INFORMATION REVELATION AND BIDDING BEHAVIOR IN ELECTRICITY AUCTION MARKETS

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1. INTRODUCTION

It is well understood that the exchange of cost and demand information among rivals may alter competitive behavior and equilibrium market price.[1] But in some circumstances a particular firm may acquire information about one or more specific rivals. This may occur as a result of accident or espionage, regulatory or legal disclosure requirements, or market rules that allow firms insight into their rivals' operations. This paper is an empirical examination of the auction market for wholesale electric power in New York in which bidders may possess nearly contemporaneous information about many aspects of the operations of some of their rivals. We are particularly interested in the relationship between the extent of such information revelation and the bidding behavior of those bidders that are most likely to be marginal in the auction market, and thus likely to determine the market equilibrium price.

Deregulation and restructuring of the electric power sector in the U.S. and elsewhere has generally involved the creation of organized auction markets run by public or semipublic authorities to elicit supply of bulk power from a merchant generation sector. In these markets bidders typically offer power on an hour-by-hour basis for the next day. The auction market operator–a so-called Independent Service Operator--combines the collective supply offers with an independently determined demand forecast to establish the uniform market-clearing price. This in turn determines the identity of the bidders that will provide power, and their quantities, in each hour. Bidders may be generators, but they may also be other participants in the electricity sector or outside firms altogether. Bidders may either own the generating units that they bid into the auction market or simply have contractual arrangements with some generating units.

The rules of the New York state auction market impose some limits on the arrangements between bidders and generators. No single generating unit, for example, can be under contract for portions of its capacity to more than one bidder at any point in time. But the rules do not prohibit any single generating

[1] See, for example, Shapiro (1986), Kihlstrom and Vives (1989), Vives (1990, 2002), Raith (1996), Huck et al (2000), Kuhn (2001), and for an especially useful outline of cases and results, Kuhn and Vives (1994).

unit from being under contract–exclusive at each point in time–with different bidders over time, and there is no minimum duration requirement for those contracts. As a result, a single bidder may have short-duration contracts with many generating units over time. Thus, at the time of bidding, a bidder may bid some number of generating units into the day-ahead market, but with nearly contemporaneous nonpublic information about the costs, capacity, schedule, and other operational aspects of additional generators with which it had recent, but expired, contracts. Such information about rivals is not generally available in ordinary markets and its existence is not reflected by simply noting the number of generators that the bidder currently controls. Our question is whether and to what extent this nonpublic information affects the bidding behavior of those bidders most likely influential in determining price in the auction market.

This paper presents a simple model based on existing theory demonstrating that a bidder that anticipates that its own and its rival's generating units may represent the marginal units in the auction can profitably alter its bidding behavior based on knowledge of its principle rival's costs. The reason is simply that such knowledge reduces or eliminates the risk that its higher bid might result in its own generating unit(s) not being called into service. We can show that such information is more valuable depending on the bidder's cost structure, inframarginal quantity, and inframarginal rents.

Next we put this theory to empirical test. We have compiled data for all bidders and all generating units for each hour of the calendar years 2006, 2007, and 2008 for the New York ISO–a total of about 26,000 hours. During this time there were about 360 generating units and 330 distinct bidders, although on average in any hour 65 bidders were active in the market. For each hour, each bidder's unique history of control over (that is, ownership of or contract with) generating units is recorded. We measure the extent of information from such control by two metrics: the total number of distinct units under the bidder's control in the six months preceding a bid, and also the total capacity of those generating units. The latter captures the extent of the market supply whose cost information was revealed to the bidder by prior control.

It is clear from the data that bidders often have a sizeable number of distinct generators that they previously controlled, implying a considerable stock of recent information about those rivals in the auction markets. To identify the actual effect of this information, regression analysis is performed on the panel of hourly bid price data for 2006-2008. If this control conveys useful private information to bidders, we would expect to find that a greater number and size of previously controlled generators would result in higher bid prices by marginal (and hence market-price determining) bidders, relative to other bidders without such prior insights.

Controlling for other influences, we find a statistically significant relationship in most models between our measures of information revelation and marginal bid prices, precisely as predicted. This effect appears to be more important up to some number of previously-controlled generators, with little or no additional effect thereafter. Moreover, this effect holds most strongly for bidders that are likely to be marginal and hence price-determining in the auction, and also for bidders in markets where equilibrium prices are above long-run marginal cost. Each of these outcomes is consistent with the underlying theory and predictions about bidding behavior.

The next section of this paper discusses the New York auction market for wholesale electricity in greater detail and provides some summary statistics about the extent to which bidders change the portfolio of generation units that they control. This is followed by an outline of the theoretical model that links information about rivals' costs to bidding strategy by a particular bidder. The subsequent section sets out our empirical model and the test results.

2. THE NEW YORK AUCTION MARKET FOR ELECTRICITY

Since its formation in 1999, New York auction market for wholesale electric power has accounted for more than 90% of all quantities transacted in the NYISO. According to the procedures of the Independent Service Operator (ISO), by 5 AM of each day, each bidder must submit an offer schedule for each of its generating units for each hour of the following day. Each offer schedule may consist of up to 12 price-quantity pairs, together with information about certain other characteristics of the generator (e.g., startup costs, minimum dispatch, must take energy). Figure 1 gives an illustrative offer schedule for one particular bidder for a single hour in 2008, described in terms of its price-quantity pairs.

After all offer schedules are submitted, NYISO ranks all generating units based on their bids and constructs a total market supply schedule. This market supply schedule is combined with a load forecast for each hour, which is prepared by the ISO, to determine the market-clearing price for each hour of the following day. In the absence of constraints on supply or transmission, sophisticated optimization software can guarantee optimal (i.e., least cost) generation dispatch. Modifications are required to incorporate anticipated constraints. In any case, a uniform price is established,[2] and that price in turn determines which generation units are actually dispatched (that is, designated to supply) and in what amount. All dispatched units are paid the single market-clearing price, which is the offer price of the marginal unit needed to meet market demand.

Among the several markets organized on these principles in the U.S., there are two different protocols for the submission of offer curves. In one type, illustrated by the PJM and New England ISOs, bidders submit the same offer curves for their generation units for each of the 24 hours of the following day. This type of bid procedure, called “long-lived bids,” can be contrasted to the “short-lived bids” in the New York ISO. In the latter, bidders submit separate sets of bids for each hour of the upcoming day. Short-lived bids obviously allow generators to respond to changes in demand and other conditions, thus yielding real-time market prices that more closely reflect within-day conditions. Yet short-lived bids reveal more information about rivals and may in fact permit more strategic behavior by individual bidders.[3]

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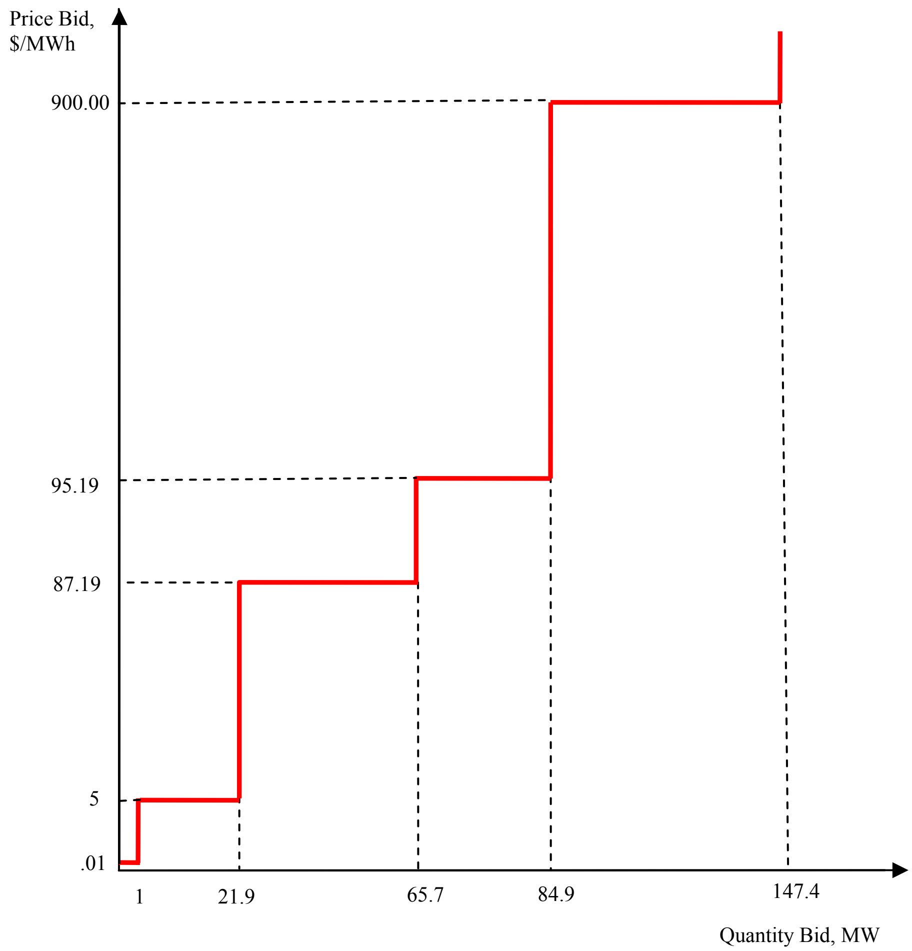
[2] This so-called “reference bus price” applies to the entire ISO area but may be adjusted to reflect market conditions in any of the eleven zones served by the ISO.

[3] Interestingly, Farba, von der Fehr, and Harbord (2006) find that long-lived bidding in uniform price auctions result in lower average prices than short-lived bids. They also report that the set of pure-strategy equilibrium outcomes is not affected by the number of steps in each supplier’s offer curve.



Quantity Bid, MW	Price Bid, $/MWh
1	.01
21.9	5
65.7	87.19
84.9	95.19
147.4	999

Figure 1 Day-Ahead Offer Schedule of Bidder 75755750 for generating unit 29636180 for January 16, 2008, 16:00

What permits such possible behavior in the New York market are the rules concerning bidders. As noted earlier, bidders may be owners of one or more generators, but bidders in fact can be any entity in or out of the electric power sector that registers with the New York ISO and satisfies certain credit requirements.[4] Thus, bidders include merchant generation companies, electricity-related companies from outside New York, non-electric power companies, and financial companies such as hedge funds and

[4] See New York ISO Market Services Tariff. Moreover, different individual bidders may work for the same company.

others interested in energy trading. Furthermore, ownership of actual generation facilities is not a requirement for bidding. Rather, many of these bidders simply have contractual arrangements with one or more generators, on whose behalf they submit bids to the ISO.

Crucially for our research, such contractual arrangements are not subject to any minimum duration requirements. The implication of this fact is readily seen in a two-period model. A single registered bidder i may have generators j= 1,…, n under contract at time t = 1, and then switch to generators j = n+1, ...m at time t = 2.[5] As a result, that bidder's bidding strategy in period 2 is informed by its knowledge of the costs and operating characteristics of generating units j = 1,...n from the previous period–information not available to rivals in competitive markets. More generally, in additional periods the bidder may continue to change its portfolio of generating units under contract, thereby acquiring information about the costs of additional rivals.

While the information revealed by this sequence of contracts is not exactly contemporaneous, it remains valuable to bidder i for two reasons: First, there is substantial persistence over time in the costs and other relevant characteristics of the generators that the bidder previously controlled. As a result, the stock of information about those generators is not likely to depreciate very rapidly. Secondly, the contract periods t may in fact be quite short so that any single bidder may have acquired nearly contemporaneous information about a considerable number of rival generators. Indeed, by bidding in their supply even briefly, the bidder acquires competitively useful information for potentially many subsequent periods in which it bids its new portfolio of generating units.[6]

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[5] This bidder may also have other wholly owned generators, but changing ownership is more expensive and less likely than changing contractual arrangements. Obviously, too, the bidder need not change all of its contracts in each time period.

[6] Exactly how short the contract periods may be is made clear from this statement by an employee of the energy trading company Dynegy to one of the authors: "In NY it is quite likely that a marketer has the ability to bid a unit into the market, and they may have an arrangement with the owner that they can bid in that unit during, say, on-peak hours (5x16). So, that unit might get bid in by the owner from midnight to 6am, by the marketer for the next 16 hours, and then by the gen owner again at night on any given weekday." (Personal conversation, December 1, 2009)

The extent of this "churn" in contractual arrangements and its implications for the stock of information is made clear from the summary statistics in Table 1. Our data set consists of information on all bidders, generators, and offer schedules for each hour in calendar years 2006, 2007, and 2008–a total of 26,304 hours. As described in this table, there were 348 different generators and 199 bidders in the market in the single year 2008, which was typical of all three years. On average, approximately 300 of these generators and 65 bidders were present in any hour. While the number of generators per bidder averaged 4.7, this varied from a single generator to nearly 60.

With respect to generators, about two-thirds of the total were bid into the market by more than a single bidder during each year. The number of different bidders that controlled any single generator during 2008 varied from 1 to 15, with the average of 5 bidders. Only 107 generators (less than one-third of the total) had only one bidder throughout the year; presumably, many of these sole bidders are the owners of the generating units they bid for.

Table 1 Summary Statistics of New York ISO Day-Ahead Market Participation

	NYISO			
Characteristic	2006	2007	2008	Overall
Bidders (Total)	211	202	199	332
Bidders / Hour (Mean)	65	65	63	64
Generators (Total)	345	349	348	362
Generators / Hour (Mean)	304	301	303	303
Generators / Bidder (Hour)				
Mean	4.66	4.63	4.82	4.70
Minimum	1	1	1	1
Maximum	58	57	57	58
Bidders / Generator (Hour)				
Mean	6	5	5	7
Minimum	1	1	1	1
Maximum	16	15	15	22
Generators with a Single Bidder (Total)	35	107	107	28
Percent Hours by Same Bidder				
Mean	13.78%	14.74%	14.44%	11.60%
Minimum	0.0038%	0.0038%	0.0038%	0.0038%
Maximum	99.80%	99.80%	99.80%	99.80%

3. THEORETICAL FOUNDATIONS

The New York day-ahead electricity market operates as a uniform multi-unit auction. Bidders make simultaneous-move bids for multiple units that they represent, and all dispatched units are then paid a uniform market-clearing price. All bidders have perfect information about the costs and other characteristics of their own generators but may face uncertainty about other features of the market, specifically, demand, competitors' costs, and the availability at any moment of competitors' generating units.[7] In our research we focus on the uncertainty with respect to competitors' costs. Uncertainty with respect to demand is resolved by the public release of hourly load forecast data by the ISO before bids are submitted. This procedure ensures that market participants have identical information on demand.

With respect to units' actual availability, we note that the New York ISO requires that all generators that participate in the capacity market and get paid for their capacity must offer that capacity in the day-ahead market at all times, with exceptions only for scheduled maintenance and if not needed to satisfy forecasted demand. While this leaves some discretion to generators and bidders, we would argue that the extent of uncertainty about individual rival's possible unanticipated outages is considerably less important than the uncertainty with respect to rivals' costs.[8]

We therefore examine a market in which each bidder adopts a bidding strategy based on complete information about its own generating units and incomplete or no information on competitors' characteristics. Bidding strategies depend on the costs of each generator's output and the likelihood that the bid might be marginal and hence that it might affect the market equilibrium price. Since low-cost generation is almost never marginal, bidders of such capacity can simply bid the marginal cost of those

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[7] Good early discussions of auction design and related issues can be found in McAfee and McMillan (1987) and Milgrom (1989).

[8] The ISO requires all units to be available during the summer due to lower capacity margins during those peak hours. Even during non-summer months maintenance must be approved by the ISO and can only be scheduled if market forecasted demand can be reliably satisfied by existing capacity.

units, or as is sometimes observed, even less than marginal cost or actual below-zero bids to ensure that the units are dispatched.

A bidder whose generating units are higher-cost, or in the limit are peaking units with very high costs, has a more complicated strategy involving the following trade-off: A higher offer price may increase the market equilibrium price, and since all dispatched units are paid a uniform market-clearing price, this yields higher profits on all the bidder's units and will be especially valuable to the extent that it has greater inframarginal capacity. Simultaneously, however, the higher offer price reduces the supplier's probability of being dispatched.[9] The optimal strategy will therefore depend on a number of factors, including various characteristics of the bidder's inframarginal and marginal units and the probability of being dispatched. The latter, in turn, can be informed by access to information about the costs characteristics of rival generators.

We can demonstrate the role of information about rivals' costs, as well as other factors, in this strategy choice with a stylized model of bidding behavior. [10]We assume exactly two bidders, A and B, each with exactly one unit to be bid into the auction but only one is required. Whichever unit is dispatched will be market-marginal and hence price determinative. Further, suppose constant marginal costs for each unit, denoted by c_a and c_b, with B's marginal costs higher:

$$c_b = c_a + \delta, \quad \delta \geq 0 \qquad (1)$$

If δ is strictly positive and bidder A knows its value with certainty, obviously A will bid its unit into the auction at a price just short of c_b, thereby setting market price at c_b and earning profits of

$$\pi_1^c = c_b - c_a = \delta \qquad (2)$$

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[9] See Milgrom, p. 4: Wolfram (1998).

[10] This model borrows from those of Kuhn and Vives, and Wolfram (1998), although neither of those directly captures the present issues. We also note that the present concern over the effect of information on one firm's bidding behavior differs from concern over coordination among multiple bidders through either explicit or implicit means. For discussions of the latter, see, inter alia, Blunsack, Apt, and Lave (2006) and Lye (2004).

We can generalize this case by supposing that A has multiple generating units. Its marginal unit—the Nth--again has costs given by c_a, but its other (N – 1) units have lower but identical costs $c_0 < c_a$ and play no role in market price determination. As before, A's last unit may be market-marginal, but now A's inframarginal units represent additional sources of profit (i.e., rents). The same strategy of bidding up to B's known and higher costs c_b now yields total profit to A in the amount

$$\pi_N^C = \delta + (N - 1)\cdot(c_a + \delta - c_0) \qquad (3)$$

This exceeds the previously calculated amount since by elevating the uniform price A earns rents profit on all its other units as well.

Next we contrast this certainty outcome with the profits that bidder A can expect from bidding its marginal unit into the auction at c_a plus some increment θ, but now without knowledge of B's actual costs. Assume with probability *p* that $\delta > \theta$, so that B's costs are in fact higher than A's bid price $(c_a + \theta)$. In this case A will earn

$$\theta + (N - 1)\cdot(c_a + \theta - c_0) \qquad (4)$$

This expression is similar to that from bidding with certainty, and would be identical if A's chosen θ happened to exactly equal the cost difference δ. Otherwise, A's profits fall short of their maximum possible value, as obtained under certainty.

Moreover, with probability $(1 - p)$, $\delta < \theta$ so that B's cost on its marginal unit is actually less than A's marginal bid of $(c_a + \theta)$. In this case bidder A's marginal unit is not dispatched, but A does collect profits on all its (N – 1) inframarginal units, since they have costs c_0 that are exceeded by the eventual market-clearing price c_b. A's total profit now becomes

$$(N - 1)\cdot(c_b - c_0) \qquad (5a)$$

which by virtue of equation (1) can be written

$$(N - 1) \cdot (c_a + \delta - c_0) \qquad (5b)$$

Overall, then, under uncertainty bidder A's expected profit is given by

$$E(\pi_N^U) = p\cdot [\theta + (N - 1)\cdot(c_a + \theta - c_0)] + (1-p)\cdot [(N - 1)\cdot(c_a + \delta - c_0)] \qquad (6)$$

Simplification of this expression provides further insight into the determining factors for a bidder to raise its marginal bid price with the expectation of increasing its profit. Specifically, simplification yields the following condition:

$$E(\pi_N^U) = (N - 1) \cdot (c_a - c_0) + \delta \cdot (N - 1) \cdot (1 - p) + p \cdot \theta \cdot N \qquad (7)$$

The determining factors are therefore seen to be the number of inframarginal units, the rents associated with those units, cost difference between the bidders' marginal units, and the likelihood of excessive bidding by A.

Further generalizations of this model are possible to reflect cost differences among bidder A's inframarginal units, size differences among bidder A's generating units, and multiple units for bidder B. The essential results from the present model are preserved. These models provide the theoretical foundation for the empirical estimation that follows.

4. MODEL AND DATA

Our empirical work focuses on those bidders that ex post are (or ex ante are likely to be) the marginal units bid into the auction market in each hour of the day ahead. We examine in particular the marginal bids of those bidders. Theory implies that if such a marginal bidder acquires information about other important bidders' costs, the first bidder will likely bid its quantity into the market at a higher lvel than otherwise would be the case. While we do not have direct knowledge or measures of whatever information may be in possession of a bidder, we are uniquely able to identify and quantify opportunities to acquire such information as a result of each bidder's recent contracts with generating units now bid in by its rivals. We examine two measures of information revelation. The first is a count of the number of different generators that the bidder had contractual arrangements with during the preceding six months.[11] This is the simplest and perhaps most direct measure of the opportunity to acquire such information.

[11] Examination of three months and twelve month periods made little difference in the results.

The second variable is the total capacity of those generators with which the bidder had contractual arrangements in the preceding six months. While more pieces of information are conveyed merely by controlling more generating units, the value of that information might differ depending on whether those units account for a larger or smaller proportion of the entire market capacity. This variable should be viewed as complementing the simple count of the number of previously controlled generators.

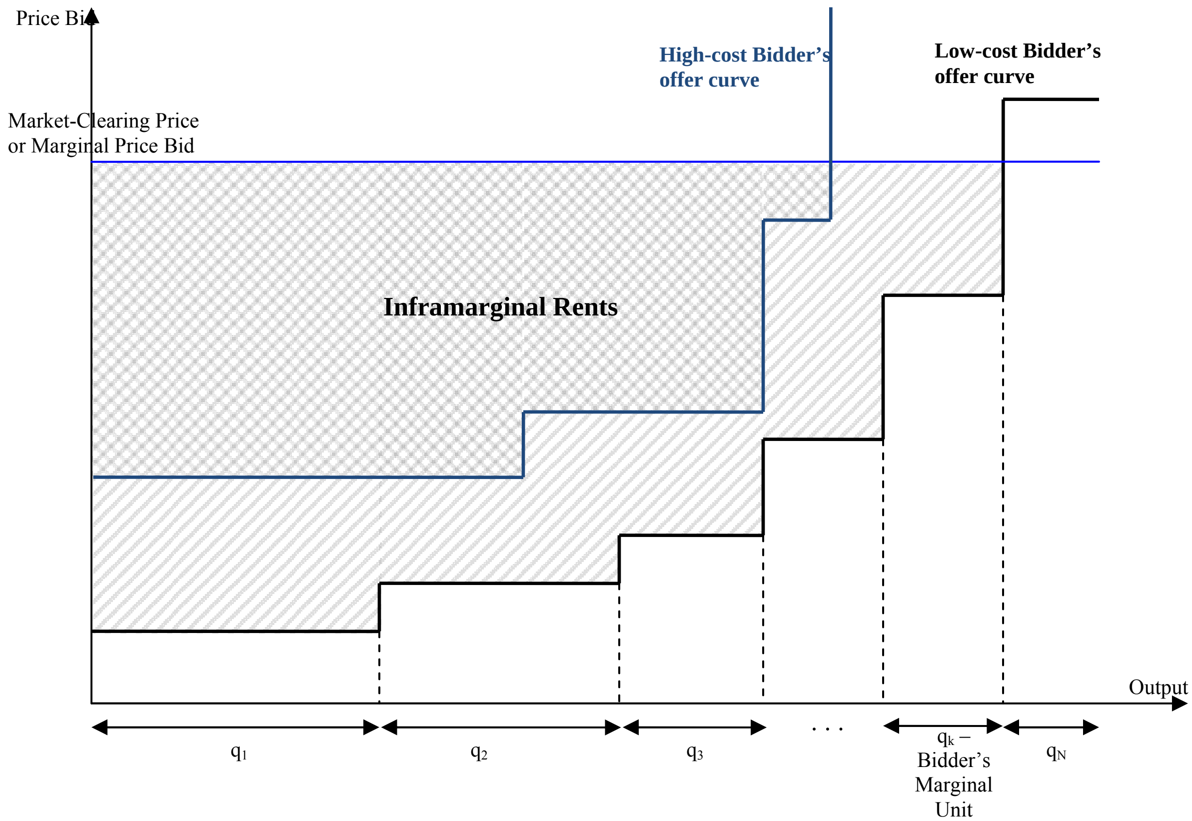

Figure 2 Inframarginal Rents

From theory and previous empirical studies, we also know that these bids will be affected by certain other factors, notably, the bidder's bid quantity and its inframarginal rents. The importance of these variables is suggested by equation (7) above. As discussed there, a bidder with much low-cost inframarginal generation will have a greater incentive to bid its marginal unit higher because that bidder will gain more from receiving a higher market-clearing price for each of its inframarginal units. Since we do not have generators' marginal costs, we use generation bid data–that is, the schedule of price-quantity offers--as a proxy. From these data we create a variable Inframarginal Rents to capture the extent to which the placement of offer curves (and likely the underlying marginal costs) imply differential incentives for strategic bidding. Figure 2 illustrates this proposition with offer curves for a high-cost bidder and for a low-cost bidder. Shaded areas in the graphs represent inframarginal rents, which clearly differ between the two cases, and would do so even if both involved the same bid-in quantity.

In addition, throughout we control for load forecast. The greater is anticipated market demand, the greater the opportunity for strategic bidding by any single bidder. When market demand is low, equilibrium price will likely fall along the horizontal portion of the market supply curve, reducing or eliminating the ability to alter that price. Load forecast data for each hour is common knowledge to all bidders, and is available ex post from the New York ISO website.

Finally, we investigate the expectation that attempts to affect bidding outcomes will be more effective during periods where market-clearing price is elevated. During many hours price is low and constant, reflecting only fuel costs. As demand rises toward fixed capacity, however, price may start to rise, and with it opportunities for more profitable exploitation of market conditions. Our analysis will take a particularly close look at those periods, since if the theory has explanatory power, it is when price is already at least moderately high. This is illustrated by the two alternative positions for demand in Figure 3. We also examine the possibility of seasonal effects, and those results will be reported as well.

Our formal model can therefore be written as follows:

$$\begin{aligned}\text{MarginalPriceBid}_{\text{it}} &= \beta_0 + \beta_1 \cdot NumberGenerators_{it} + \beta_2 \cdot TotalSizeGenerators_{it} + \beta_3 \cdot LoadForecast_t \\ &+ \beta_4 \cdot InframarginalRents_{it} + \beta_5 \cdot TotalInframarginalQuantity_{it} + \beta_6 \\ &\cdot Season\ Dummies_t + \varepsilon_{it}\end{aligned}$$

for bidder i in hour t. (8)

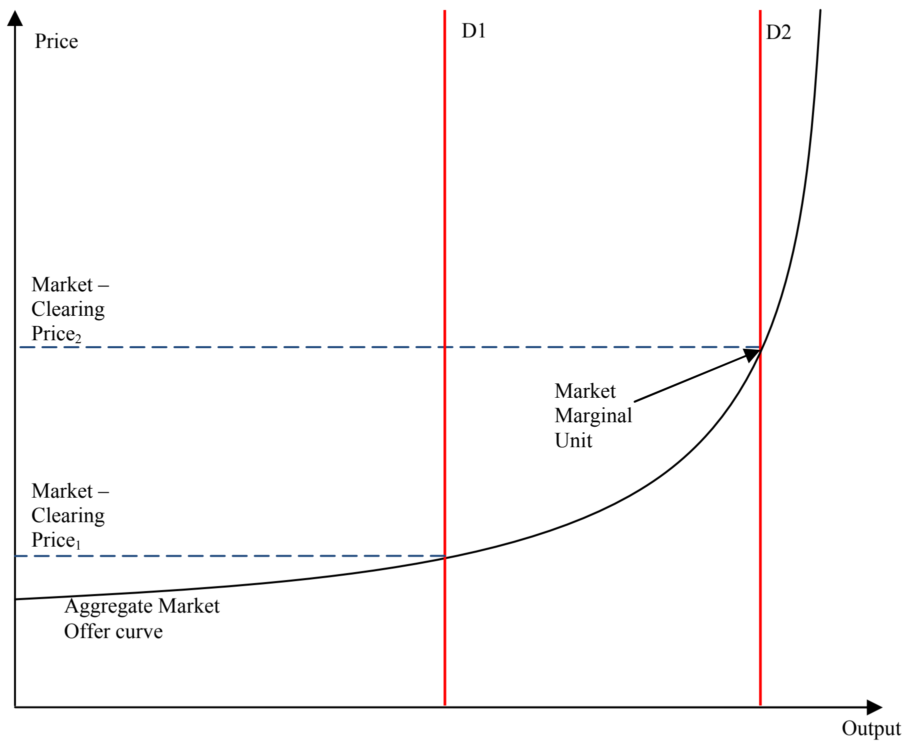

Figure 3 Low Demand vs. High Demand Conditions

The raw data used in this analysis are extracted from the data compiled by and available on the website of the New York ISO. Although the ISO does not disclose the names of generators or bidders, it does identify each with a unique ID number. These ID s remain unchanged over time, thus permitting determination of the history of contractual or ownership control and of bidding behavior. Our data are for the three-year period from January 1, 2006, through December 31, 2008.

For present purposes, these data need considerable processing. To begin, the generating units controlled by each bidder in each hour must be identified and linked to that bidder by hour. Once this is done, the number of generators controlled by each bidder in the six months preceding each hour can be determined. This is the first of our two information variables. The ISO data set includes information about the bid quantities and capacity of each generator. Aggregating these magnitudes for the generators controlled by each bidder for each hour during the preceding six months reflects the extent of information about market rivals that is revealed. This is our second information variable.

The focus of our research, of course, is on the effect of information revelation on the incentives of a marginal bidder to raise its bid on its marginal unit. In order to conduct this empirical test, we therefore need to determine (a) which generating unit is marginal for each bidder in each hour, and (b) which generating unit is actually the market marginal unit (and which bidder controlled that unit).

While tedious, these exercises pose no conceptual problems. We construct hourly bidders' offer curves from the data on price and quantity bids and determined bidders' marginal units as the last unit offered at a price below market-clearing price. Although every bidder in our data set with at least some dispatched capacity has a marginal generating unit, or the last unit dispatched in this bidder's generating portfolio, some of these bidders have no impact on the market-clearing price if they hold a baseload or a low-cost generating portfolio (price-takers). Since our analysis only applies to those bidders that hold price-setting units or units with a high chance of being price-setters, we are only interested in a small percentage of the price-setting or close to be price-setting bidders.

For our first data set, we keep only the "true" marginal bidders for each hour, i.e., those bidders whose marginal units were bid at a price equal or the closest to the market-clearing price. The bid prices on this marginal generating unit for each of the 26,000 hours comprise our first data set. This price applies to the entire marginal block of the marginal bidder, of course. Moreover, for some number of hours, two or more bidders may have submitted the same marginal bid, all of whom are therefore treated as marginal.

Our second data set derives from the fact that the bidding strategy described in our theory applies to any bidders who ex ante had reason to expect they might be marginal, not just those that ex post proved to be marginal. Accordingly, we develop a data set of marginal bids in each hour for all bidders whose marginal bids lie within some small percent of the market-clearing price. We report results for data sets for such bidders within 1 percent and 3 percent of market-clearing price.[12]

[12] We also examine 5 percent and 10 percent. Results are broadly consistent.

Table 2 provides summary statistics on these data sets and variables. The number of observations on the top single bidder data set is 23,431, a number that doubles and then doubles again for the 1 percent and 3 percent data sets. Mean, minimum, and maximum bid prices do not differ greatly, nor does the number or total size of prior generators controlled. With these data sets, we can now test our hypotheses.

Table 2 Summary Statistics for the Three Data Sets Used in the Analysis

Characteristic	Top Bidder	Top 1%	Top 3%
Number of Observations	23431	48302	103454
Marginal Bid Price			
Mean	61.21	69.23	68.61
Minimum	5	10	5
Maximum	191.19	191.19	191.19
Number of Prior Generators			
Mean	19	26.12	24
Minimum	1	1	1
Maximum	66	66	66
Total Size of Prior Generators			
Mean	2025	2369	2204
Minimum	1	1	1
Maximum	5494	5476	5476

5. ESTIMATION RESULTS

The model in equation (8) is estimated using panel data techniques with fixed effects, and with robust standard errors. Hausman test of our model with fixed effects and random effects indicate that a fixed effects model is a more efficient model to run. Heteroskedasticity test of our fixed effects panel model indicates the need for Huber –White estimates of standard errors in the model, though we find in most cases only modest differences relative to estimation without such corrections. Models are run both in linear and log forms, with somewhat better fits (but otherwise similar results) from the linear form that will be the focus of discussion.[13]

[13] It should be noted that while in some respects Wolfram's approach most closely resembles ours, she does not examine information flows and in any event we cannot replicate her empirical work. She calculates bidders' price-cost margins directly, but the NYISO market does not reveal generators' cost

1. Preliminary Results

Before reporting our key results, it is useful to present some preliminary estimations that serve to motivate the exact specification. Table 3 presents those preliminary results, using the Top Bidder data set.[14] Column (a) is the most simple and straightforward model, with marginal bid price related to the two information variables and the three control variables. As is evident, while the overall fit is reasonable and many variables significant, the results do not bear out the theoretical predictions. In particular, the coefficient estimates on both the Number of Generators and their Total Size are negative, with the former carrying a sizeable t-statistic. Load Forecast and Rents both behave as expected, but the same cannot be said for Inframarginal Bid Q. All in all, these results would seem quite inconsistent with theory.

Further investigation, however, reveals the reason. Column (b) reports the results of a test for nonlinearity in the relationship. Specifically, we augment the prior model with a term for the square of the Number of Generators.[15] Both the linear and quadratic terms on Number of Generators are now statistically significant and carry plausible signs. They imply a rising bid price up to about 8 generating units (.486/.058 = 8.37) and, taken literally, an apparently falling bid price thereafter. Based on this suggestive evidence, we split the data into two subsets using a cutoff of eight generators and investigate the effect of our information variables on Marginal Bid Price in each. Column (c) reports the results for observations where the Number of Generators is less than 8, column (d) for the remaining observations.

Clearly now where the number of generators is less than 8, both the Number of Generators and their Total Size have positive effects on Marginal Bid Price, with the former statistically significant and the latter nearly so. By contrast, in the data set with a larger number of generating units, further increases

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information, making that impossible in the present case. In addition, she examines all potential marginal bidders and estimates their markups as a function of marginal and inframarginal capacity, the probability of being a marginal unit, and a set of other variables. We, on the other hand, identify marginal units separately, eliminating the need to estimate the probability of each unit being marginal.

[14] Similar results are found for aggregations consisting of all bidders within 1 percent of the market-clearing price and 3 percent.

[15] The alternatives of log, logistic, and reciprocal term generally confirm the nonlinearity, but do not fit the data nearly as well as the quadratic.

in those numbers or their size do not further alter the Marginal Bid Price. The Number of Generators variable is negative and insignificant while Total Size is altogether negligible. We conclude that information revelation appears to result in higher bid prices for some number of generating units but thereafter not to affect bid price further. Accordingly, the remaining results will focus on data sets where the Numbers of Generating Units is no greater than eight.

Some comment on the control variables is in order. Load Forecast behaves very much as anticipated, with the price effects larger when demand is expected to be high. We explore this set of cases more thoroughly below. Either Inframarginal Bid Quantity or Rents, but not both, appear with the expected positive and significant signs, indicating higher prices for bidders with more nonmarginal output or with lower-cost nonmarginal output. With both in the model simultaneously, however, the output variable tends to carry a negative sign due to the high collinearity between the two variables (r = .88). Without a principled basis for excluding either, we estimate models with both and report them accordingly.

2. Key Results

The key results are presented in Tables 4, 5, and 6. These tables are estimations from the same set of models on three different data sets. The first is that already discussed, namely, the marginal bid prices from the set of unique marginal bidders in each hour. The second and third data sets examine the marginal bid prices from all bidders whose marginal bid prices were within one percent of market-clearing price and three percent of market-clearing price, respectively. As noted previously, the rationale for these more inclusive data sets is that the bidding behavior described in theory should characterize all bidders who ex ante have reason to expect that their bid prices might be marginal, not just those that ex post actually were marginal bidders. We therefore estimate the model on those bidders whose marginal bid prices lie within a small percentage difference from ex post market-clearing price.

For each data set we begin with marginal bid prices for all hours in the three sample years, focusing on observations where the number of generators with which the bidder had prior contractual agreements is less than eight. Column (a) of Table 4 reports such results for the top bidder data set, which is of course the same data set, model, and results as in Table 4, column (c). As noted there, the results strongly support the hypothesis that greater revelation of information, through recent contractual control of rivals, indeed does result in higher marginal bids by marginal bidders in the auction markets. Taken literally, the magnitude suggests that each additional exposure up to eight might cause the marginal bidder to increase its bid price by over $2. Compared to the mean marginal bid price of $60.57[16], this is probably too large to be taken at value, but it certainly underscores the likely quantitative significance of the effect. Exposure to greater total size of generators, revealing information about a larger amount of available rival capacity, also seems associated with higher marginal price bids, although the statistical significance of this effect is less strong.

The second model follows from the fact that the effect of information about rivals on marginal bid price should be most profitable and hence most pronounced where market-clearing price lies along the upward sloping segment of the market supply curve, that is, at some price greater than that characterizing the horizontal portion of supply. This is the circumstance illustrated in Figure 3 above, where the ability to increase price profitably is clearly greater under demand condition D_2. Accordingly, the second equation estimates the same model on observations for which the marginal bid price is greater than $50.[17] As is evident in column (b) results, this too is strongly confirmed. Magnitudes and statistical significance of the key estimated coefficients are slightly different, but it is clear that this behavior characterizes the range of market-clearing prices to which it should apply.

Finally, the third and last model augments the preceding relationship with variables for seasonality. Such controls are routine in such model of electricity, but of course the present model already includes Load Forecast. As a result, any estimated effect should be interpreted as the effect of

[16] $60.57 is the mean marginal bid price in the Top Bidder data set. Mean marginal bid price is $67.57 in the data set with all potential marginal bidders with their marginal price bids within 3% of the market-clearing price, and $68.21 – within 1% of the market-clearing price.
[17] Use of a $70 or other cutoffs makes no significant difference in the results.

discrepancies from the common load forecast, i.e., to the extent bidders believe the load forecast is systematically in error. Interestingly, in column (c) significant deviations for Winter, Spring, and Summer (relative to Fall) do emerge.[18] Such differences persist in later regressions as well, and have the effect of substantially diminishing the magnitude and statistical significance of the variable Total Size of Generators.

Table 5 repeats these same models for the data set consisting of all bidders with marginal bid prices within 1 percent of the market-clearing price. Column (a) reports the same model as in the first column of the last table. Recalling that the observations are limited to those where the Number of Generators is less than eight, it is again clear that both the Number of Generators and (now) their Total Size are clearly and significantly related to higher Marginal Bid Prices. That result persists, in some ways even more strongly, in the next model which again looks only at observations on the upward sloping portion of the market supply curve. Both information variables are positive and with even larger t-statistics confirming their statistical significance. Much as before, in column (c) the addition of season variables results in statistical significance for seasons and reduced size and significance on the Total Size of Generators. The effect of the Number of Generators, however, remains large and statistically significant.

Finally, these same models are reported in Table 6 for the yet larger data set including all bidders whose marginal bid prices are within 3 percent of market-clearing price. The results are in all respects similar to those in the two preceding tables, with larger t-statistics on the relevant information variables in all models.

While there may be other explanations for this statistical result,[19] the evidence is certainly consistent with the hypothesis that top bidders, with reason to think their marginal price bids might

[18] Tests for Day/Night differences indicate no effect.

[19] There may be other channels of communication between firms (e.g., note 4 observed that two or more bidders may belong to the same organization, something we cannot identify here), or the group of bidders

determine market price, bid differently as a result of the greater information revealed to them by their past contractual control of rival generating units. Up to eight such units, there is a simple relationship between the number and/or size of those generators, and marginal bid price. This result is stronger where theory predicts it should be, namely, when the market-clearing price lies along the more steeply sloping portion of the supply curve.

6. CONCLUSIONS

The potential anticompetitive effects of information passage between firms is predicted by theory and corroborated by experiences, but there is little empirical work that directly tests this proposition. The reason is probably due to the fact that such information exchange and revelation are difficult to identify and quantify. This paper examines a market where the rules of operation permit information about rivals' costs, capacity, scheduling, and other characteristics to be revealed on a nearly contemporaneous basis, and where the extent of opportunities to acquire information are recorded. In the New York State electricity auction market, changing short-term contractual control of actual generating units by a single bidder reveals information about generating units no longer under that bidder's control. We find that greater exposure to such information indeed does result in significantly higher bid prices by the marginal units likely to set the uniform auction price.

We conclude from this evidence that the revelation of information about rivals' costs can result in a substantial increase in bid price and in market equilibrium. In the case of the New York auction market for electricity, market rules permit a bidder to change its portfolio of generating units at will, so that the bidder may have nearly contemporaneous information about many more generators than it is bidding in at one point in time. The information effect is the same as if a bidder could simply acquire, at some cost, data on rivals' operations that is only slightly outdated. While the effect may be predictable in theory, this paper is distinctive in putting such a prediction to test, and finding confirmation. In the case of the

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that control many generators over time are fundamentally different players than those that do not (yet our results hold for both groups).

New York ISO, some simple rule changes might remedy the problem, but in other market settings where information is revealed in other subtle ways, the remedy may be correspondingly more difficult to devise.

TABLE 3
TOP BIDDERS: PRELIMINARY RESULTS

	(a)	(b)	(c)	(d)
NUMBER OF GENERATORS	-.307	.486	2.23	-.159
	(4.81***)	(3.95***)	(5.54***)	(1.48)
NUMBER GEN-SQUARED		-.029		
		(7.11***)		
TOTAL SIZE OF GENERATORS (10^3)	-.256	-.397	4.84	.217
	(.55)	(.86)	(1.89*)	(.49)
LOAD FORECAST (10^3)	3.19	3.20	2.91	3.17
	(77.2***)	(77.8***)	(48.6***)	(57.8***)
RENTS (10^3)	.103	.104	.146	.100
	(20.1***)	(20.2***)	(25.0***)	(15.6***)
INFRAMARGINAL Q (10^3)	-1.32	-1.33	-.609	-1.81
	(11.5***)	(11.6***)	(5.25***)	(10.9***)
CONSTANT	7.18	16.5	-8.09	5.62
	(4.60***)	(7.73***)	(3.33***)	(1.44)
NUMBER OF OBSERVATIONS	23,431	23,431	11,947	11,484
F	2069	1743	948	1120
R^2	.316	.004	.231	.380

T-statistics is given in the parentheses

*** - coefficient significant at 1% level, ** - coefficient significant at 5% level, * - coefficient significant at 10% level

TABLE 4

TOP SINGLE BIDDERS

	(a)	(b)	(c)
NUMBER OF GENERATORS	2.23	1.48	1.89
	(5.54***)	(3.78***)	(4.84***)
TOTAL SIZE GENERATORS (10^3)	4.84	4.18	.867
	(1.89*)	(1.81*)	(.37)
LOAD FORECAST (10^3)	2.91	2.04	1.93
	(48.6***)	(29.2***)	(25.7***)
RENTS (10^3)	.146	.137	.137
	(25.0***)	(26.8***)	(25.8***)
INFRAMARGINAL Q (10^3)	-.609	-1.28	-1.05
	(5.25***)	(10.7***)	(8.94***)
WINTER			2.77
			(7.79***)
SPRING			8.14
			(22.7***)
SUMMER			5.32
			(12.7***)
CONSTANT	-8.09	20.3	19.0
	(3.33***)	(9.15***)	(8.67***)
NUMBER OF OBSERVATIONS	11,947	8151	8151
F	948	427	329
R^2	.231	.204	.239

T-statistics is given in the parentheses

*** - coefficient significant at 1% level, ** - coefficient significant at 5% level, * - coefficient significant at 10% level

TABLE 5
BIDDERS WITHIN 1% OF MARKET-CLEARING PRICE

	(a)	(b)	(c)
NUMBER OF GENERATORS	1.89	2.29	2.63
	(6.90***)	(8.03***)	(9.71***)
TOTAL SIZE OF GENERATORS (10^3)	7.46	6.75	1.72
	(3.52***)	(3.54***)	(.97)
LOAD FORECAST (10^3)	2.53	1.87	1.97
	(57.8***)	(39.3***)	(36.3***)
RENTS (10^3)	.151	.146	.138
	(40.9***)	(41.0***)	(38.7***)
INFRAMARGINAL Q (10^3)	-.967	-1.46	-1.16
	(10.9***)	(16.0***)	(13.0***)
WINTER			4.53
			(17.0***)
SPRING			9.95
			(36.5***)
SUMMER			3.45
			(11.3***)
CONSTANT	2.80	20.2	
	(1.71***)	(12. 5***)	
NUMBER OF OBSERVATIONS	20,910	17,245	17,245
F	1683	932	811
R^2	.207	.169	.230

T-statistics is given in the parentheses

*** - coefficient significant at 1% level, ** - coefficient significant at 5% level, * - coefficient significant at 10% level

TABLE 6
BIDDERS WITHIN 3% OF MARKET CLEARING PRICE

	(a)	(b)	(c)
NUMBER OF GENERATORS	2.19	2.39	2.73
	(13.1***)	(13.7***)	(16.6***)
TOTAL SIZE OF GENERATORS (10^3)	5.95	6.64	1.82
	(4.19***)	(4.80***)	(1.47)
LOAD FORECAST (10^3)	2.46	1.84	1.99
	(85.0***)	(59.0***)	(54.9***)
RENTS (10^3)	.146	.143	.136
	(52.3***)	(52.1***)	(50.1***)
INFRAMARGINAL Q (10^3)	-.842	-.151	-.126
	(13.0***)	(21.9***)	(18.7***)
WINTER			4.81
			(27.0***)
SPRING			10.3
			(56.4***)
SUMMER			3.12
			(15.4***)
CONSTANT	4.33	21.4	16.5
	(4.31***)	(21. 0***)	(17.0***)
NUMBER OF OBSERVATIONS	47,594	39,001	39,001
F	382	931	1784
R^2	.199	.160	.221

T-statistics is given in the parentheses

*** - coefficient significant at 1% level, ** - coefficient significant at 5% level, * - coefficient significant at 10% level

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