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Participation Screen for Collusion in Auctions

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Abstract

I propose a new statistical method of testing for collusion in a contract allocation setting. I compare this method with an existing one with Monte Carlo analysis. My method is robust to unobserved heterogeneity unlike the existing one. These two methods also complement each other. I apply both methods to procurement auctions that contract snow removal in schools of Helsinki. Two of the bidders seem to participate in a contract allocation scheme.

JEL Classification: C35 ; D44 ; L40 ; L85.

Keywords: Auctions; Collusion; Discrete choice estimation; Entry; Simultaneous equations estimation

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1 Introduction

I propose one new statistical method and use one existing method to test for collusion in a territorial allocation setting. Both of these tests can be applied to any institutional setting where independent and mutually exclusive markets can be defined. However, I discuss them in the light of my application, which is a procurement auction. Due to their simultaneous nature, auctions are particularly well suited for the static estimation methods that are applied here. These tests are based on the participation decision of the bidders instead of the bid levels. Collusion is defined here as an explicit arrangement among a group of bidders that limits competition between the participants. Collusion can take many forms in auctions. Typical methods include different contract allocation mechanisms, like territorial allocation or job rotation, and submitting phony bids. The previous literature on detecting collusion in auctions has studied only phony bidding scenarios.

I test whether the participation of one bidder affects the participation decision of other bidders. In the competitive setting the identity of competitors should not affect the participation decision, given that the auctioned contracts are identical and the bidders are symmetric. For strategic reasons bidders would like to avoid each other, but if they are symmetric, bidder C has no reason to avoid bidder A more than bidder B. Porter and Zona (1999) (denoted PZ) propose a test based on the correlation of the residuals of single equation participation choice models. Negative correlation between two bidders' residuals implies territorial allocation and positive correlation phony bidding. PZ use it to detect phony bidding. I propose a test that is robust to unobserved heterogeneity, unlike the PZ test. This is based on solving the simultaneous equations model of participation. I use estimation techniques proposed by Tamer (2003).

The central difficulty in detecting collusion is that similar market outcomes can be a result of either collusive or competitive behavior. Territorial allocation can be a result of either an explicit agreement or due to cost advantages that firms have in different areas. Due to transaction costs for example, firms could decide to bid only on those markets that are near the location of their operations. With different locations, territorial allocation emerges as a competitive result. We get suspicious if the territories overlap, but firms still systematically avoid bidding for the same contracts. Unfortunately, this can be again a result of competitive behavior if the contracts are heterogenous. Some firms may have costs advantages in some types of contracts. Therefore with heterogenous contracts and asymmetric bidders, participation patterns of any kind may emerge in the competitive setting. However, if we control for bidder and contract heterogeneity, then the identity of other participants should not affect the participation decision of any bidder in the competitive setting. This makes testing for collusion possible. I apply the methods to school yard snow removal auctions in the City of Helsinki held in the autumns of the years 2003-2005. In Figure 1. I present the spatial participation pattern in these auctions in the year 2003. It marks on the city map the schools that each bidder has participated in and the location of bidders' and city's garages. The map shows that two bidders (A and K) seem to avoid each other. Moreover they systematically avoid each other in an overlapping geographic area, the city centre. This suggests collusive behavior in this market. This I put to test.

I make two contributions to the literature on collusion in auctions. First, I propose a new test to detect collusion. I will show with Monte Carlo analysis that it is robust to missing variables unlike the existing method. I will also show that the old and the new test complement each other. Second, the empirical application is important in itself because it is the first empirical study of a territorial allocation scheme. The minor contribution of this paper is the policy implications of the empirical application.

This study is related to two different fields of empirical industrial organization. The first is the literature on the detection of collusion. The second is the entry literature, as it is possible to think of this problem as an entry game with a single auction as an analog of a single market. Harrington (2005) provides a recent survey on detecting cartels. Also Levenstein and Suslov (2006) have a recent survey on cartel studies but they do not address auctions nor the detection of cartels. Berry and Tamer (2007) provide a survey on empirical analysis of entry models. The existing studies on the detection of collusion in auctions (Bajari and Ye (2003), Baldwin, Marshall and Richard (1997), Banerji and Meenakshi (2004), Porter (1983), Porter and Zona (1993,1999)) have only applications to phony bidding scenarios.

In Section 2, I present the market of the application and analyze its characteristics with respect to collusion. In Section 3, I present both the PZ test and my own test. I conduct Monte Carlo analysis to examine the finite sample properties of these tests in Section 4. Then I present the data and descriptive statistics in Section 5 and the results in Section 6. Finally, Section 7 concludes.

2 School yard snow removal market

One of the two main objectives of this paper is to detect possible collusion in the school yard snow removal markets in the City of Helsinki. This particular market is interesting because it allows the analysis of territorial allocation. This is the first empirical application that tries to detect that form of collusion. This is surprising because territorial allocation is fairly typical form of collusion. For example of all the reported Finnish cartels from a period 1959 - 1990, when cartels were legal, 7.2 % of the cartels were of this form. On the other hand, the cases where bidders use the territorial allocation scheme with overlapping territories may be limited. In this Section, I explain the rules of the auction in question and give a general description of the market. Harrington (2005) states that "it has been shown that cartel formation is more likely with fewer firms, more homogenous products and more stable demand". In this Section, I also show that these are all true for the market under scrutiny.

In Figure 1. I present the spatial participation pattern. It marks on the city map the schools that each bidder has submitted bids on in year the 2003. Also the location of the bidders' and city's garages is marked on the map (bold and larger letters). Most firms seem to participate more actively near their garages than further away. The map shows the bidders A and K seem to avoid each other. Moreover they systematically avoid each other in an overlapping geographic area, as we can see at the lower left corner. Of the other bidders, bidder R submits bids to all but two contracts and three small bidders, T, S and P, only a few bids. This map raises suspicions about collusive territorial allocation. Maps for years 2004 and 2005 are in Appendix 1. It is interesting to note that in the year 2005 the participation pattern no longer implies collusive behavior.

[Figure 1. about here]

Starting from the autumn 2003, the City of Helsinki has auctioned the snow removal services for school yards. All the contracts are auctioned simultaneously. The bidders submit single sealed bids for four different type of services for each school. First service type consists of snow ploughing and sanding. Second service is the transportation of snow from the school to the snow dump. Third service is the transportation of sand from the school to the snow dump and the fourth is washing the yard. The last two services are needed only once every spring. Different services can be allocated to different firms within the same school. The lowest bid wins the given contract and the winner is paid their unit bid times the respective size of the contract. After the auction, all the bids are public knowledge. Thus all bidders detect deviators from collusive agreements easily. The bids are in unit costs. In the first service for example, winner's bid is in euro per square meter. That times the school yard size in square meters is the payment per ploughing. Snow has to be ploughed every time there is 5 cm of snow on the ground. Typically, bidders submitted bids to all of the services, but there are exceptions. For example one firm participated only in the snow transportation service and they bid for all the schools. I consider only the bidding to the first service type because it is the most important in monetary terms. For the purpose of this study, the chosen service type does not matter. The amount of schools contracted differs from year to year. In the year 2003 there were 153 schools, in 2004 37 schools and in 2005 65 schools. This number varied according to how much of the services the City wanted to provide itself. I restrict the discussion in this Section mainly to the year 2003 because that is the year that I suspect that the collusion took place.

It states in the invitation to tender that "the buyer reserves the rights to transfer some of the contracts to be serviced by the city itself". This means that city announces that it has set a secret reserve price for the contract. The secret reserve price means that the city does not accept bids that are too high. In this case too high means a bid higher than the costs that the City would incur by providing the service itself. It seems that this secret reserve price is binding for many firms in most auctions. In 2003 a total of six bidders participated in the snow ploughing and sanding services. Of 153 contracts there were 2 with zero bidders, 85 with one bidder, 60 with two bidders, 5 with three bidders and 1 with four bidders. If the secret reserve price was not binding, we would expect all the potential bidders that are not capacity constrained to submit a bid in all the auctions. Also entry costs could limit the participation. However, there is little reason to suspect that bid preparation includes large costs to the firms in these markets because the bidding process is very simple and they have previous experience from providing the service under contract. An industry expert explained that it would take him about two minutes to calculate a bid in this sort of market because costs are very well known. The actual number of submitted bids can still change due to capacity constraints and different number of potential bidders in different areas of the city. PZ observe a similar distribution of actual bidders on their data set of school milk bidding. They suggest that small number of actual bidders indicates that "there may not be significant firm-specific information in the markets. If bidders knew their costs as well as the costs of the other potential suppliers, then under a set of standard assumptions either one or two bids would be observed. The low cost supplier would submit a bid just below the cost of the next-lowest-cost supplier, and the next-lowest supplier would be indifferent between bidding at its own cost and not bidding." In contrast to the markets analyzed in PZ, there is more uncertainty about the costs of other bidders evident in this market. The bidders use somewhat different equipment, they have different main activities and possibly efficiency differences. It is also implausible that the asymmetries among bidders would be so large that it is common knowledge which will be the cost ordering of the bidders in all the auctions. I think that the explanation of a binding secret reserve price possibly jointly with territorial allocation is more plausible. Also capacity constrains could limit the bidding of especially the small bidders.

Snow removal is typically a secondary activity for the firms. The main activities of three larger participants are construction, paving, delivery services and landscaping. Three smaller firms do real estate maintenance as their main activity. The common feature for all these firms is that they use the snow removal equipment for these main activities outside the winter period. Flambard and Perrigne (2006) argue in their study of snow removal contracts in Montreal, that because snow removal is a secondary activity to supplement income, capacity constraints do not seem to be a major issue in their auctions. For the Helsinki auctions, this is probably true for the larger companies. On the other hand, the smaller companies are typically one man firms with very limited amount of equipment. Three smaller firms only submit from three to six bids to schools located near their office. Another reason to suspect that the large firms are not constrained by capacity is the fact that they have subcontracting deals with each other. Thus they have access to additional capacity beyond their own. These firms also participate in other snow removal auctions that the City holds. The secondary nature of the activity also acts as an entry barrier. No seller can enter just the snow removal activity alone. The required equipment is too expensive in relation to the industry's part-year nature for it to be profitable. On the other hand there are numerous construction firms in the area that already have the necessary equipment.

Flambard and Perrigne (2006) investigate the potential asymmetry among bidders. They find empirical evidence of asymmetry resulting from firm location, because in the urbanized part of the city the storage costs are prohibitive. Their assessments of most of the market conditions hold also for the snow removal contracts here. The only difference being that in they study streets and I study schools. They argue that because of the equipment size and weather conditions, firms located far from the snow removal location will have to rent storage space for their equipment. This additional cost can induce some asymmetry among firms. They further argue that this asymmetry may prevent the least efficient firms from participating to the auction as their bids will not be competitive.

Markets can be described by the nature of demand, the nature of the production process and the nature of competitive interaction among bidders. Demand for snow removal services is very inelastic, because the weather is not affected by the price. Neither do the conditions stated in the invitation to the tender about when the service should be provided depend on prices. This property makes collusion more profitable because the increase in prices due to collusion does not reduce demand. The product is homogenous. There can be very little quality differences in snow removal. It is either removed or not. On the other hand, the existence of the secret reserve price makes the demand elastic. If cartel bids too high, the contract may not be awarded to anyone. Thus reservation prices reduce the incentives to collude. The production processes can be different due to differences in snow removal equipment.

Besides the fairly inelastic demand, there are other characteristics in this market that may facilitate collusion. First, firms compete only on prices, which simplifies the cartel operations. Thus the cartel needs only to coordinate the participation or the level of bids. Second is that publicly announcing all the bids and the bidder identities make it easier for the cartel to detect deviation. Markets are easily defined, allowing the assignment of territories. The set of participating firms is small and there are entry barriers making it possible to submit higher carter bids. Subcontracting is typical in this market. This provides an easy way to distribute the cartel rents and also facilitates direct communication and a pretext for the meetings of the cartel. The representative of the buyer (City service center PALMIA) thinks it is plausible that some of the firms could be colluding. However, there is no legal outside evidence. On the other hand, the simultaneous nature of these auctions makes it more difficult to sustain collusion. Bidders can punish from deviation only in the next year auction. However if the bidders meet in the other markets that they are active on, for example construction, they can possibly punish there. Also subcontracting deals allow a way to punish deviators.

As can be seen from the participation maps (Figures 1-3) the behavior of bidder A changes over time. In the year 2005 it bids to seven same schools as bidder K whereas in the year 2003 they never bid to the same school. K generally bids to the same schools in 2005 as in 2003. Therefore, with respect to equipment and location, it would probably have been possible for A to compete with K also in the year 2003, because I am not aware of any technology or location changes for A. This is further evidence for collusive behavior in 2003.

Job rotation is a similar phenomenon to territorial allocation. In a sequential auction setting job rotation can exist either as a result of collusion or as a result of an efficient outcome of a competitive bidding process when capacity constraints or decreasing returns to scale matter (Hendricks and Porter 1989). This makes the detection of collusion more difficult in sequential setting. In contrast to sequential auctions where the winners of previous auctions are observed, in simultaneous auctions the bidders do not observe how much capacity is already committed when making the decisions of participating in a given auction. Thus there is no backlog. In a simultaneous setting, capacity constraints or decreasing returns to scale affect only the total number of auctions that seller participates in. If there is enough uncertainty about other bidders' costs, competitive bidding should not result in the case where certain bidders systematically avoid each other. Assuming that bidders don't know to which homogenous auctions the competitors are going to bid, we can think that firms randomly submit bids to contracts up to their capacity. Then it is highly unlikely that some firms manage to systematically avoid each other when there are many contracts. Also in sequential auctions, the bidders may signal their preferences to other bidders more easily than in simultaneous auctions. Territorial allocation can be a result of competitive behavior when there are large observable cost differences among bidders. Still if these differences are controlled for we should not observe that identity in itself matters in a competitive setting.

The important players are probably not capacity constrained. If they were, they would have more incentives to avoid bidding to the same contracts. In a simultaneous game it is not possible to exactly know where the others are going to bid. Therefore we should observe that bidders anyway sometime bid to the same contracts if there is no way of communicating to each other what actions firms are going to take. Explicit communication is explicit collusion. If the game is played repeatedly, bidders can perhaps infer each others' future actions from past decisions. If incumbency for example explains a lot of participation decision, the collusion could as well be tacit. Existence of capacity constraints does not make this testing approach invalid but it can change the interpretation on the type of possible collusion. Unfortunately the information on contracts in 2002 was not available and thus the effect of incumbency cannot be checked.

3 Testing

In this section, I present the methods that I use to detect the possible collusion in this market. I present both the existing PZ test and propose a new test. I also discuss their relative strengths and weaknesses.

3.1 The old test

PZ propose several tests to detect collusion in auctions. They utilize both the participation decisions and the bid levels to test whether some bidders submitted phony bids. PZ use legal evidence to create a control group made up of nondefendant firms that bid on Ohio school milk contracts. They compare the behavior of this control group with the behavior of defendant firms. I present here one of their many tests that can be used also to detect territorial allocation and can be applied outside an auction setting. They test for the statistical independence in the probability of bidding using a standard pairwise procedure. PZ state: "Under the null hypothesis of independent action based on public information and the maintained specifications of our probit submission model, knowledge of whether one particular firm bids should not help predict whether another firm has also bid. In the case of complementary bidding, if one cartel member bids, then other ring members also bid. In this case the unexplained portion of the competitive bidding equation is positively correlated across cartel firms. In the case of territorial allocation, if a particular cartel member bids, then other cartel members will tend to not bid. Then the unexplained portion of the competitive bidding equation is negatively correlated across cartel firms." They propose to use the Spearman correlation coefficients computed using pairs of weighted residuals based on the control group probit models. PZ use the control group estimates also for the cartel group to address the problem of endogeneity that arises because the participation decisions of cartel firms are affected by collusion. This biases the estimates of the effect of observables on their participation. Assuming that all the bidders are identical, the control group estimates can be used as unbiased estimates also for the treatment group. There is a trade-off between the endogeneity problem and the need to make the assumption that all the firms react identically to changes in the explanatory variables when deciding whether to use the control group or not, when such is available. In situations where bidders have different production technologies or differ in some other important respects, it could be better not use a control group at all.

I present both the PZ test and the new test that I will propose below only in a two-bidder case. Both tests extend to a n-bidder case by conducting pairwise analysis for all the possible pairs of bidders. The PZ test could also be extended to the n-bidder case by using multivariate probit analysis. Assume that there are two competitive firms, denoted 1 and 2, who are considering entry into a single market. The PZ test is a standard test of endogeneity in a following bivariate probit model:

$$
\begin{aligned}
& y_1^* = x_1\beta_1 + u_1 \\
(1)\quad & y_2^* = x_2\beta_2 + u_2, \\
& \binom{u_1}{u_2} \tilde{}\, IIDN\left(\begin{bmatrix}0\\0\end{bmatrix}, \begin{bmatrix}1 & \rho\\ \rho & 1\end{bmatrix}\right), \\
& y_i = 1 \text{ if } y_i^* \geq 0, \text{ otherwise } y_i = 0,\ i = 1, 2.
\end{aligned}
$$

Now y_i^* denotes the latent continuous variable that determines the participation decision. In an auction setting, y_i^* is the expected profit of bidder i from submitting a bid. Bidder i submits a bid to an auction if $y_i^* > 0$. x includes all the observable variables that affect the bidder's costs and its probability of winning the auction. We observe $y_i = 1$ if the bidder submitted a bid and $y_i = 0$ if it did not. In practise PZ propose to estimate both equations of (1) separately with probit and then test whether the residuals are correlated. If the Spearman correlation is negative and statistically significant, we can conclude that we are missing some variable from the estimation that affects the bidders differently and significantly. If we have no other missing variables, this is the competitor's decision to bid. For example, firm 1 bids on those contracts that are allocated to it in the collusion scheme and firm 2 avoids those contracts as agreed. The benefit of this test is that it does not require many observations and that it is identifiable even when the firms under scrutiny never bid to the same contracts. It is also computationally very fast, easy to implement and has better convergence properties than simultaneous equation methods. The test hypothesis in PZ case is:

No collusion, H_0: $Corr(u_1, u_2) = 0$,
Collusion, H_1: $Corr(u_1, u_2) \neq 0$.

PZ detect positive correlation and thus conclude phony bidding. The first test of endogeneity in a bivariate probit model was introduced by Kiefer (1982) to the statistics literature. There are also numerous other ways to test for endogeneity in this model. Monfardini and Radice (2006) survey and compare these tests with a Monte Carlo analysis in a recursive probit framework. Typically, the test hypothesis is written as

No collusion, H_0: $\rho = 0$,

Collusion, H_1: $\rho \neq 0$.

Firms would prefer being the only bidder to competing against other firms. If this is not controlled for in the estimation, it creates negative correlation in the residuals that would make us point out innocent firms as guilty of territorial allocation or make it harder to detect phony bidding. For this reason PZ include the observed competitors' characteristics in x in their estimation. They seem to implicitly assume that this captures all the strategic reasons for the bidders to avoid each other in a competitive setting. I maintain this assumption also in my test.

The main problem with the PZ test is that it is not robust to unobserved heterogeneity, in particular to missing variables that are correlated with the participation decision. Any missing variable that affects both bidders (in the same or in a different direction) will enter the residuals and thus corrupt the test. Next, I propose a new test that is robust to all such missing variables that would corrupt the PZ test.

3.2 The new test

Assume that there are two competing firms, 1 and 2, that do not know ex ante to which markets the other firms are going to bid. Assuming that the value of the outside option is zero and the payoffs are linear, a standard simultaneous entry game can be presented with the following payoffs:

	$y_2 = 0$	$y_2 = 1$
$y_1 = 0$	$0, 0$	$0, x_2\beta_2 - u_2$
$y_1 = 1$	$x_1\beta_1 - u_1, 0$	$x_1\beta_1 + \delta_1 - u_1, x_2\beta_2 + \delta_2 - u_2$

This game maps directly into a following model:

$$y_1^* = x_1\beta_1 + y_2\delta_1 + u_1,$$

$$y_2^* = x_2\beta_2 + y_1\delta_2 + u_2, \quad (2)$$

$$\binom{u_1}{u_2} \tilde{} IIDN\left(\begin{bmatrix}0\\0\end{bmatrix}, \begin{bmatrix}1 & \rho\\ \rho & 1\end{bmatrix}\right),$$

$$y_i = 1 \text{ if } y_i^* \geq 0, \text{ otherwise } y_i = 0.$$

There are two reasons for the firms to avoid each other. The first is the strategic reason that is in play when firms are competing. The second is the possible collusive agreement. Therefore, $y_j\delta_i = y_j\mu_i + y_j\gamma_i$, where the term $y_j\mu_i$ captures the strategic (competitive) effect, and $y_j\gamma_i$ the collusive effect.

When firms are colluding, they communicate their entry decision. Thus firm i knows the value of y_j. However when firms are competing, they can only build expectations on other firm's participation decision. This allows for separating the effects of the competitor's participation in the estimation. Identification of this model is based on the assumption that when the firms compete, the shocks are private and therefore $\Pr(y_j = 1|x_j)\mu_i$ captures the strategic effects more accurately that using the actual participation decision $y_j\mu_i$. Firm i forms an expectation on $\Pr(y_j = 1|x_j)$ based on its competitor's observed characteristics. Therefore we get $y_j\mu_i = \Pr(y_j = 1|x_j)\mu_i = d_j\mu_i$, where d_j denotes those characteristics of bidder j that are observed by bidder i, $i \neq j$. Then the strategic element is controlled for by simply including the characteristics of the analyzed competitor in x. The characteristics of other competitors are thought of as contract characteristics and are therefore in the x vector as well. Now this model reduces back to equation (2), but now $y_j\delta_i$ consists only of the collusive effect $y_j\gamma_i$. Because colluding firms do not compete against each other, we have $\gamma_i < 0$ (territorial allocation) or $\gamma_i > 0$ (phony bidding) and $\mu_j = 0$, for all $i \neq j$ when the firms collude. When the firms are competing, $\gamma_i = 0$ and $\mu_j < 0$. If the firms collude only in some auctions and compete in others, both the terms could be negative but are still correctly identified since the other term is estimated based on the actual participation and the other term on the expected participation. Instead of d_j, one could include more refined estimates of $\Pr(y_j = 1|x_j)$ in the equation. One could utilize for example the two stage approach proposed by Bajari et al. (2007a). Because an improvement in this dimension is not the objective of this paper, I maintain this linear identification assumption that PZ make for the sake of simplicity.

Whether the shocks are private or common depend on whether the firms collude. For us to be able to control for the strategic behavior in the way explained above, firms must get private shocks to the profitability of entry when competing. With incomplete information, the bidders form beliefs about other bidders' participation decisions. Given these beliefs, they have a unique response in a two-bidder game, given their own shock. These beliefs can be controlled for by including the competitors' characteristics in the x. With complete information u_1 and u_2 are common knowledge to the firms but unobserved by the econometrician. With incomplete information u_i is private information and thus observed only by firm i. This assumption makes a difference to the econometric analysis. There is currently no method for determining which information structure the data generating process follows. Fewer bidders and more experience in the market make complete information more plausible. The incomplete information assumption that PZ need to make seems to be natural in most auction settings when firms are competing. Gibbons (1992) for example, uses auctions as an example of incomplete information games in his influential textbook on game theory. This assumption was made for example in the entry analysis conducted by Seim (2006). However, when firms are colluding it seems natural that they communicate these private shocks to each other, thus making the environment that of complete information.

The main contribution of this paper is following. I propose to test for collusion by estimating the simultaneous equation system (2) fully and basing the collusion test on whether the δ's differ significantly from zero. If they are zero, the model reduces to the competitive model. The main benefit of this test is that it is robust to unobserved heterogeneity, in particular to any missing variables that affect the entry decisions, given that they are not correlated with the other observed explanatory variables. Note that the shock structure in equation (2) also allows for common shocks, i.e. missing variables that are observed by both the firms but not by the econometrician. These enter into the common component of the error term ρ. When estimating all the parameters simultaneously, including ρ, ρ captures the effects of all the missing variables that affect the entry decisions of both the bidders directly or indirectly through the other bidder (in the same or in a different direction). Therefore the δ's are estimated correctly. For example there could be differences in production technologies that make it more costly for bidder 1 to provide the service to certain schools, but the characteristics of these particular schools do not hinder bidder 2. For example firm 1 has larger vehicles and thus trouble getting them through the gates of certain schools. This is unobserved by the econometrician but observed by bidder 2. Then bidder 1 would usually avoid those schools and therefore bidder 2 would bid more often to those schools. This will make ρ negative. The PZ test would be corrupted but my test would not. Variables that are observed by one bidder and unobserved by the other bidders and the econometrician enter in the private part of the error term. Both the old and the new test are robust to such missing variables. Therefore the new test is robust such missing variables that would corrupt the old test. In the case of territorial allocation, both δ's are negative and in case of phony bidding they are positive. The test hypothesis is now:

No collusion, H_0: $\delta_i = 0$ for all $i = 1, 2$

Collusion, H_1: $\delta_i \neq 0$ for some $i = 1, 2$.

3.3 Estimation in the new test

Model (2) is exactly the one discussed in Tamer (2003), the only difference being that he does not specify the distribution of the error term. Tamer (2003) assumes that the error terms are common knowledge for the firms but unobserved by the econometrician. According to Tamer (2003), this game always has multiple equilibria for large enough supports of the error terms. This needs to be taken into account in the estimation. There are some recent studies on structural analysis of entry games in auctions. They have different approaches to addressing the problem of multiplicity of equilibria. For Bajari and Hortacsu (2003) multiple equilibria is not a concern as they only consider the number of bids, not the identity of the entrant. Athey et al. (2004) abstract away from the multiple equilibria problem by arguing that "as is often the case with entry models, there may be many equilibria, as a result, our results compare sets of equilibria across auction methods". Krasnokutskaya and Seim (2006) verify the uniqueness of the equilibrium entry probabilities numerically. Li and Zheng (2006) take the fully structural approach to estimate a model that allows for endogenous entry, an uncertain number of actual bidders, unobserved heterogeneity and mixed strategy entry equilibrium under the independent private values paradigm. Their model requires observations where $n \geq 2$. Most of the auctions in my application data have only 1 bidder. Also Li (2005) allows for mixed strategies. Both of these papers assume symmetric bidders. Bajari et al. (2007b) use simulations to calculate all the equilibria. One common econometric goal of all these structural auction papers is to estimate the distribution of bidder's private costs and the distribution of entry costs. They do not provide any methods to test for collusion, which is the aim of this study. I follow the existing literature on detecting collusion in auctions and use reduced form methods. It is much easier to answer my questions in a reduced form. This is an unrealistic but hopefully innocuous assumption.

Various methods to conduct this estimation have been proposed in the literature. For example, Greene (1998) states that this kind of model can be estimated with a bivariate probit model without having to pay any heed to the simultaneity problem. It seems that Greene (1998) is implicitly assuming a unique equilibrium, as he states: "in the bivariate probit model, unlike in the linear simultaneous equations model, if the two dependent variables are jointly determined, we just put each other on the right-hand side of the other equation and proceed as if there were no simultaneity problem". I do not use this method in the application because according to a Monte Carlo analysis, it always overestimated the negative effect of δ's, thus making the empirical size 100% in every model in table 1. I used STATA command "biprobit" to estimate a seemingly unrelated simultaneous probit equation. It also had severe convergence problems. To be able to obtain any results, I had to limit the number of iterations in the maximization for over half of the simulated sets of data for most data generating processes in table 1.

In territorial allocation setting it is natural to assume that δ_j are both negative. Then, according to Tamer (2003), it is easy to see that $Pr[(0,0|x)] + Pr[(0,1|x)] + Pr[(1,0|x)] + Pr[(1,1|x)] > 1$. This is an example of an incoherent model. Typically, econometricians have imposed a coherency condition $\delta_1 * \delta_2 = 0$. This condition changes the model into a recursive one and thus eliminates the simultaneity. Bresnahan and Reiss (1990 and 1991, denoted BR) and Berry (1992) transform the model into one that predicts the joint outcome [(0,1) or (1,0)]. This provides consistent point estimates for the parameters on interest but involves loss of information. Bjorn and Vuong (1985) and Kooreman (1994) assume that unique outcome is chosen with known probability in the region of incompleteness. According to Tamer (2003) this may lead to inconsistent estimates. Toivanen and Waterson (2005) eliminate the possibility of multiple equilibria by assuming that the entry game proceeds as Stackelberg competition. Seim (2006) uses simulations to show that her model has a unique equilibrium.

BR provides one estimation method that is useful in my case. Instead of using an ordered probit as BR do, I use the simultaneous equation formulation of their idea provided by Tamer (2003). Tamer (2003) also proposes a new and more efficient estimator. It is however computationally more challenging and conducting Monte Carlo analysis using it would take a lot of time. Moreover, it uses multidimensional kernel smoothing that requires more data points than I have available in the application. For these two reasons, that estimation method is not used here.

The maximum likelihood estimator presented by Tamer (2003) that uses the BR idea, is defined by a following log-likelihood

$$(3) \qquad L_{ML}(b) = \sum_{t=1}^{T} \begin{bmatrix} y_{t1}y_{t2}\log(P_1(x_t,b)) + (1-y_{t1})(1-y_{t2})\log(P_2(x_t,b)) \\ +((1-y_{t1})y_{t2} + y_{t1}(1-y_{t2}))\log(1-P_1(x_t,b)-P_2(x_t,b)) \end{bmatrix},$$

where $P_1(x_t,b) = \Pr[(y_{t1}=1, y_{t2}=1)|x] = \Pr(u_{t1} \geq -x_{t1}\beta_1 - \delta_1; u_{t2} \geq -x_{t2}\beta_2 - \delta_2)$ and $P_2(x_t,b) = \Pr[(y_{t1}=0, y_{t2}=0)|x] = \Pr(u_{t1} < -x_{t1}\beta_1; u_2 < -x_{t2}\beta_2)$

There are $t = 1, ..., T$ auctions in the data. y_{t1} gains value one if bidder 1 submitted a bid in auction t, otherwise it is zero. Assuming that u_1 are distributed bivariate normal, P's are known functions and (3) can be maximized with standard numerical optimization methods.

The benefit of this test is that it is robust with respect to missing variables, but that comes with a cost. This test requires more observations than the PZ test. It also requires that there are some auctions in the data where both bidders have submitted a bid. The need to rely on numerical optimization methods means that it is also harder to implement, may have convergence problems and is computationally time consuming.

4 Monte Carlo analysis

I conduct Monte Carlo analysis to compare the finite sample properties of the new test that I propose (called BR) with the existing PZ test. This is done by comparing the empirical power and size of these different tests. The Monte Carlo model is chosen to reflect the characteristics of the actual application. Variable x can be thought of as a contract characteristic, like contract size and variables z's as the bidder characteristics, like distance. The BR estimation is based on the model (4) and is estimated with the equation (3). The PZ model is estimated with single equation probits omitting $y_j\delta_i$ from the model (4).

$$\begin{aligned} & y_1^* = \beta_{10} + x\beta_{11} + z_1\beta_{12} + z_2\beta_{13} + y_2\delta_1 + u_1 \\ (4)\quad & y_2^* = \beta_{20} + x\beta_{21} + z_2\beta_{22} + z_1\beta_{23} + y_1\delta_2 + u_2 \\ & \binom{u_1}{u_2}\,\tilde{}\,IIDN\left(\begin{bmatrix}0\\0\end{bmatrix}, \begin{bmatrix}1 & \rho\\ \rho & 1\end{bmatrix}\right). \end{aligned}$$

I use eight different specifications in the data generating process. They are summarized in table 1. To adress the multiplicity of equilibria, the data generation is conducted in a following way. First I generate x from a uniform (0,1) distribution. The z's are discrete variables that gain values 1,2,3 and 4 each with 25 % probability. Then I calculate the following cell probabilities for y's. Let $\beta_{10}+x\beta_{11}+z_1\beta_{12}+z_2\beta_{13} = x_1\beta_1$ and $\beta_{20} + x\beta_{21} + z_2\beta_{22} + z_1\beta_{23} = x_2\beta_2$. Then, I assign the multiple region (see Tamer (2003)) an equal change of being a bid by either bidder. This is done by reducing $[(P_{00} + P_{01} + P_{10} + P_{11}) - 1]/2$ from both P_{01} and P_{10}. Then I use these new cell probabilities to randomly assign simultaneously values for the pair (y_1, y_2).

	$y_2 = 0$	$y_2 = 1$
$y_1 = 0$	$P_{00} = BVN(-x_1\beta_1, -x_2\beta_2, \rho)$	$P_{01} = BVN(-x_1\beta_1 - \delta_1, x_2\beta_2, \rho)$
$y_1 = 1$	$P_{10} = BVN(x_1\beta_1, -x_2\beta_2 - \delta_2, \rho)$	$P_{11} = BVN(x_1\beta_1 + \delta_1, x_2\beta_2 + \delta_2, \rho)$

[Table 1. about here]

The results are presented in table 2. The PZ results were obtained using STATA "simulate" routine. The results for BR were obtained using the R statistical package, with the "optim"-command solving the maximization problem[1]. Monte Carlo analysis for the BR method was very time consuming. It would have taken about half a year of computer time to get all the results in table 2, if I had used only my 3,0 GHz single processor computer. The calculations were made feasible by dividing the tasks into multiple processors. At best I used 16 different processors.

The results are overall very encouraging for the use on the new test. For models with no unobserved heterogeneity (1.-4.) PZ has much better power. It detects guilty firms more often. For these models, it however does worse in size, meaning it points out innocents as guilty too often. For models with unobserved heterogeneity (5.-8.), which is generated with ρ, PZ fails utterly as expected. Either having huge amount of type I errors (model 5.) or very low power (model 8.), depending on the sign of ρ. BR estimation does almost as well with unobserved heterogeneity as without it. The only concern with BR is the low power results. This concern is alleviated by the fact that the BR method produces on average accurate estimates for all the parameters. Only the estimates for δ's seem to be slightly closer to zero than they should be. Because ρ is estimated accurately, BR can be used jointly with PZ as a way to evaluate whether there are missing variables. Therefore the Monte Carlo analysis shows that BR method in cases with unobserved heterogeneity works much better that PZ and in the case with no unobserved heterogeneity is complementary to PZ. Therefore the test that I propose works as expected and should be used instead of or in addition to the existing PZ method.

[Table 2. about here]

5 Data and modeling choices

There are 258 auctions in the data with 335 bids submitted. 28 auctions did not receive any bids, of which 19 where held in 2004. Nine bidders participated in these auctions. Six in 2003, three in 2004 and six in

[1] I examined the different algorithms available in "optim" command with Monte Carlo analysis. The Nelder-Mead algorithm worked the best. It also gave more accurate results on average than the "nlm"-command, that utilises the delta method.

2005. Three firms exited the market after 2003 and three new entered in 2005. The participation decisions of bidders are described in table 1 along with the bid levels. It shows the number of bids submitted, the number of contracts won, the number of contracts won conditional on facing any competition and bid level information for each bidder. It also shows to which city areas a given bidder submitted bids and in which years the bidder submitted any bids. Only three players submitted bids every year. By looking at the map we notice that only A and K avoid each other in the same city area. Therefore I conduct the tests only for the bidders A and K. Moreover, bidder R submitted too many bids in the year it participated and bidders T,S, H and O too few bids to be of any use in analysis of discrete choice models. There is too little variation in their decisions to use the tests for them.

[Table 3. about here]

The data includes information on contract characteristics and bidder characteristics. Contract characteristics include the school yard size and some measures of its shape or "tighness" that is intended to capture how difficult it is to plough the yard. These are the number of walls or fences that surround the yard, the number of permanent obstacles like trees or small buildings in the yard and dummy for whether the yard includes tight spaces. The shape variables are obtained by looking at the 1:1250 -maps of the school areas. This allows detail to the point of a single tree. Contract characteristics also include the distance to the schools from the city's garages to account for possible changes in the secret reservation price. The information on the bidders is very limited. Bidders did not agree to be interviewed. They only answered a few short questions. The most important variable that we are interested in is the location of bidder garages. We could use that to calculate the distances from garages to the contracted schools. I did not receive the accurate addresses of the garages but the firms gave their location information on postal code level. I assumed that the garage is located in the middle of the given postal code area. This creates measurement errors to distance variable. Another and perhaps even more important reason to use something else than just the distance to capture the cost shifters of the firms is that according to an industry expert another important factor is where the bidders' main activities are located at the time. Bidders prefer schools near their construction sites for example. This is not observable. Thus we need to construct proxy variable for firms' cost shifters. I also use four area dummies in the analysis to capture the bidders' strengths in larger area around the school. These area dummies also capture the possible changes in the number of potential bidders.

To proxy all firm specific cost shifters, I construct a variable called "sact" - subjective activity. First I counted a variable "ofsix" - how many of the six nearest schools of a given school a given bidder submitted a bid in a given year. I formed an index variable "sact" out of this that gains a value one for the highest value a given bidder had in "ofsix", two for the second highest and so on up to seven in case the bidder had all the values from zero to six in the "ofsix" variable. Note that different bidders can both have a value one in "sact" with different values of "ofsix". This variable captures not only the distance, but also the overall costs of the bidder in the close proximity of the given school. There is a possible endogeneity problem with this proxy. Bidder might have or might not have bid to some of the near schools due to collusion instead of cost conditions. Experimenting with different proxies for distance and using distance alone does not change the results of the tests. When explaining the distance with the "sact" proxy for bidder A, R^2 is about 0.5 for year 2005 and about 0,3 for year 2003. Correlation is significantly positive for both years. These facts imply that the proxy is valid and that endogeneity problem is not necessary significant.

Another source of possible endogeneity is that unlike PZ, I do not have a control group. PZ use parameter estimates gained from control group probit estimations in testing. This is because the participation of collusive firms is affected by collusion thus biasing the estimated effect of observables on their participation. Assuming symmetry the control group estimates can be used as unbiased parameter estimates also for the test group. I do not have any outside evidence nor enough bidders to form a control group. I need to assume that this possible bias in the parameters of the control variables does not bias the estimates of the test statistics. However, I do not need to assume bidder symmetry like PZ.

Figure 2. shows the scatter plots of bids in relation to school yard size for each bidder separately. Bidder A participated in smaller auctions than other bidders. The reason for this could be that they operate only in the centre of the city where yards are typically smaller. It can also be because they specialise in smaller yards due to their different equipment. We note that unit bids are decreasing in yard size, implying economies of scale. These seem to be decreasing. Thus I include yard size and its square in the econometric analysis.

[Figure 2. about here]

6 Results

The results of the PZ test are presented in Table 4. I have estimated probit models separately for bidders A and K. First I estimate the model for year 2003 alone and then for the joint data of all the years. The subjective activity variable is significant for both bidders and has the expected negative sign. Bidder A seems to bid close to city garages, more in the south region of the city and more to difficult yards. This is in line with the fact that they advertise having equipment best suited for difficult yards. Bidder K seems to get some returns to scale from yard size. Both bidders are more active in 2005. The residuals of these two probit models are negatively correlated. This correlation is significant for the 2003 data. This implies collusion in the year 2003 but not in 2004-2005. Collusion is also supported by the fact that competitors' characteristics are not important for bidder K and bidder A bids more often to schools to which one would expect bidder K to bid. When using more refined area dummies, the correlation is no longer significant even for the 2003 data. I also conducted this test with smaller control set separately for 2005 and 2003 alone. Then the residual correlation was positive and not significant for 2005 and negative and significant at every standard level for 2003. "sact" variable is not significant for any of the omitted bidders but including them in the model with many area dummies makes the negative residual correlation again significant for 2003. The model is not very robust to different specifications but overall the results seem to support collusion that took place in 2003. This is assuming that I have not overlooked any important explanatory variable.

[Table 4. about here]

The results from estimating the simultaneous equation model (2) with using the BR approach are presented in Table 5. Unfortunately, the convergence properties of BR likelihood maximization with my data are not very good. The results are not robust to the starting values of the algorithm nor to different algorithms used. Often convergence is not achieved and the parameter estimates are those that the algorithm reached at the iteration limit. The Hessian matrix is only rarely well behaving. I report the results from three different approaches to these problems. First set of parameter estimates is picked from the set of results with arbitrary chosen starting values so that the likelihood function has the largest value, conditional on the hessian matrix being well behaving. The second set of parameter estimates is gained when the starting values for the control variables were taken from the single equation probit estimates. Third set of results is gained from a nested method where the rho is fixed zero at the first stage and then estimated at the second stage alone, fixing the other variables to the values reached at the first stage. There are cases when the likelihood function gained larger values than for any of the reported results but then the parameter estimates gained absurd values and/or rho went to exactly 1, thus limiting the model to one with a common error term for both equations, and/or the Hessian matrix was not well behaving. Due these problems in the numerical optimization, these results should be treated with caution.

[Table 5. about here]

The subjective activity variable is significant for both bidders and has the expected negative sign. Competitors' characteristics are typically not important. A also bids more to schools with difficult yards. The results for K concerning how difficult the yard is to plough are ambiguous. K is significantly more active in 2005. A bids more to south area. The test statistics are not significant. According to the PZ test, bidders A and K seem to collude. The BR test does not support this conclusion, as the test statistics are not significant. Their sign however suggests collusive behavior. More importantly BR results show that rho is close to zero and the null hypothesis of zero rho is not rejected in any of the results. Because we do not seem to be missing any important variables from the model, the PZ results are valid. Collusion is also implied by the fact that strategic elements do not seem to be important for the bidders, because they do not avoid bidding to contracts that their competitors are likely to bid to.

The behavior of firms A and K seems to be more consistent with a collusive than a competitive model. In terms of Harrington (2005), this is a screening result, which means that I have identified this market as suspectible to collusion. This can also be thought of as the verification of the cartel because the method by construct identifies the exact model of collusion. This is not however sufficient for the prosecution of the colluding firms. Screening is useful in fairly quickly analysing the market to detect those where more attention should be put to find legal evidence.

7 Conclusions

I have a proposed a new test to detect collusion that is based on participation decisions. The test is conducted by estimating two simultaneous discrete choice equations with methods proposed by Tamer (2003). This test can be applied to all environments where independent and mutually exclusive markets can be defined. Auctions are only one potential application environment. The test is best suited for detecting territorial allocation schemes. It can also be used to detect phony bidding but there are others and better tests for that purpose. Monte Carlo analysis shows that this test has the desired properties. Namely that it is robust to missing variables unlike the existing test with similar properties by PZ. Its size properties are also shown to be better. The PZ test is better in a sense that it requires less from the data, both in terms of number and the nature of observations. The old test also has better convergence properties and better power. The new test complements it as it can be used to check whether the model has important missing variables that would invalidate the existing test approach.

I apply both these tests to school yard snow removal auctions in the City of Helsinki and find some evidence of collusion. The PZ test suggests collusion and the new test shows that it is likely that there are no missing variables. Moreover the analyzed firms do not behave strategically as we would expect in the competitive setting. Two bidders seem to participate in a contract allocation scheme. The collusive regime seems to last only the year 2003. However due to possible endogeneity problems and problems in the numerical optimization, these results should be treated with caution. Still, this analysis should validate closer legal study to support the prosecution of these two companies.

Table 1. Different model specifications used in the Monte Carlo analysis

Model	β_{10},β_{20}	β_{11},β_{21}	β_{12},β_{22}	β_{13},β_{23}	δ_1,δ_2	ρ
1.	0	0.3	-0.3	0	0	0
2.	0	0.3	-0.3	0	-0.3	0
3.	0	0.3	-0.3	0	-0.45	0
4.	0	0.3	-0.3	0	-0.6	0
5.	0	0.3	-0.3	0	0	-0.5
6.	0	0.3	-0.3	0	-0.45	-0.5
7.	0	0.3	-0.3	0	0	0.5
8.	0	0.3	-0.3	0	-0.45	0.5

Table 2. Power and Size results for the Monte Carlo comparison of the tests with 5 % significance level.

Model	Obs	PZ, power	PZ, size	BR, power	BR, size	BR, ρ
1.	500		13.5%		8.9%	0.06; 6.5%
1.	1000		18.9%		9.7%	0.05; 7.1%
2.	500	69.5%		28.6%		0.07; 6.8%
2.	1000	90.1%		34.5%		0.04; 6.4%
3.	500	89.7%		39.8%		0.07; 7.2%
3.	1000	98.7%		48.0%		0.06; 6.8%
4.	500	97.0%		50.6%		0.08; 5.5%
4.	1000	99.7%		62.6%		0.07; 6.8%
5.	500		54.4%		11.1%	-0.42; 34%
5.	1000		80.7%		10.8%	-0.45; 55%
6.	500	100%		28.0%		-0.45; 35%
6.	1000	100%		34.5%		-0.46; 64%
7.	500		0.0%		5.2%	0.52; 73%
7.	1000		0.0%		7.1%	0.52; 90 %
8.	500	7.0%		46.7%		0.55; 72%
8.	1000	4.0%		61.6%		0.53; 89%

In the last column titled "BR, ρ", the first number is the mean of the estimated ρ's and the second number is the share of these estimates that are significantly different from zero.

Figure 1. Bidder participation in school yard snow removal auctions in Helsinki 2003.

Small capital letters present the location of schools and which bidders (A,K,P,R,S,T) have bid to a given school. "-" means that there were no bids. The approximate location of bidders' and city's (C) garages are marked with larger and bold capital letters.

Table 3. Descriptive statistics for the bidders in years 2003-2005. Participation and bids.

	A	K	R	T	S	P	H	J	O
# of bids	42	98	151	3	3	16	1	19	2
# wins	33	89	97	1	1	4	1	2	2
# of wins|com	16	66	12	1	1	1	0	0	2
mean bid	0,097	0,071	0,089	0,100	0,090	0,107	0,050	0,103	0,097
sd bid	0,005	0,020	0,005	0,017	0,052	0,021	NA	0,022	0,018
min bid	0,082	0,040	0,085	0,080	0,060	0,068	0,050	0,071	0,084
max bid	0,110	0,156	0,980	0,110	0,150	0,135	0,050	0,140	0,110
South(centre)	Yes	Yes	Yes	No	No	No	Yes	No	No
Northwest	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
North	No	Yes	Yes	No	No	No	No	Yes	Yes
East	No	Yes	Yes	No	Yes	No	No	No	No
Year 03	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
Year 04	Yes	Yes	No	No	No	Yes	No	No	No
Year 05	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes

Figure 2. Scatter plots of bids and school yard size for each bidder separately for snow ploughing and sanding contract (bid 1 + bid 2) in year 2003.

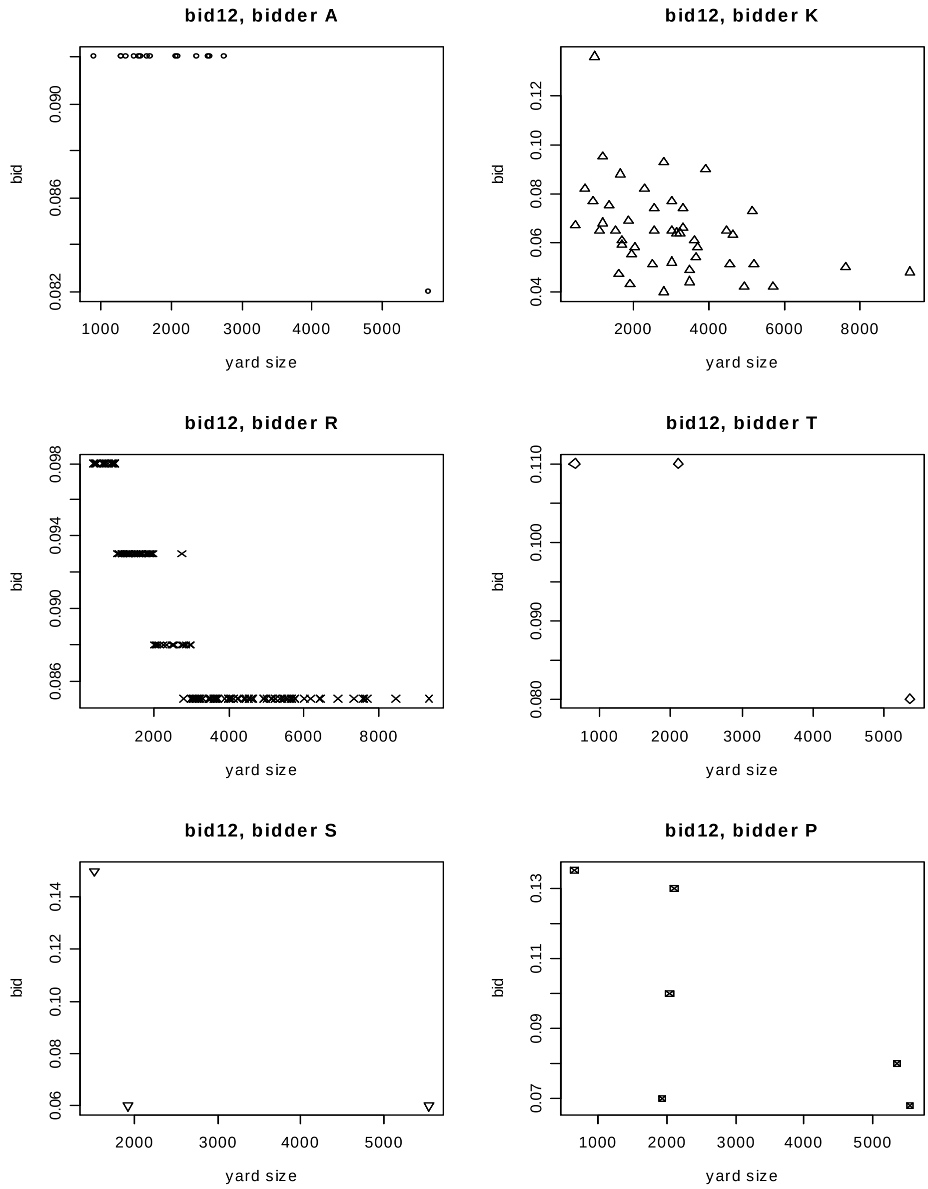

Table 4. Results of the single equations probit estimations and the residual correlation test.

	2003		2003-2005	
	Bidder A	**Bidder K**	**Bidder A**	**Bidder K**
constant	+	+	+	+
cd	-**	-	-****	+
ys	-	+	-	+*
ys^2	-	-	+	-
w	-	-	+	+
o	+	+	+	-
s	+	+	+**	+
t03			ref group	ref group
t04	NA	NA	-	-
t05			+***	+**
sactA	-***	+	-****	+
sactK	-	-**	-*	-****
sactP	-	-	-	-
Area S	+	+	+***	+
Area NW				
Area N	ref group	ref group	ref group	ref group
Area E				
Log lik	-11,3	-86,2	-25,9	-142
AIC	44,5	194	77,8	310
Corr	-0,188**		-0,082	

Unit of observation is school. n=153 for 2003 and n = 258 for 2003-2005. "cd" is the distance from the nearest City garage. "ys" is the yard size and "ys^2" its square. "w" is the number of walls surrounding the yard, "o" the number of obstacles in the yard and "s" a dummy for yard including tight areas. "t03 - t05" are the year dummies and "Area X" the area dummies. "sacti" is the subjective activity of bidder i. "*" means 10 % significance level, "**" means 5 % significance level, "***" means 1 % significance level and "****" means 0,1 % significance level for two-sided tests.

Table 5. Results of the simultaneous equations estimation.

	Results 1		Results 2		Results 3	
	Bidder A	Bidder K	Bidder A	Bidder K	Bidder A	Bidder K
constant	+	+	+	+	+	+
cd	-	+	-***	+	-	-
ys	-	+	-	-	-	+
ys^2	-	-	+	-	+	-
w	+	+	-	+	+***	-**
o	+	-	+	-	+**	-
s	+	-	+*	-	+	+*
t03	ref group	ref group	ref group	ref group	ref group	ref group
t04	-	+	-	-	-	+
t05	+	+**	+	+*	+	+****
sactA	-**	+	-**	+	-**	+
sactK	+	-****	-	-****	-	-****
sactP	+	-	+	-*	-	-
Area S	+	+	+*	+	+*	+*
Area NW						
Area N	ref group	ref group	ref group	ref group	ref group	ref group
Area E						
y1	response	-0.397	response	-0.285	response	0.013
y2	-0.419	response	-0.219	response	-0.518	response
rho	0.087		-0.158		-0.182	
Lik	-139.7604		-144.9183		-148.8319	

A unit of observation is school. n = 258. "cd" is the distance from the nearest City garage. "ys" is the yard size and "ys^2" its square. "w" is the number of walls surrounding the yard, "o" the number of obstacles in the yard and "s" a dummy for yards including tight areas. "t03 - t05" are the year dummies and "Area X" the area dummies. "sacti" is the subjective activity of bidder i. "*" means 10 % significance level, "**" means 5 % significance level, "***" means 1 % significance level and "****" means 0,1 % significance level for two-sided tests.

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Appendix 1. Participation patterns

Figure 3. Bidder participation in school yard snow removal auctions in Helsinki 2004.

Small capital letters present the location of schools and which bidders (A, K, P) have bid to a given school. - means that there were no bids. The approximate location of bidders' and city's (C) garages are marked with larger and bold capital letters.

Figure 4. Bidder participation in school yard snow removal auctions in Helsinki 2005.

Small capital letters present the location of schools and which bidders (A, H, J, K,O, P) have bid to a given school. - means that there were no bids. The approximate location of bidders' and city's (C) garages are marked with larger and bold capital letters.