof (Hlasny 2002).[13] The final price is recorded as revenue regardless of whether a bidder or a shill-bidder wins, and the seller must pay auction fees on this amount. Thus, comparing the final prices at similar auctions can serve as an indicator of shill-bidding. The researcher may deploy ordinary least squares regressions on the set of benchmark auctions to fit final prices using all observable properties of the auctions, and use the estimates to predict the final prices in the suspected auctions. Significant unexplained deviations of positive sign are indications of shill-bidding.

As with the tests of Section 4, this test is more applicable in comparing sets of auctions or auction environments, rather than individual auctions, due to high auction-

[11] Another story consistent with the above phenomenon is of a bidder who strives to persuade other bidders that shill-bidding *is* occurring in that auction, in order to discourage them from participating. This bidding strategy has, to my knowledge, neither been reported nor analyzed in auction theory, but is not ruled out.
[12] For instance, auctions ending early in the morning are expected to have a greater left tail than auctions ending in the evening, because bidders do not want to wait until the last moment to place their bids.
[13] This claim, in general, is invalid for common value auctions, where factors opposing to the shill-bidder's objective come into play. See Milgrom and Weber (1982). With endogenous bidder participation, the effect of shill-bidding on final price is theoretically inconclusive even in the private value auctions (although empirical evidence suggests a positive relationship). Occurrence of shill-bidding in the early stage of an auction raises current high bid and thus decreases the bidders' expected surplus from winning the auction. Consequently, bidders may switch to bidding in another auction where they expect a higher surplus from winning. The ultimate effect on the final price depends on all distributional and probabilistic assumptions, and is an empirical question.

specific variability (unaccounted for product quality, seller feedback, time of day etc.). Furthermore, just as the tests in the previous section, this test is vulnerable to the 'hot-headed bidder' explanation.

6. Minimum bid – secret reserve relation

Shill-bidding can be interpreted as being equivalent to a secret reserve price under which a seller does not want to sell the good, and which he can update throughout the duration of an auction.[14] I thus use the relationship suggested by Vincent (1995) and tested on the Internet auctions by Bajari & Hortacsu (2001) to test for shill-bidding from an alternative perspective. Vincent shows (and proves for a special case) that there may be strategic reasons for a negative relationship between the level of the minimum bid (i.e., starting price) and the presence of secret reserve price in an auction (the decision to shill-bid). He suggests that when planning to use a secret reserve price, the seller ought to set a lower minimum bid than without a secret reserve, because the lower minimum bid can attract a greater amount of bidding, and the seller is protected from receiving a low final price by his ability purchase his item back. Bajari & Hortacsu (2001) conduct a test of this hypothesis in online auctions and confirm the presence of a negative relationship (although their theoretical analysis suggests that the claim does not hold in general).

The test that I propose therefore compares the minimum bid in an auction (or the average, in an auction environment) where shill-bidding is suspected to that in similar auctions. The conjecture is that sellers who expect to shill-bid set a lower minimum bid than if they do not. If a particular minimum bid (or the average in a group of auctions) is significantly below the norm in similar auctions, it is likely due to the seller's plan to shill-bid. We can explain the level of the minimum bid using ordinary least squares regressions, controlling for all observable properties of the auctions. Statistical difference between the predicted levels and the actually observed levels in the suspected auctions

[14] In common-value auctions a seller may have a private signal about the product's value to him, but he may use the bidding history to update his belief.

gives us the chance that the minimum bids were established using the same principles as in the benchmark auctions versus using another (shill-bidding) strategy. Although this test assumes great amount of technical astuteness from the seller, empirically sellers seem to possess the fundamental understanding of this property.

The advantage of this test is that it is not vulnerable to the 'hot-headed bidder' story. The level of the minimum bid (and the preset secret reserve, if available at an auction site) results solely from the seller's deliberation, is set once and does not require resetting during the auction, and does not depend on any events between the beginning of the auction until its end. No shock on the bidders' side influences the relation between the level of the minimum bid and the decision to shill-bid. Once the minimum bid is set, it also does not affect the seller's decision whether to shill-bid or the level of his bids.

One problem with this approach is that the optimal tradeoff between the minimum bid and the secret reserve is unclear even to experienced sellers, and depends on the probability distribution of bidders' values. One would expect high variation in minimum bids, both when shill-bidding is used and when it is not.

7. Bidding blatantly irrationally

Kauffman and Wood (2003a and 2003b) suggest a simple and sensible test that is consistent with the economic theory and that is likely to endure even the 'hot-headed bidder' story.[15] They note that some online bidders bid in an auction even though a lower priced identical product is offered at an auction that ends sooner. This behavior is hard to justify even by allusions to the bidders' lack of peripheral vision, given that auctions ending sooner are listed – and highlighted – at the top of the page.

For individual bids, bidders or auctions, we can note whether such 'irrational' bidding has occurred, and we can follow individual bidders and the types of auctions over time to evaluate persistence of this behavior across observations. For a larger group of

[15] A fairly implausible exception would occur if a bidder started bidding on a lower-priced item in an auction ending later than a similar auction, and continued to 'hot-headedly' bid in this auction even when the auction ending sooner had a lower going price.

observations, using an *a priori* conjecture regarding a set of auctions (or bids, or bidders) where shill-bidding is unlikely and another set where it is suspected, we can observe the prevalence of rational and irrational bidding in each group. We can test for the plausibility of such chance occurrence using, for instance, the Fisher's Exact test. Using another set of auctions where we have a prior belief about the volume of shill-bidding, we can evaluate our ability to predict the volume of irrational bidding.

One could of course question whether the particular auctioned goods identified as similar are truly homogeneous and comparable. Secondly, this testing method is vulnerable to the existence of automatic bids placed by proxy agents, because it assumes that all auction participants are aware of all auctions and can change their bidding strategy in real time. Inasmuch as bidders can enter the auction without seeing a listing of similar auctions, or seeing different sets of similar auctions[16], this argument could break down because of its strong reliance on full information. This test attributes any unexplained variability in bids to shill-bidding, rather than, for instance, to physical bidding constraints. Finally, this testing method implicitly assumes shill-bidders to bid irrationally 'blatantly,' and at the same time assumes away irrationality of other bidders.

The final point, that sellers bid conspicuously differently than other bidders, is softened by the fact that shill-bidders always face a trade-off between the risk of being detected and the chance of spurring a price war. Rather than bidding irrationally, they simply optimize in the presence of this trade-off.

8. Additional grounds for tests

There are myriad conjectures how to distinguish between competitive and unfair behavior in (online) auctions. Some are suggested by economic theory, some by anecdotal – and yet unproved – evidence. Many are based on a one-sided argument which may hold in real auctions, but which the theory can turn around to show a different result. Here I list a

[16] The list of similar items is generated based on the exact phrasing of the search that a bidder performed. If two bidders reach the same auction using different keywords, they likely see different lists of similar auctions.

number of suggestions that are unsupported by theory, depend on particular behavioral assumptions, are data-intensive or depend on information that is unattainable.

8.1 Interest in similar auctions: Shopping around

Kauffman and Wood (2003a and 2003b) suggest evaluating how many auctions bidders who are active in a particular auction bid in during a period of time (even before and after the duration of a particular auction). Their story is that shill-bidders are not interested in purchasing and therefore bid in a single auction, while other bidders may 'bid around.' Particularly if the researcher can follow individual bidders over time, bidders who always bid in a single auction at a time are potentially shill-bidding.

8.2 Interest in similar auctions: After not winning

A similar idea is to look at post-auction behavior of aggressively bidding bidders who eventually lose, to see whether they bid in another auction. Since the competitive explanation for aggressive bidding in an auction is eagerness to buy the product, once bidders lose in an auction, one could expect them to bid in another auction for a similar object. If they do not, one can interpret their one-time aggressive bidding as shill-bidding. Alternative explanations or stories can be that the bidder lost interest, lost nerves or quit bidding because of some constraints (e.g., on time). When the researcher can follow the non-winning bidders over time, seeing them repeatedly (unsuccessfully) bid in only one of all similar auctions (in the same product category around the same time) can imply shill-bidding. In any case, this test focuses only on detection of successful shill-bidders, those who did not accidentally win their items back. Since this is only one of the potential outcomes of shill-bidding, this test cannot test for all occurrences of shill-bidding, and is of limited usefulness.

8.3 Reselling of an accidentally purchased item

Similarly, one could follow the seller (or the winning bidder) in an auction, under the hypothesis that if the shill-bidding seller accidentally wins the item back (himself or using another identity), he will auction it off again shortly. Especially if one believes that

the success of shill-bidding is correlated over time for particular sellers, one can follow sellers over time to find repeated deviations from the honest-seller default hypothesis. The Fisher's Exact test or a similar test of a pair of observed variables tells us the probability that the observed number of deviations in two subsets of auctions arose by chance. However, this test can only detect unsuccessful shill-bidders, those who have accidentally overbid other bidders. This test is thus limited in its usefulness, because even if we detect all shill-bidders who have won their items back, we do not learn how much latent successful shill-bidding activity there occurs. Inasmuch as there are rings of shill-bidders[17], it may also be difficult to follow the destiny of the items purportedly purchased by accident. Also, since commercial sellers may have more than one identical item for sale, it is difficult to ascertain that a particular item is the same as one previously sold.

8.4 Other distinguishing auction characteristics

We may believe that different types of sellers and buyers have different motives for illicit behavior. Businesses selling in online auctions may be more constrained by government, and stakeholder and employee oversight, and may not be able to shill-bid as easily as private citizens. Tax considerations may further reduce commercial sellers' motives for shill-bidding. Seller names may hint on the experience and the specialization of sellers. Low price items may be less worth shill-bidding on, since shill-bidding requires effort and physical presence and carries a risk of defamation and a penalty. Times of bids may tells us the likelihood that a seller, in a particular time zone, is awake or otherwise capable of shill-bidding. While speculative, these tests can supplement the results of other, more robust, tests. Indeed, once shill-bidding is strongly suspected, the researcher should evaluate all of these claims to ensure robustness of his primary test.

8.5 Private-values versus common-values auctions

As was mentioned previously, auctions can be distinguished according to how bidders form their valuation of the auctioned item (for instance Milgrom and Weber 1982). In private value auctions, bidders do not update their value based on the behavior of other

[17] The media have recently reported collusion among sellers of antiques on eBay.

bidders (Hlasny 2002). They may only update their belief regarding the probability of winning in the auction and the price paid, based on the distribution of others' bids. Shill-bidding can affect bidders' behavior – the likelihood of bidding – only in this way. In common-value auctions, shill-bidding also affects the value that bidders place on the auctioned item, so there is a greater potential gain from shill-bidding. Therefore, comparing auctions with similar products, one labeled as private-values and one as common-values, after controlling for the differences in strategies of honest bidders, is a potential testing approach.

8.6 Bidders' experience

One could also form a hypothesis regarding a normal bidding pattern for an agent with a given bidding experience, bidding for a given type of goods. (As Roth & Ockenfels 2002, and Wang et al. 2000, for example, verify in online auctions, bidders with longer bidding history tend to bid later in an auction.) Then one could test the consistency of an observed bidding pattern with this norm. (See Bapna et al. 2001, Gulati 2001, or Wang et al. 2000, for the discussion of the types of bidders.) The conflict in mind is that while shill-bidders do want to present themselves as experienced bidders, they presumably bid earlier in the auction. More experienced sellers may be more likely to shill-bid, and may also use a more sophisticated strategy to do so. Bidding early in the auction, for instance, is of course inconsistent with our expectation of an experienced bidders' behavior, and is thus grounds for a test.

8.7 Alternative auction ending rules

An interesting question that remains to be rigorously studied is how shill-bidders behave in auctions with flexible ending times, such as at Yahoo (Ariely et al. 2001). While bidders have no incentive to prolong an auction, shill-bidder may want to prolong its duration until the risk of winning the item back surpasses the chance of inviting a bid from another bidder. The statistical test could thus compare the length of auctions, or the number of times that the duration was extended in a group of auctions where shill-bidding is suspected.

These ideas are not stand-alone tests of shill-bidding, but may be used to complement other tests. They are data-intensive or depend on certain speculative beliefs regarding a group of agents. Nevertheless, they may be used to quickly evaluate a particular accusation of shill-bidding in order to warrant or suspend further investigation.

9. Final Remarks

A valid criticism of the methods proposed in Sections 4 – 7 is that they require the existence of clearly distinguishable treatment- and control- groups of auctions. As most econometric tests, they evaluate a particular claim against a benchmark, which in this case refers to auctions where shill-bidding is either known to be absent or is less likely to be a problem. The problem of this definition of a benchmark, and of the use of a particular set of auctions as a benchmark, is that online auction sites are not an environment where one could easily isolate a control group of auctions. To differentiate auctions with respect to their vulnerability to shill-bidding, one must either look for a good criterion that makes shill-bidding less likely in a certain set of auctions compared to another set, or one must run a controlled experiment in which this criterion is unnecessary.

Experiment that is readily in mind has to do with re-auctioning goods that have been auctioned online before. If conditions of the original auction are closely reproduced, and if the bidder pool fails to realize the link between the original and the new auctions, one can use the above tests to evaluate whether shill-bidding could indeed have been present in the original auctions. Unfortunately, the sample size of auctions for such an experiment, particularly those in the control group, would likely be small.

Alternatively, there exist criteria that make a group of auctions more susceptible to shill-bidding than another set. Policy changes provide a good testing ground. When an auction site modifies its bidding rules, researcher can use the above tests to evaluate the effect of the policy change on the occurrence of shill-bidding. The assumption of ceteris paribus is frequently plausible. (If not, the econometrician must control for self selection,

which affects the auction-site-variant expected number of bidders, the types of bidders and of auctioned goods attracted by a site, etc.) Examples of such policy changes from recent history include the introduction of auction fees at Yahoo, the establishment of the credit-card-number requirement for bidder registration at Amazon, and the modification of fees on exercised secret reserves at eBay. As the online auction environment develops, the lack and asymmetry of information disappear, and the opportunities for illicit behavior change for the better. The econometrician has an opportunity to measure the effect of each policy on the latent body of illicit behavior.

To summarize, this paper has offered four major different approaches to testing for the presence of shill-bidding in auctions. Although all of the above methods are consistent with the economic theory of auctions, they are likely used in finite sets of auctions. Due to high amount of randomness in most auction parameters, some tests may turn out to be valid only for larger sets of auctions. Those tests may be used to evaluate the risk of shill-bidding in auction environments or auction houses, rather than in individual auctions. But while some tests may not be helpful at reviewing specific cases of shill-bidding, they may offer great assistance at evaluating auction rules and other conditions intrinsic in an auction environment. Finally, the proposed tests use different properties of the auction markets to detect shill-bidding. As Sections 4 – 7 have mentioned, some of the tests may be vulnerable to a specific phenomenon that other tests are robust to. Since the assumptions on rationality of agents, or the amount of their strategizing, are subject to debate and may indeed vary across agents, it may be necessary to test for various events accompanying or resulting from certain alleged behavior. Having a set of tests that examine observed actions from different angles is of great value when one deals with such opponent as another human mind.

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