Testing Competition in U.S. Offshore Oil and Gas Lease Auctions

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Ken Hendricks (Wisconsin)  Rob Porter (Northwestern)

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Introduction

- Minerals Management Service (MMS, now BOEM) oil and gas auctions
  - exploration/drilling rights, U.S. Outer Continental Shelf (OCS)
  - offshore leasing program began in 1954
  - few alterations in the auction mechanism
  - considerable revenue for the government
  - excellent data
Introduction

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  - excellent data

- Figure 1: plots sales revenue and royalty payments from Gulf of Mexico in two year increments; millions of 1982 dollars.
  - Sales revenue fell dramatically after 1982.
  - Coincides with introduction of Area Wide Leasing (AWL) in 1983; expansion in number of tracts sold.
Figure:
Question

- How competitive are the auctions? Did behavior change during the AWL period?
- Tracts often have adjacent tracts that are already under lease and, in some cases, drilled;
  - Owners of these tracts (neighbors) may have incumbency advantages that deter non-neighbor firms;
  - Benefits to neighbors from not competing: lower prices, information pooling
  - Costs: not clear, joint bidding (except for Big 8) is legal; neighbors coordinate on production, incentive to coordinate on drilling.
- Figure 2 illustrates how fraction of tracts with neighbor leases has grown; dominate sales since mid 1970s.
Figure: Fractions of Tracts with Neighbors
Objective

- This paper: develop tests of competitive bidding in first-price, common values auctions where rejection suggests collusion.
- Apply those tests to sample of tracts with neighbors to determine whether neighbors bid competitively;
- Focus on neighborhood cartels:
  - spatial markets
  - joint bidding ventures are location-based, rather than firm- or sale-based
- Important question on its own and as a specification test: can competitive model be used to examine changes in information structure and policy?
- Focus here on test of affiliation of neighbor participation and bidding decisions
Contributions

- Tests provide a way of detecting collusive behavior in common value environments
  - previous literature has focused on private value environments
- In related work, develop a strategy for identifying common value models when realized values are available only for a selected sample;
  - tract value observed only if tract is leased and drilled.
- Results inform mechanism design.
Previous work:

  - Bidding consistent with BNE of pure common value auction in which neighbors are better informed and collude, non-neighbors are uninformed.

- Hendricks, Pinkse & Porter (RES, 2003): pre-1980 wildcat auctions
  - Bidding consistent with BNE of symmetric pure common value auction
  - Rents are mostly competed away.

- Haile, Hendricks & Porter (IJIO, 2011):
  - Firms earned higher profits, larger share of rents during AWL period than before 1980
  - Returns highest on deep water tracts, especially on tracts with neighboring leases.
Mechanism

- Offshore lands divided into tracts, typically 5,760 acres (see map)
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- Government announces area available for exploration
  - prior to 1983: restricted area, firms nominated tracts.
  - after 1983, AWL: unrestricted; western and central gulf
- Seismic testing and analysis of area by industry; no drilling
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- Bidding consortia negotiations, often tract-specific
- Bidding: first-price sealed bid
  - many tracts sold simultaneously in parallel auctions
  - minimum bid: $15 per acre; gvt also may reject high bid
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- Bidding: first-price sealed bid
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- Exploration and production
  - fixed lease term: 5 years on shallow, 8, 10 years on deep; automatic renewal if productive
  - fixed royalty rate: 1/6 on shallow, 1/8 on deep.
Data Overview

- Complete bidding and lease ownership data
- Discounted revenue
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  - for leases that are still productive in 2008, forecast future output based on an econometric model of historical decay rates in lease production
  - GDP deflator to 1982, 5% annual real discount rate.
- Costs: based on well drilling records and annual API surveys of drilling costs by location, depth and well type
**Table: Summary Statistics**

<table>
<thead>
<tr>
<th></th>
<th>Pre-AWL</th>
<th>Shallow</th>
<th>Deep</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Leases Bid</td>
<td>3,693</td>
<td>9,062</td>
<td>7,389</td>
</tr>
<tr>
<td>No. of Bids</td>
<td>3.23</td>
<td>1.50</td>
<td>1.37</td>
</tr>
<tr>
<td>High Bid</td>
<td>13.20</td>
<td>1.11</td>
<td>0.89</td>
</tr>
<tr>
<td>No. of Leases Sold</td>
<td>3,271</td>
<td>8,602</td>
<td>7,192</td>
</tr>
<tr>
<td>Drill Rate</td>
<td>0.80</td>
<td>0.38</td>
<td>0.14</td>
</tr>
<tr>
<td>Hit Rate</td>
<td>0.51</td>
<td>0.50</td>
<td>0.43</td>
</tr>
<tr>
<td>Revenue</td>
<td>Hit</td>
<td>130.75</td>
<td>51.35</td>
</tr>
<tr>
<td>Cost</td>
<td>Drilled</td>
<td>13.51</td>
<td>11.60</td>
</tr>
<tr>
<td>Net Profits</td>
<td>19.25</td>
<td>2.54</td>
<td>15.69</td>
</tr>
</tbody>
</table>

*Dollar figures are in millions of 1982 dollars.

Net Profit = Revenue - Cost - Bid - Royalty.
Neighbor Tracts and Neighbor Firms

- Focus on all offered tracts in a sale with \( N \) active neighbor firms
- Neighbor *tracts*
  - tracts sharing an edge or a boundary point
  - typically 8 neighbor tracts
- Neighbor *firms*
  - owners of at least one neighbor tract
  - ownership graph: two firms are connected if they are joint owners of a tract.
  - number of neighbor firms is the number of components of the graph (including isolated firms).
## Table: Statistics by Lease Type - Pre-AWL

<table>
<thead>
<tr>
<th></th>
<th>Isolated</th>
<th>Neighbor</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Leases Bid</td>
<td>1,723</td>
<td>1,970</td>
</tr>
<tr>
<td>No. of Bids</td>
<td>3.88</td>
<td>2.66</td>
</tr>
<tr>
<td>High Bid</td>
<td>12.30</td>
<td>13.98</td>
</tr>
<tr>
<td>No. of Leases Sold</td>
<td>1,575</td>
<td>1,696</td>
</tr>
<tr>
<td>Drill Rate</td>
<td>0.77</td>
<td>0.83</td>
</tr>
<tr>
<td>Hit Rate</td>
<td>0.45</td>
<td>0.57</td>
</tr>
<tr>
<td>Revenue</td>
<td>Hit</td>
<td>137.46</td>
</tr>
<tr>
<td>Cost</td>
<td>Drilled</td>
<td>10.80</td>
</tr>
<tr>
<td>Av. Net Profits</td>
<td>17.99</td>
<td>20.43</td>
</tr>
</tbody>
</table>

*Dollar figures are in millions of 1982 dollars.*
Table: Statistics by Lease Type - AWL Shallow

<table>
<thead>
<tr>
<th></th>
<th>Isolated</th>
<th>Neighbor</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Leases Bid</td>
<td>924</td>
<td>8,138</td>
</tr>
<tr>
<td>No. of Bids</td>
<td>1.39</td>
<td>1.51</td>
</tr>
<tr>
<td>High Bid</td>
<td>1.89</td>
<td>1.02</td>
</tr>
<tr>
<td>No. of Leases Sold</td>
<td>904</td>
<td>7,698</td>
</tr>
<tr>
<td>Drill Rate</td>
<td>0.30</td>
<td>0.38</td>
</tr>
<tr>
<td>Hit Rate</td>
<td>0.35</td>
<td>0.51</td>
</tr>
<tr>
<td>Revenue</td>
<td>Hit</td>
<td>98.49</td>
</tr>
<tr>
<td>Cost</td>
<td>Drilled</td>
<td>11.76</td>
</tr>
<tr>
<td>Av. Net Profits</td>
<td>3.14</td>
<td>2.47</td>
</tr>
</tbody>
</table>

*Dollar figures are in millions of 1982 dollars.*
Table: Statistics by Lease Type - AWL Deep

<table>
<thead>
<tr>
<th></th>
<th>Isolated</th>
<th>Neighbor</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Leases Bid</td>
<td>2,574</td>
<td>4,815</td>
</tr>
<tr>
<td>No. of Bids</td>
<td>1.31</td>
<td>1.40</td>
</tr>
<tr>
<td>High Bid</td>
<td>0.86</td>
<td>0.91</td>
</tr>
<tr>
<td>No. of Leases Sold</td>
<td>2,535</td>
<td>4,657</td>
</tr>
<tr>
<td>Drill Rate</td>
<td>0.11</td>
<td>0.15</td>
</tr>
<tr>
<td>Hit Rate</td>
<td>0.37</td>
<td>0.46</td>
</tr>
<tr>
<td>Revenue</td>
<td>Hit</td>
<td>638.28</td>
</tr>
<tr>
<td>Cost</td>
<td>Drill</td>
<td>21.59</td>
</tr>
<tr>
<td>Av. Net Profits</td>
<td>19.17</td>
<td>13.79</td>
</tr>
</tbody>
</table>

*Dollar figures are in millions of 1982 dollars.
## Table: Top 11 Firms

<table>
<thead>
<tr>
<th>Name</th>
<th>Pre-AWL</th>
<th>Shallow</th>
<th>Deep</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell</td>
<td>349*</td>
<td>613*</td>
<td>1,401*</td>
<td>2,363</td>
</tr>
<tr>
<td>Getty/Arco/Conoco/Cities</td>
<td>630*</td>
<td>607*</td>
<td>604*</td>
<td>1,841</td>
</tr>
<tr>
<td>Chevron</td>
<td>389*</td>
<td>415*</td>
<td>560*</td>
<td>1,364</td>
</tr>
<tr>
<td>BP</td>
<td>264*</td>
<td>259</td>
<td>710*</td>
<td>1,233</td>
</tr>
<tr>
<td>Texaco</td>
<td>260</td>
<td>320*</td>
<td>602*</td>
<td>1,182</td>
</tr>
<tr>
<td>Exxon</td>
<td>303*</td>
<td>249</td>
<td>622*</td>
<td>1,174</td>
</tr>
<tr>
<td>Gulf/Hess</td>
<td>454*</td>
<td>332*</td>
<td>382</td>
<td>1,168</td>
</tr>
<tr>
<td>Amoco</td>
<td>248</td>
<td>382*</td>
<td>392*</td>
<td>1,022</td>
</tr>
<tr>
<td>Mobil</td>
<td>266*</td>
<td>300*</td>
<td>379</td>
<td>945</td>
</tr>
<tr>
<td>Unocal</td>
<td>224</td>
<td>258</td>
<td>299</td>
<td>781</td>
</tr>
<tr>
<td>Kerr-McGee</td>
<td>229</td>
<td>206</td>
<td>344</td>
<td>779</td>
</tr>
</tbody>
</table>

*Firm is in top 7 for the period
Why focus on the participation decision?

- Few tracts with multiple neighbor firms receive more than one neighbor bid
- Bidding in AWL Deep dominated by solo major firm bids, but ex post more joint lease ownership
  - 10 largest firms acquire 64% of tracts
    - 55% are solo major firm bids, 9% two or more majors
  - 72% of drilled tracts have a major firm owner before the time of the first well
    - 48% have solo major firm owners, 24% two or more majors
Model: Pure Common Value Auction

- Potential bidders for lease \( t \):
  - neighbors \( \mathcal{N}_t, |\mathcal{N}_t| = N_t \)
  - non-neighbors \( \mathcal{M}_t, |\mathcal{M}_t| = M_t \)
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- Value of lease $V_t$, same $\forall$ firms
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  - non-neighbors $\mathcal{M}_t$, $|\mathcal{M}_t| = M_t$

- Value of lease $V_t$, same $\forall$ firms

- Publicly observable lease characteristics $Z_t$

- Neighbor $i$ has private signal $X_{it}$
  (can assume any strictly increasing marginal distn $F_X$ wlog)

- Non-neighbor signals $Y_{jt}$, $j = 1, \ldots, M_t$. 
Informational Assumptions

- Publicly observable: $N_t, M_t, Z_t$
- For now, condition on $M_t, Z_t$ and suppress
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- For now, condition on $M_t, Z_t$ and suppress
- Given $N_t = n, M_t = m$,
  - $V_t, X_{1t}, \ldots, X_{nt}, Y_{1t}, \ldots, Y_{mt}$ affiliated
  - nice joint distribution $F_{V,X}(V_t, X_{1t}, \ldots, X_{nt}, Y_{1t}, \ldots, Y_{mt}; n)$
  - exchangeable wrt neighbor indexes (neighbors ex ante symmetric)
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  - exchangeable wrt neighbor indexes (neighbors ex ante symmetric)
  - $E [V_t | X, Y]$ strictly increasing in $X_i \forall i$. 
Auction Rules

- First-price sealed bid
- Public reserve price $r$. 
Competitive Neighbors

- Null hypothesis: competitive participation & bidding
Competitive Neighbors

- Null hypothesis: competitive participation & bidding
  - symmetric BNE participation thresholds
  - neighbor $i$ bids when $x_{it} \geq x^*(n)$
  - where thresholds defined by
    \[
    E \left[ V_t \mid X_{it} = x^*, \max_{j \neq i} X_{jt} \leq x^*, \max_j Y_{jt} \leq y^* \right] = r
    \]
    - note "winner’s curse" correction
- Equilibrium bids $B_{it} = \beta(X_{it}; n)$, strictly increasing in $X_{it}$
Collusive Neighbors

• Many forms of collusion possible
• Possible goals
  ▶ avoid competing away rents: compete only against outsiders
  ▶ pool information
• Next: two simple models meant to suggest what to expect under the alternative hypothesis of collusion.
“Designated Bidder Model”

- Bidding cartel includes all neighbors
- One firm $i$ selected to bid
- $i$ learns its signal, competes against non-neighbors (if any)
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- $i$ learns its signal, competes against non-neighbors (if any)
- Threshold and bidding equations as if $N_t = 1$
- vs. competitive bidding
  - less competition for lease
  - smaller winner’s curse
“Information Pooling Model”

- Bidding cartel includes all neighbors
- Neighbors pool their information
- Cartel participates when \( E [V_t | X_{1t}, \ldots, X_{nt}] \geq r \)
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- FOC for designated bidder similar to that for BNE with one neighbor, but beliefs about \( V \) conditioned on all signals
- vs. competitive bidding
  - less competition for lease
  - better private information than a single bidder
Affiliation of Bids

Competitive bids are monotone in signals

- \( B_1, \ldots, B_n \) affiliated, e.g.,

**Proposition 1.** With competitive neighbor participation, for any \( n > 1 \), any \( i, j \in \mathcal{N} \), and any \( b \geq r, b' \geq r \),

\[
\Pr \left( B_{it} \geq b \mid B_{jt} \geq b', N_t = n \right) \geq \Pr \left( B_{it} \geq b \mid N_t = n \right) \\
    \geq \Pr \left( B_{it} \geq b \mid B_{jt} \leq b', N_t = n \right).
\]
Comments on this Restriction

\[ \Pr \left( B_{it} \geq b \mid B_{jt} \geq b', N_t = n \right) \geq \Pr \left( B_{it} \geq b \mid N_t = n \right) \geq \Pr \left( B_{it} \geq b \mid B_{jt} \leq b', N_t = n \right) \]

1. If \( b = b' = r \), this focuses on positive dependence in participation (conditional on \( M_t, Z_t, N_t \))
Comments on this Restriction

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2. If cartel makes only one bid, there will be negative dependence (both inequalities strictly reversed)
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3. *Phantom bidding* could give positive dependence among cartel bids (e.g., phantom bid proportional to “serious” cartel bid)
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\]

1. If \( b = b' = r \), this focuses on positive dependence in participation (conditional on \( M_t, Z_t, N_t \))
2. If cartel makes only one bid, there will be negative dependence (both inequalities strictly reversed)
3. **Phantom bidding** could give positive dependence among cartel bids (e.g., phantom bid proportional to “serious” cartel bid)
4. All of above true with unobserved heterogeneity, but *uh* likely strengthens positive dependence.
Nonparametric Affiliation Test: Participation

Participation equation for tract $t$: $P_{it} = 1 \{ x_{it} > x^* (Z_t; n_t) \}$

- Symmetry: given $N_t = n_t$, thresholds are same for each neighbor firm; vary across $n$.
- $(x_{1t}, \ldots, x_{nt})$ are affiliated $\leftrightarrow (P_{1t}, \ldots, P_{nt})$ are affiliated conditional on $Z_t$.
- Affiliation under symmetry implies that:

\[
\begin{align*}
\left( \binom{n_t}{k} \right)^2 \Pr (A_t = k - 1|Z_t, n_t) \Pr (A_t = k + 1|Z_t, n_t) \\
\geq \left( \binom{n_t}{k - 1} \right) \left( \binom{n_t}{k + 1} \right) \Pr (A_t = k|Z_t, n_t)^2
\end{align*}
\]

(1)

where $A_t = \sum_{i=1}^{n_t} P_{it}$, for $k = 1, \ldots, n_t - 1$
The Test Statistic

- Density-weighted version of the affiliation inequality:
  Let $Pr(A = k | Z, n) = G_{k,n}(Z)$. Define $\tau_{k,n}(Z)$ as the difference

  $$
  \left( \begin{array}{c} n \\ k \end{array} \right)^{-2} G_{k,n}^2(Z) - \left( \begin{array}{c} n \\ k - 1 \end{array} \right)^{-1} \left( \begin{array}{c} n \\ k + 1 \end{array} \right)^{-1} G_{k-1,n}(Z) G_{k+1,n}(Z)
  $$

  weighted by the squared density $f_{Z,n}^2(Z, n)$, and let

  $$
  Q_{k,n} = E_Z \left[ \max \{ \tau_{k,n}(Z), 0 \} \cdot \omega(Z, k, n) \right],
  $$

  $$
  Q = \sum_{n=\bar{n}}^{\bar{n}} \sum_{k=1}^{n-1} Q_{k,n}
  $$

  where $\omega(X, k, L)$ is a positive weighting function.

- Affiliation of $(P_{1t}, \ldots, P_{nt})$ conditional on $Z_t$ implies $Q = 0$, $Q > 0$ if affiliation is violated.
Constructing the Test Statistic

- Details worked out in Aradillas-Lopez (2014).
- We employ kernel-based nonparametric estimators.
- The estimators compute the sample analog of $\tau_{k,n}(Z)$, weighted by a kernel function of $Z$, aggregated over $n$.
- Under smoothness and regularity conditions, $\hat{Q}$ satisfies the asymptotic condition:

$$\hat{Q} = Q + \frac{1}{T} \sum_{t=1}^{T} \gamma_T(Z_t) + O_p \left( T^{-1/2-\epsilon} \right)$$

where:

(i) $E[\gamma_n(Z_i)] = 0$,
(ii) $\gamma_n(Z_i) = 0$ w.p.1 if the inequalities hold strictly
Test Statistic

• Let $\Sigma_T^2 = \text{Var}(\gamma_T(Z_i))$. Our test statistic is

$$\hat{s}_T = \frac{\sqrt{T} \cdot \hat{Q}}{\max\{\kappa_T, \hat{\Sigma}_T\}}.$$  

where $\kappa_T$ is a bandwidth sequence that converges to zero very slowly (at a logarithmic rate).

• Critical value is 1.96 for 2.5% significance level, 1.645 for 5% level.
Nonparametric Affiliation Test: Bid Levels

- We construct an analogous test statistic for bid levels.
- Divide each neighbor bidder’s actions into three bins: \{no bid, low bid, high bid\}
- Test statistic examines frequency of these three actions for each neighbor
  - submitted bids are categorized as low vs. high, relative to the median bid for the sample under consideration
Sub-Samples for Tests

- **Main challenge: unobserved heterogeneity**
  - most available tracts do not receive bids, not well predicted by available $Z$.

- **Isolated sub-sample: tracts with no active neighbor leases**

- **NN sub-sample: non-isolated tracts bid by at least one non-neighbor**
  - no selection on leasing if non-neighbors are uninformed
  - allows analysis of pre-AWL period where set of offered tracts is not observed

- **NB sub-sample: non-isolated tracts bid by at least one neighbor**
  - test statistics are valid if restrict attention to subset of tracts with at least one neighbor bid
Data: Covariates

- We employ many covariates to minimize unobserved heterogeneity
- Three categories of variables:
  - Sale characteristics:
    - Real oil and gas prices (offshore Gulf first purchase price); year
  - Tract characteristics:
    - water depth; whether tract is re-offered
  - Neighborhood characteristics, for varying neighborhood sizes:
    - number of active neighbor leases
    - neighbor tract bidding history
    - neighbor lease exploration and production history as of the sale date for the tract in question
    - whether any neighbor lease has expired after drilling
Participation Tests

**Table:** Affiliation Test for All Neighbor Firms - Pre-AWL

<table>
<thead>
<tr>
<th>$s$</th>
<th>#</th>
<th>teststat</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$NB$</td>
<td>886</td>
<td>2.13</td>
<td>0.016</td>
</tr>
<tr>
<td>$NN$</td>
<td>810</td>
<td>1.73</td>
<td>0.042</td>
</tr>
<tr>
<td>$NB\cup NN$</td>
<td>1,191</td>
<td>0.90</td>
<td>0.183</td>
</tr>
</tbody>
</table>

NB : Tracts Bid by Neighbor Firms
NN : Tracts Bid by Non-neighbor Firms
### Table: Affiliation Test for All Neighbor Firms - AWL Shallow

<table>
<thead>
<tr>
<th>$\hat{s}$</th>
<th>#</th>
<th>teststat</th>
<th>$p - value$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$NB$</td>
<td>2,635</td>
<td>3.85</td>
<td>0.000</td>
</tr>
<tr>
<td>$NN$</td>
<td>4,827</td>
<td>3.86</td>
<td>0.000</td>
</tr>
<tr>
<td>$NB\cup NN$</td>
<td>6,485</td>
<td>1.96</td>
<td>0.025</td>
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</table>

Samples as indicated

### Table: Affiliation Test for All Neighbor Firms - AWL Deep

<table>
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<tr>
<th>$\hat{s}$</th>
<th>#</th>
<th>teststat</th>
<th>$p - value$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$NB$</td>
<td>1,478</td>
<td>2.73</td>
<td>0.003</td>
</tr>
<tr>
<td>$NN$</td>
<td>1,651</td>
<td>6.65</td>
<td>0.000</td>
</tr>
<tr>
<td>$NB\cup NN$</td>
<td>2,715</td>
<td>4.05</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Samples as indicated
### Table: Affiliation Test for Top7 Firms - Isolated Tracts

<table>
<thead>
<tr>
<th>$\hat{s}$</th>
<th>#</th>
<th>teststat</th>
<th>$p$ – value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre – AWL</td>
<td>1,723</td>
<td>1.05</td>
<td>0.147</td>
</tr>
<tr>
<td>AWL Shallow</td>
<td>924</td>
<td>1.70</td>
<td>0.045</td>
</tr>
<tr>
<td>AWL Deep</td>
<td>2,574</td>
<td>4.62</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Samples as indicated

Tests are for Top 7 firm participation
Bid Level Tests

**Table**: Affiliation Test for All Neighbor Firms - Pre-AWL

<table>
<thead>
<tr>
<th></th>
<th>( t )</th>
<th>#</th>
<th>teststat</th>
<th>( p - \text{value} )</th>
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</thead>
<tbody>
<tr>
<td>NB</td>
<td>886</td>
<td>1.19</td>
<td>0.116</td>
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</tr>
<tr>
<td>NN</td>
<td>810</td>
<td>2.21</td>
<td>0.014</td>
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<tr>
<td>NB_U_NN</td>
<td>1,191</td>
<td>1.44</td>
<td>0.075</td>
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Samples as indicated
Table: Affiliation Test for All Neighbor Firms - AWL Shallow

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<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>2,635</td>
<td>1.05</td>
<td>1.05</td>
<td>0.146</td>
</tr>
<tr>
<td>NN</td>
<td>4,827</td>
<td>5.41</td>
<td>5.41</td>
<td>0.000</td>
</tr>
<tr>
<td>NBUNN</td>
<td>6,485</td>
<td>3.63</td>
<td>3.63</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Samples as indicated

Table: Affiliation Test for All Neighbor Firms - AWL Deep

<table>
<thead>
<tr>
<th></th>
<th>( \hat{t} )</th>
<th>( # )</th>
<th>teststat</th>
<th>p-value</th>
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</thead>
<tbody>
<tr>
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<td>1.18</td>
<td>1.18</td>
<td>0.119</td>
</tr>
<tr>
<td>NN</td>
<td>1,651</td>
<td>10.77</td>
<td>10.77</td>
<td>0.000</td>
</tr>
<tr>
<td>NBUNN</td>
<td>2,715</td>
<td>4.31</td>
<td>4.31</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Samples as indicated
### Table: Affiliation Test for Top7 Firms - Isolated Tracts

<table>
<thead>
<tr>
<th>Test</th>
<th>$\hat{t}$</th>
<th>#</th>
<th>teststat</th>
<th>$p$ – value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre - AWL</td>
<td>1,723</td>
<td>0.36</td>
<td>0.359</td>
<td></td>
</tr>
<tr>
<td>AWL Shallow</td>
<td>924</td>
<td>2.12</td>
<td>0.017</td>
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<tr>
<td>AWL Deep</td>
<td>2,574</td>
<td>3.45</td>
<td>0.000</td>
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</tr>
</tbody>
</table>

Samples as indicated

Tests are for Top 7 firm bid levels
• 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

• Remaining questions:
  ▶ Information asymmetries: are neighbors who own more tracts, or those who own productive tracts, better informed?
  ▶ do non-neighbors have private information?

• If we conclude there is collusion, can we say more?
  ▶ firm identities and cartel patterns across neighborhoods