Tests of Competition in Common Value Auctions: The Case of U.S. Offshore Oil and Gas Auctions

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Introduction

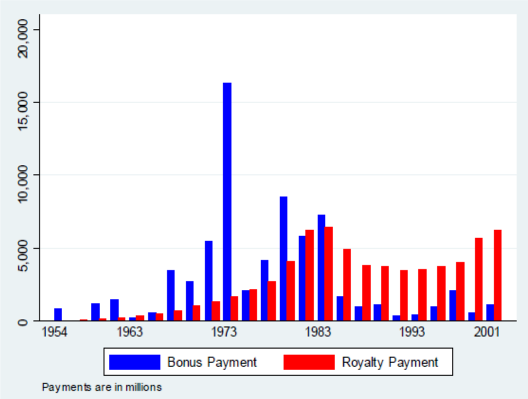
- Auctions are a widely-used trading mechanism for procurement and sales, especially by governments
  - Explicit model of price formation, well-specified rules.
  - Competitive bidding behavior is well-defined, can often be characterized
- However, evidence of collusion in many auction markets.
  - Developing diagnostics tools that can screen for collusion is an important policy issue
  - But no canonical model of collusion; it can take many forms. .
- Basic empirical approach: develop tests of competitive bidding, where rejection suggests collusion.

Objectives and Motivation

- Goal is to develop and apply these kinds of tests for first-price, common value auctions.
- Our application is the sale of oil and gas leases on federal lands in Gulf of Mexico from 1954 to 2002
    - Bidders uncertain about location and size of deposits.
    - They face similar drilling rig rental rates and wellhead prices, so (ex post) tract values are common, not idiosyncratic.
    - Their valuations vary due to different information about this common value
- CBO and GAO recently studied the leasing program at request of Congress
    - Concern over lack of drilling: are lease tenures too long?
    - Concern over lack of competition: are auction revenues too low? Should royalty rates be higher?

Revenues

- Figure plots auction revenue and royalty payments from Gulf of Mexico in two year increments.



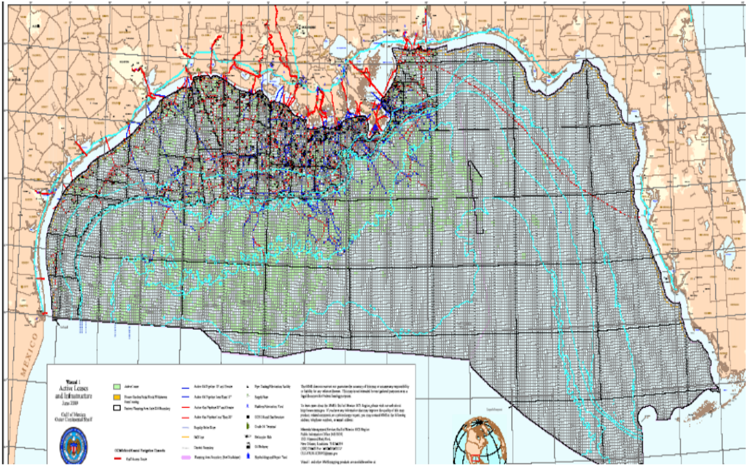
- Key event: area-wide leasing (AWL) introduced in 1983.

Questions

- How competitive are the auctions? Did behavior change after 1983?
- We focus mainly on neighborhood cartels.
  - Since mid 1970s, most of the tracts sold in a sale have adjacent tracts that are under lease.
  - Owners of these tracts (neighbors) have incumbency advantages that may deter non-neighbors.
  - They often coordinate on drilling (free-rider problem), and are required to coordinate on production.
- Main question: did neighbors coordinate on bidding or did they compete against each other?

Contributions

- Our tests provide a way of detecting collusive behavior in common value environments
  - Previous literature (e.g., Porter & Zona (1993,1999), Kawai et al (2022a, 2022b, 2022c)) study private value environments.
- Important specification test: can competitive model be used to examine changes in information structure and policy?
  - Government is considering modifications of lease work requirements, tenure, and royalty rates.
- Results inform not only lease design, but also auction design


MISSISSIPPI
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Active Leases
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Federal Offshore Leasing Program

- OCS divided into tracts, typically 5,760 acres (9 sq. miles)
- Lease sale:
  - Many tracts sold simultaneously in parallel, sealed bid, first-price auctions
  - Minimum bid: $15 - $25 per acre, but govt can reject high bid
  - Prior to 1983: offer set consists of several hundred tracts in selected areas, nominated by firms
  - After 1983: all unleased tracts available for bid each year
- Lease contract:
  - Holder has right but not obligation to drill
  - Royalty rate: 1/6 on shallow, 1/8 on deep ($>$ 200 meters)
  - Term: 5 years on shallow, 8 - 10 years on deep; automatic renewal if productive

Information Environment

- Prior to sale, bidders can acquire and analyze seismic data.
    - Data cost is hundred thousands dollars per tract, often shared.
- Seismic analysis provides noisy, but qualitatively similar, private signals.
    - Lots of dispersion: firms frequently bid on different tracts, and their bids vary widely.
- Drilling outcomes (dry vs wet) and production is more or less observable.
    - Drill core reports are made public within 2 years of drilling date, or after lease expires.
- Main source of private information is seismic data and analysis.

Joint Bidding and Ownership

- Prior to sale, but after seismic analysis, bidders often negotiate joint *bidding* agreements.
    - Agreements are area and sale-specific; legally binding.
    - They specify firms' shares of costs (including bid) and revenues, designates operator
    - After 1975, eight (then) largest oil and gas firms banned from bidding jointly with each other
- After the sale, firms often sign shared work or acquired interest agreements, typically with owners of adjacent leases
    - Big Eight are free to sign joint *drilling* and/or *production* agreements with each other; affects future competition
    - Common on deep-water tracts.
    - Agreements need to be approved by BOEM, so we can track ownership changes

Neighbor Firms and Bidders

- We focus mainly on sale of tracts that have adjacent tracts under lease at time of sale (aka neighbor leases).
  - Neighbor *tracts:*
    - Tracts sharing an edge or a boundary point
    - Typically 8 neighbor tracts
  - Neighbor *firms:*
    - Owners of *active* leases on adjacent tracts.
- Neighbor *bidders*
  - If A and B jointly own a neighbor lease, they do not bid against each other.
  - If A and B jointly own a neighbor lease, and B and C jointly own another neighbor lease, then A, B, and C do not bid against each other$\Rightarrow$ same ownership group.

Summary Statistics: Pre-AWL, AWL-Shallow, AWL-Deep

Table 2: Summary Statistics for Neighbor Leases

Variable	Pre-AWL	AWL-Deep	AWL-Shallow
No. of Leases Bid	1,619	4,815	8,111
Avg. No. of Bids	2.611	1.404	1.508
Fraction of Leases Sold	0.863	0.967	0.946
Drill Rate	0.820	0.156	0.388
Hit Rate	0.547	0.322	0.497
Avg. Win Bid (if sold)	13.684	0.922	1.020
Avg. Rev |Hit	146.763	354.870	40.210
Avg. Cost |Drilled	15.360	21.260	11.467

Dollar figures are in millions of 1982 dollars.

Revenue is computed using realized production and prices.

Model: Notation

- r_t : announced reserve price on auction t
- N_t : number of neighbors (groups) on auction t
- NN_t: number of non-neighbor bidders on tract t
- $K_t = N_t + NN_t$: total number of bidders
- V_t : value of lease t, same $\forall$ firms
- S_{it} : private signal of firm i
- $S_t = (S_{1t}, \ldots S_{k_t t})$: signals of bidders
- X_t : publicly observable auction covariates; number of active leases, neighborhood characteristics (up to three rings)

Assumptions

- Information structure:
  - Affiliation: (V_t, S_t) are affiliated conditional on any $K_t = k$, $X_t = x$,
  - Symmetry: $F(V_t, S_t | K_t, X_t)$ is exchangeable wrt bidder indices (i.e., all firms have same information technology)
  - Normalization: $S_t \sim U[0, 1]$
- Entry model:
  - Neighbor bidders have signals based on prior seismic studies
  - Non-neighbors can acquire signals at some cost
  - For any (N_t, X_t), NN_t is unique $\Rightarrow K_t = k(X_t, N_t)$ is common knowledge, $F(V_t, S_t | K_t, X_t) = F(V_t, S_t | N_t, X_t)$
  - For any $X_t = x$, $k(x, n)$ is weakly increasing in n, strictly for some (x, n).
- Variation in N_t (ownership) is exogenous.

Competitive Neighbors

- Null hypothesis: competitive participation & bidding
- Key issue: bidders may not bid due to binding reserve price and/or bidding cost
  - Firm i bids when $s_{it} \geq s^* (x, n)$ where thresholds solve

$$E [V_t | S_{it} = s^*, Y_{it} \leq s^*; N_t = n, X_t = x] = r_t$$

  - Y_{it} is the maximum signal among i's rivals
  - Event of winning is "bad news"
- Equilibrium bids $B_{it} = \beta (S_{it}; n, x)$, strictly increasing in S_{it} for $S_{it} \geq s^* (x, n)$
  - Implies (B_{it}, B_{jt}) are affiliated conditional on X_t, N_t for any bidders i and j

Collusive Neighbors

- A designated bidder model *suggests* what to expect under the alternative
  - Cartel selects one neighbor firm at random to bid in auction
  - Non-neighbors act as if $N_t = 1$
  - Neighbor firm participation and bids are negatively dependent
  - No winner's curse correction: neighbor and non-neighbor participation and bids do not vary with N
  - If neighbors pool info, cartel bidder is more informed $\Rightarrow$ likely violations of our tests
- *Phantom bidding* could give positive dependence among cartel bids (e.g., phantom bid proportional to "serious" cartel bid)
- All of above true with *unobserved heterogeneity*, but *uh* likely strengthens positive dependence

Nonparametric Affiliation Test

- Develop algorithm that generates affiliation inequalities for arbitrary values of N and discretization of bid space
  - Eliminate trivial or redundant inequalities due to symmetry and dependence
- Focus on two bins: $\{no\ bid, bid\}$ and three bins: $\{no\ bid,\ low\ bid, high\ bid\}$
  - In two bin case, number of inequalities equals n, number of bidders.
  - In three bin case, number equals 9 with 3 bidders, 18 with 4 bidders, etc.
- Test statistic examines frequency of the actions for each neighbor (do not observe NN)
  - Sample: tracts with neighbor leases that receive at least one bid (including tracts not bid) and $2 \leq N \leq 5$.

Affiliation Inequalities: Participation

- Affiliation under symmetry implies that:

$$\begin{aligned} & \binom{n_t}{l}^2 \Pr\left(A_t = l-1 | X_t, n_t\right) \Pr\left(A_t = l+1 | X_t, n_t\right) \\ \geq \; & \binom{n_t}{l-1}\binom{n_t}{l+1} \Pr\left(A_t = l | X_t, n_t\right)^2 \qquad (1) \end{aligned}$$

  where $A_t = \sum_{i=1}^{n_t} 1\left\{S_{it} > s^*\left(X_t; n_t\right)\right\}$ for $l = 1, .., n_t - 1$.
- Use nonparametric estimators of the event probabilities to compute sample analogues of the affiliation inequalities
  - Retain the value of difference if it is violated, zero if not
  - Under the null, test statistic should not be significantly different from zero (Aradillas-Lopez (2014))
  - Critical value is 1.96 for 2.5% confidence level, 1.65 for 5%.

Monotone Screening Levels

- Recall: bidder i submits a bid on tract t if $S_{it} > s^*(X_t, N_t)$ where

$$E\left[V_t | S_{it} = s^*, Y_{it} \leq s^*; N_t = n, X_t = x\right] = r_t$$

  - Winning at r is “bad news"$\Rightarrow$ rivals have signals below s^*
  - The larger is n, the worse is the news
  - $\Rightarrow s^*(x, n)$ strictly increasing in n for some (x, n)

- Equality vs Positive Inequality Test:

$$H_0 : s^*(x, n+1) = s^*(x, n)$$

  - Alternative is strict positive inequality.

Stochastic Dominance of Pivotal Expected Values

- Define pseudo-pivotal expected value

$$w(s, n, x) = E[V|S_i = s, Y_i = s; N = n, X = x]$$

  - Fixing s, more bidders with signals less than s is worse news
  - $\Rightarrow w(x, n)$ is strictly decreasing in n.(HHS)

- Best reply b_i of bidder i with signal s_i satisfies

$$w(s_i, n, x) = b_i + \frac{G_{M|B}(b_i|b_i, n, x)}{g_{M|B}(b_i|b_i, n, x)}$$

  - M is the maximum rival bid
  - Given estimates of $G_{M|B}$, $g_{M|B}$ for each (n, x), obtain estimates of $w(s, n, x)$ from bids

Stochastic Dominance Test

- Define
$$W_{it} = \begin{cases} w(S_{it}, n, x) \text{ if } S_{it} > s^*(n, x) \\ 0 \text{ if } S_{it} \le s^*(n, x) \end{cases}$$
with distribution function F_W
- Equality *vs.* Positive Inequality Test:
$$F_W(w; n+1, x) = F_W(w; n, x) \; \forall w \ge \max_n w(s^*(x, n); x, n)$$
  - Alternative is strict positive inequality
  - Note support restriction.
- Main sample for "winner's curse" tests is offer set of tracts with active adjacent leases.

Pre-AWL Offer Set

- In AWL period, the offer set for a sale consists of all tracts not under lease on the sale date
- For each Pre-AWL sale, observe number of nominated tracts τ but not the set.
  - Drop early sales in which most tracts receiving bids are isolated
  - Consideration set includes all unleased tracts in an area code, if at least one tract received a bid
- Estimate $\Pr\{\text{tract } t \text{ receives bid } | N_t = n, X = x\}$ via random forest
- Offer set is the τ tracts with the highest probability of receiving a bid.

Homogenization

- Standard approach:
  - Run a linear regression of bids on covariates and use residuals to estimate distributions
  - Not feasible in our case, we don't observe set of non-neighbors
- Our approach: based on sufficient index assumption

$$F(V_t, S_t | N_t = n, X_t = x) = F(V_t, S_t | n, \lambda(x))$$

  - Bid distributions inherit this property.
- Estimate $\widehat{\lambda}(n, x)$ by fitting a random forest to predict value of high rival bid $M_{it} | N_t, X_t$ (including zero bids)
  - Sample is set of bid pairs $\{M_{it}, B_{it}\}$ such that $B_{it} > 0$.
  - Normalization: $\widehat{\lambda}(x) \equiv \widehat{\lambda}(2, x)$

Estimation

- Estimate equilibrium screening value on offer set.

$$s^*(n,x) = \Pr\{S_{it} < s^*(x,n)\} = \Pr\{B_{it} = 0 | X_t = x, N_t = n\}$$

- Kernel regression of $\Pr\{B_{it}^{NB} = 0 | N_t = n, \widehat{\lambda}(x)\}$
  - Neighbors only, do not observe NN.
  - Yields estimate $q_n(\widehat{\lambda}(x))$, probability a neighbor bidder does not bid.
- Use standard GPV kernels to estimate $G_{M|B}(b|b,n,\widehat{\lambda}(x))$ and $g_{M|B}(b|b,n,\widehat{\lambda}(x))$ on sample of positive bids
  - Also estimate $G_B(b|n,\widehat{\lambda}(x))$ on this sample using a kernel regression

Simulation

- Randomly draw a value of x from its empirical distribution and compute $\widehat{\lambda}(x)$
  - For each n, draw S bids b^s from $G_B(\cdot|n, \widehat{\lambda}(x)$, setting $b^s = 0$ with probability $q_n(\widehat{\lambda}(x))$
  - Plug each positive bid into GPV formula to get a pseudo-value estimate $\widehat{w}(s, n, \widehat{\lambda}(x))$
  - Draw another value of x and repeat the process.
- Collect the simulated values averaging across the draws of X for each n, and plot the empirical distribution $\widehat{F}_W(\cdot; n)$.
  - Distribution is corrected for sample selection.
  - Trim extreme values of x to ensure $K > 1$, and extreme values of $\widehat{\lambda}(x)$ to avoid boundary bias

Test Statistics

- Screening value:
  - For each draw x, compute the value of $q_n(\widehat{\lambda}(x))$ for each n.
  - Averaging across draws yields a point estimate $\widehat{q}_n$ for each n.
  - Pairwise test statistic is the difference between the point estimates $\widehat{q}_{n+1}$ and $\widehat{q}_n$.
- Distribution of pivotal expected values:
  - Pairwise equality vs positive inequality tests: one sided Cramer-von Mises statistic

$$CVM = \int_{\underline{w}}^{\overline{w}} \left(\left[\widehat{F}_W(w, n+1) - \widehat{F}_W(w, n) \right]_+ \right)^2$$

    where $[u]_- = u \times 1\{u < 0\}$.
- All test statistics are computed using the bootstrap.

Affiliation Tests: Neighbor Tracts

Table 7: Affiliation Test for Neighbor Bids

	Pre-AWL	AWL Shallow	AWL Deep
{No Bid, Bid}	0.90 (0.18)	1.96 (0.025)	4.05 (0.00)
{No Bid,Low Bid,High Bid}	1.44 (0.075)	3.63 (0.00)	4.31 (0.00)
Number of Bids	1,191	6,485	2,715

Pre-AWL Participation Test Results

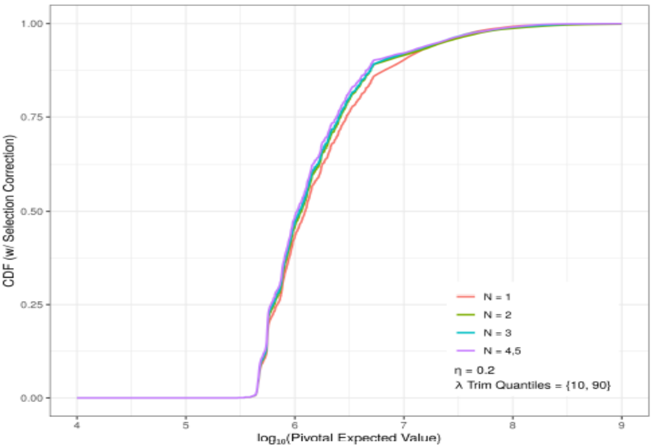
Table 1: Summary of q_N across 200 bootstrap replications.

Sample Period	q_N Point Estimate	Bootstrap Replication Estimates Distribution					
		Mean	5%	25%	50%	75%	95%
Pre-AWL1	0.765	0.767	0.748	0.760	0.767	0.775	0.784
Pre-AWL2	0.832	0.835	0.821	0.830	0.836	0.841	0.848
Pre-AWL3	0.856	0.854	0.841	0.849	0.855	0.859	0.868
Pre-AWL4	0.887	0.879	0.847	0.870	0.882	0.891	0.900
AWL-deep1	0.963	0.963	0.961	0.962	0.963	0.964	0.965
AWL-deep2	0.964	0.966	0.964	0.965	0.966	0.966	0.967
AWL-deep3	0.965	0.962	0.959	0.961	0.962	0.963	0.965
AWL-deep4	0.973	0.967	0.961	0.965	0.968	0.970	0.973

Test Stat	P-value	Point Estimate
Pre-AWL $q_2 - q_1$	0	0.067
Pre-AWL $q_3 - q_2$	0	0.025
Pre-AWL $q_4 - q_3$	0	0.031
AWL-deep $q_2 - q_1$	0.385	0.002
AWL-deep $q_3 - q_2$	0.025	0.001
AWL-deep $q_4 - q_3$	0	0.008

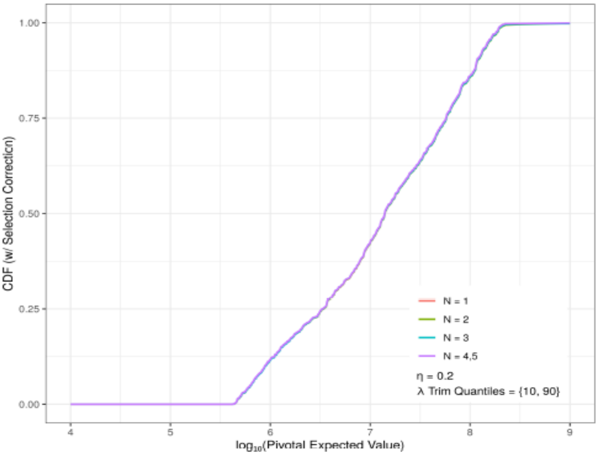
Pre-AWL Pivotal Expected Value Distribution

Figure 1: **Pre-AWL** Pivotal Expected Value Distributions



AWL-Deep Pivotal Expected Value Distribution

Figure 3: **AWL-deep** Pivotal Expected Value Distributions



Summary

- Affiliation Tests:
  - Neighbors appear to bid competitively pre-AWL, but not under AWL, especially in deep water
  - Big 7 appear to bid competitively on isolated tracts pre-AWL, less so for AWL Shallow, not for AWL Deep
- Screening Level and Stochastic Dominance Tests:
  - Pre-AWL: Participation thresholds and distribution functions of pseudo-pivotal expected values are ordered in N as predicted by competitive bidding under common values
  - AWL: No evidence of competitive ordering predictions under common values