The Effects of Technological Improvements on Offshore Oil and Gas Bidding, Exploration and Development

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PRELIMINARY
Introduction

The US Mineral Management Service (MMS) uses auctions to allocate exploration and drilling rights on federal lands on the Outer Continental Shelf (OCS).

The federal offshore leasing program began in 1954, and there have been few alterations in the auction mechanism.

Offshore oil and gas today accounts for about a third of US production.

The stakes are high, and the leasing program has generated considerable revenue for the government.

Excellent data are available.

Our research asks positive questions concerning bidder behavior.

E.g., Is observed behavior consistent with some equilibrium model?

What share of rents accrue to the bidders?

We are also interested in normative issues.

Could different auction rules improve revenues or efficiency?

Is an auction the appropriate allocation mechanism?
The OCS Auction Mechanism 1954-1982

1. Government announces area is available for exploration.
2. Seismic testing of area by industry.
3. Bidding consortia negotiations.
4. Wildcat lease sale.
   - at least 100 tracts offered simultaneously (up to 515)
   - tracts are typically 5,000 or 5,760 acres (up to 9 square miles)
   - each tract sold in a first-price, sealed bid (bonus) auction
   - announced minimum bid: $15 per acre
   - terms: pay bonus at sale date, 1/6 royalty rate on revenues
5. Government bid adequacy decision.
   - based in part on MMS’s independent assessment of tract value
6. Exploratory drilling of wildcat tracts.
   - fixed lease term (5 years)
   - automatic renewal if productive
   - fixed (minimal) rental fees during exploration
7. Drainage and developmental sales.
   - previously explored areas, near productive tracts
   - some wildcat tracts reoffered after relinquishment or high bid rejection
2-D Seismic Analysis

Prior to wildcat sale, firms hire a geophysical company to “shoot” a seismic survey of a large (50 block) area. Cost ($12 million circa 1980) shared equally, usually by six oil companies. Participating firms may not know identities of partners. Seismic data are collected by setting off a boom, and then recording the echoes that result, to draw inferences about underlying geological structure. There are several million echo traces from a 20-30 square mile survey. Seismic analysis selects a mathematical model of the structure (within a class of models) that is most consistent with the echo data. Before 1990, feasible models were limited to two dimensions, or 2-D; vertical cross sections of strata. The interpretation of seismic data varies, and firms focus on different tracts. Second stage: Each firm conducts an in-depth evaluation of some tracts.
OCS Data

Sample: Tracts receiving at least one bid, 1954 - present.

Tract Information:
- date of sale(s)
- location and acreage
- auction rules (e.g., minimum bid, royalty rate)
- lease type (wildcat, drainage, or developmental)
- identity of all bidders and the amounts bid
- if joint bid, the participants and their shares
- whether high bid was rejected
- if lease transferred, date of transfer and new owner(s) identity
- number and date of wells drilled
- monthly production data through 2007
  - oil, condensate, natural gas, other hydrocarbons

Can construct ex post discounted tract value (revenues minus costs), and government share of that value (bonus bid plus royalties).

Also know how many tracts offered in a given sale did not receive bids.
Which Decision to Study?

Participants make the following decisions:
- selection of tracts for seismic analysis
  - not observed
- the formation of bidding coalitions
- entry decisions: which tracts receive bids
- bidding levels
- drilling decisions
  - whether to drill
  - timing and number of wells
- drilling outcomes
  - whether there is production
  - amount recovered
  - date when lease abandoned

Distinguish between wildcat and drainage sales.
Findings for 1954-1979

Wildcat Sales:
- Bidding coalitions
  - frequent, although less common on marginal tracts
  - equal division sharing rules among large firms
- Bidding
  - competitive, but with considerable dispersion
- Drilling
  - non-cooperative plans in areas with multiple lease owners
  - delay and duplication at lease term deadline
  - hit rates about 50%
- Returns
  - government captures large share of rents
  - bids and royalty payments of similar magnitude

Drainage sales:
- Asymmetric information favors owners of neighboring wildcat leases.
- Government share of rents is smaller than on wildcat leases.
  Beneficiaries are neighboring owners.
Research Questions

There have been many important changes in the last 30 years.
- wide swings in oil and gas prices
- new areas of exploration (most notably, deep water)
- beginning in 1983, Area Wide Leasing (AWL)
- changes in allocation (auction) rules
- royalty rate changes (e.g., 1995 Deepwater Royalty Relief Act)
- industry consolidation via mergers
- widespread adoption of 3-D seismic analysis
- changes in drilling technology
  - directional drilling
  - “measurement-while-drilling”
  - both complement the improvements in seismic analysis
  “The rig site has become a server.”

What are the effects of changes in the allocation mechanism?
What are the effects of seismic (and related) advances?
The OCS Auction Mechanism 1983-present

With the advent of Area Wide Leasing (AWL) in 1983:

Wildcat lease sale:
- at least 3,500 tracts offered simultaneously (range: 3,647 – 8,868).
- tracts are typically 5,000 or 5,760 acres
- each tract sold in a first-price, sealed bid (bonus) auction
- announced minimum bid now $25 per acre
- terms: pay bonus at sale date, 1/6 royalty rate on revenues

Deep water:
- Drilling costs are much higher (esp. platform costs)
- 1/8 royalty rate if water depth is more than 400m
- longer lease term (8 or 10 years)
- 1995 Deepwater Royalty Relief Act
  - leaseholders exempt from royalties on production below a fixed amount
  - relief contingent on oil prices not exceeding $35/bbl (except in 1998-1999)

Government bid adequacy decision:
- MMS no longer computes independent assessment of tract value.
- lower rejection rates

Drainage and developmental sales:
- with advent of directional drilling in 1990s, less frequent
3-D Seismic Analysis

3-D seismic imaging first came into commercial use in 1975, but the analysis was slow and expensive. A small shoot today generates on the order of 800 gigabytes of data.

The cost of analyzing a 50 square mile 3-D survey fell from $8 million in 1980, to $1 million in 1990, to less than $100 K in 2000.

In 1989, less than 5% of the wells drilled in the Gulf of Mexico made use of 3-D seismic data; by 1996 the figure was 80% and the surveys were more sophisticated.

3-D is more accurate than 2-D, but uncertainties remain, and there remain differences in the interpretation of seismic data.

On deep water tracts, firms often use 2-D analysis to decide where and how much to bid.

If they acquire a tract, they may conduct further 3-D analysis to decide whether and where to drill.

This decision process reflects two factors:
- Deep water drilling costs (and those of a seismic shoot) are much higher.
- Since the advent of AWL, bid levels have fallen considerably.
- i.e., a large change in the relative costs of acquisition and exploration
In a first price sealed bid common value auction, what are the effects of more precise bidder information?

Consider Wilson’s symmetric “mineral rights” model, in which bidder signals are unbiased estimates of the unknown pure common value, and bidder signals differ, but are equally precise (drawn from the same distribution).

Suppose that the number of potential bidders is fixed.

Then the effect of more precise signals is straightforward:

- Winner’s curse is less of a concern, and bids are more aggressive for a given signal. Bids for a given tract are less disperse.
- Moreover, signals themselves are more precise estimates of value.
- Thus a valuable tract (one with value above the reserve price) is more likely to be sold, and the winning bid is closer to the true value, in expectation and with lower mean square error.

In offshore oil and gas auctions, however, one must also consider the effect on the decisions to acquire a signal, to enter into a joint bidding consortium or to bid solo, and to drill after acquiring the lease.

Consider the various decisions recursively:
The Effect of Improved Seismic Information 2

Drilling outcomes:
- for given tract characteristics, success more likely

Drilling decisions (Hendricks & Porter, AER 1996):
- timing game with information externalities
- if isolated tract, or if cooperative outcome in area with multiple owners
  - improved information results in fewer dry wells, and fewer unproductive leases
- if non-cooperative outcome with multiple owners:
  - less delay and duplication of drilling near end of lease term, as information externalities are less important
  - hence, more efficient plans
- for leases sold in period 1954-1990, 30% of tracts were never drilled
- for period 1954-1979, 22% not drilled; of those drilled, only 50% were productive (i.e., positive amount of oil and/or gas recovered), and fewer had sufficient production to cover costs (drilling costs and amount bid).

The potential gains from improved information are considerable.
The Effect of Improved Seismic Information 3

Bid levels:
- if bidders symmetric (similar precision of information), then more aggressive bidding as winner’s curse mitigated, because there is less dispersion in bidder’s estimates, and because drilling plans are more efficient

Entry (bid submission) decision:
- direct payoff improvement (+) vs. more competitive bidding (-)

Joint bids (Hendricks, Porter & Tan, RAND 2008):
- joint bids more likely
  - offset more competitive bidding
  - interim participation constraints are less likely to bind

Seismic testing:
- direct effect: higher return to testing (+)
- indirect effects: ?
  - more efficient drilling (+)
  - more competitive bidding (-)
  - more joint bids (+/-) (collusive returns vs. free riding)
Table 1: Summary of Offshore Oil and Gas Lease Sales, Gulf of Mexico 1954-2006*

<table>
<thead>
<tr>
<th>Period</th>
<th># of Tracts Offered</th>
<th># of Tracts Bid</th>
<th>Bids per Tract</th>
<th># of Tracts Sold</th>
<th>Total Winning Bids</th>
<th>Mean Winning Bid</th>
<th># of Bids Rejected</th>
<th>Mean Rejected Bid</th>
</tr>
</thead>
<tbody>
<tr>
<td>1954-82</td>
<td>7,175</td>
<td>3,974</td>
<td>3.24</td>
<td>3,525</td>
<td>53,104</td>
<td>15.065</td>
<td>449</td>
<td>2.302</td>
</tr>
<tr>
<td>1983-87</td>
<td>71,243</td>
<td>3,763</td>
<td>1.47</td>
<td>3,473</td>
<td>9,424</td>
<td>2.714</td>
<td>285</td>
<td>1.802</td>
</tr>
<tr>
<td>1988-92</td>
<td>60,228</td>
<td>3,811</td>
<td>1.16</td>
<td>3,701</td>
<td>1,956</td>
<td>0.528</td>
<td>107</td>
<td>0.436</td>
</tr>
<tr>
<td>1993-97</td>
<td>52,563</td>
<td>5,183</td>
<td>1.52</td>
<td>5,017</td>
<td>2,501</td>
<td>0.498</td>
<td>149</td>
<td>0.328</td>
</tr>
<tr>
<td>1998-06</td>
<td>57,946</td>
<td>6,175</td>
<td>1.37</td>
<td>5,951</td>
<td>3,667</td>
<td>0.616</td>
<td>236</td>
<td>0.455</td>
</tr>
</tbody>
</table>

|          | 1954-06             | 249,155         | 22,906        | 1.71            | 21,667            | 70,653           | 3.261             | 1,226             |

*Dollar figures are in millions of 1982 dollars.
Before and After Area Wide Leasing

1954-1982:

- 3,525 tracts sold (49% of tracts offered for sale)
- 3.2 bids per tract
- Mean high bid (in 1982 dollars): $15.07 million
- 64% of tracts received at least 2 bids
- Government rejection rate: 11.2%

1983-2006:

- 18,142 tracts sold (7% of tracts offered for sale)
- 1.3 bids per tract
- Mean high bid (in 1982 dollars): $0.967 million
- 25% of tracts received at least 2 bids
- Government rejection rate: 4.0%
Table 2: Bidding 1954–1984 and 1996-2005 by Number of Bidders*

<table>
<thead>
<tr>
<th>Number of Bidders</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5–6</th>
<th>7–9</th>
<th>10–18</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1954-1979</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># of Tracts</td>
<td>902</td>
<td>463</td>
<td>255</td>
<td>212</td>
<td>264</td>
<td>234</td>
<td>180</td>
<td>2,510</td>
</tr>
<tr>
<td>(B1–B2)/B1</td>
<td>—</td>
<td>0.55</td>
<td>0.49</td>
<td>0.46</td>
<td>0.39</td>
<td>0.34</td>
<td>0.30</td>
<td>0.44</td>
</tr>
<tr>
<td>1980-1982</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># of Tracts</td>
<td>292</td>
<td>131</td>
<td>72</td>
<td>47</td>
<td>59</td>
<td>39</td>
<td>15</td>
<td>655</td>
</tr>
<tr>
<td>B1</td>
<td>3.952</td>
<td>10.675</td>
<td>16.759</td>
<td>26.102</td>
<td>34.126</td>
<td>44.545</td>
<td>50.589</td>
<td>14.497</td>
</tr>
<tr>
<td>(B1–B2)/B1</td>
<td>—</td>
<td>0.56</td>
<td>0.39</td>
<td>0.42</td>
<td>0.37</td>
<td>0.31</td>
<td>0.28</td>
<td>0.44</td>
</tr>
<tr>
<td>1983-1984</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># of Tracts</td>
<td>1,479</td>
<td>438</td>
<td>128</td>
<td>67</td>
<td>51</td>
<td>15</td>
<td>0</td>
<td>2,178</td>
</tr>
<tr>
<td>(B1–B2)/B1</td>
<td>—</td>
<td>0.42</td>
<td>0.41</td>
<td>0.41</td>
<td>0.34</td>
<td>0.33</td>
<td>—</td>
<td>0.41</td>
</tr>
<tr>
<td>1996-2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># of Tracts</td>
<td>3,983</td>
<td>879</td>
<td>352</td>
<td>131</td>
<td>96</td>
<td>32</td>
<td>6</td>
<td>5,479</td>
</tr>
<tr>
<td>B1</td>
<td>0.508</td>
<td>1.066</td>
<td>1.301</td>
<td>2.422</td>
<td>3.888</td>
<td>4.444</td>
<td>4.905</td>
<td>0.781</td>
</tr>
<tr>
<td>(B1–B2)/B1</td>
<td>—</td>
<td>0.48</td>
<td>0.45</td>
<td>0.41</td>
<td>0.41</td>
<td>0.34</td>
<td>0.70</td>
<td>0.46</td>
</tr>
<tr>
<td>2001-2005</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># of Tracts</td>
<td>3,356</td>
<td>667</td>
<td>230</td>
<td>82</td>
<td>36</td>
<td>7</td>
<td>2</td>
<td>4,380</td>
</tr>
<tr>
<td>B1</td>
<td>0.459</td>
<td>0.868</td>
<td>1.935</td>
<td>3.591</td>
<td>6.403</td>
<td>5.679</td>
<td>12.869</td>
<td>0.721</td>
</tr>
<tr>
<td>(B1–B2)/B1</td>
<td>—</td>
<td>0.43</td>
<td>0.48</td>
<td>0.48</td>
<td>0.32</td>
<td>0.26</td>
<td>0.14</td>
<td>0.44</td>
</tr>
</tbody>
</table>

*B1 denotes the highest bid on a tract, and B2 the second highest bid. Dollar figures are nominal, except for 1954-1979, where they are in millions of 2000 dollars.
### Table 3: Drilling and Production 1954-2006

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td># of Tracts Sold</td>
<td>3,525</td>
<td>3,468</td>
<td>3,591</td>
<td>5,035</td>
<td>6,305</td>
</tr>
<tr>
<td># Drilled</td>
<td>2,256</td>
<td>1,479</td>
<td>968</td>
<td>1,053</td>
<td>1,009</td>
</tr>
<tr>
<td>(fraction of sold)</td>
<td>(0.64)</td>
<td>(0.43)</td>
<td>(0.27)</td>
<td>(0.21)</td>
<td>(0.16)</td>
</tr>
<tr>
<td># Productive (by 2006)</td>
<td>1,121</td>
<td>589</td>
<td>403</td>
<td>472</td>
<td>395</td>
</tr>
<tr>
<td>(fraction of drilled)</td>
<td>(0.50)</td>
<td>(0.40)</td>
<td>(0.42)</td>
<td>(0.45)</td>
<td>(0.39)</td>
</tr>
<tr>
<td>(fraction of sold)</td>
<td>(0.32)</td>
<td>(0.17)</td>
<td>(0.11)</td>
<td>(0.09)</td>
<td>(0.06)</td>
</tr>
<tr>
<td># Productive in 2006</td>
<td>294</td>
<td>185</td>
<td>313</td>
<td>373</td>
<td></td>
</tr>
</tbody>
</table>
Drilling Lags by Lease Term 1954-1987

Tenure5 54-82

Tenure5 83-87

Tenure8-10 83-87
Drilling Lags by Lease Term 1988-1997

Tenure5 88-92

Tenure8-10 88-92

Tenure5 93-97

Tenure8-10 93-97
## Table 4: Profits and Government Receipts 1954-1997*

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Crude Price</td>
<td>28.97</td>
<td>23.86</td>
<td>18.54</td>
<td>17.11</td>
<td></td>
</tr>
<tr>
<td># of Tracts Sold</td>
<td>1,527</td>
<td>612</td>
<td>3,468</td>
<td>3,591</td>
<td>5,035</td>
</tr>
<tr>
<td>Revenue per tract drilled</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual prices</td>
<td>33.18</td>
<td>36.80</td>
<td>26.63</td>
<td>22.05</td>
<td></td>
</tr>
<tr>
<td>Sale date prices</td>
<td>28.89</td>
<td>34.83</td>
<td>37.86</td>
<td>16.58</td>
<td>11.16</td>
</tr>
<tr>
<td>Cost per tract drilled</td>
<td>9.98</td>
<td>28.02</td>
<td>16.74</td>
<td>13.56</td>
<td>14.33</td>
</tr>
<tr>
<td>Mean Bid per tract sold</td>
<td>9.54</td>
<td>17.21</td>
<td>2.71</td>
<td>0.53</td>
<td>0.50</td>
</tr>
<tr>
<td>Bid + Royalty per tract sold</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual prices</td>
<td>20.51</td>
<td>4.89</td>
<td>1.56</td>
<td>1.19</td>
<td></td>
</tr>
<tr>
<td>Sale date prices</td>
<td>13.35</td>
<td>20.74</td>
<td>5.00</td>
<td>1.18</td>
<td>0.86</td>
</tr>
<tr>
<td>Profit per tract sold</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual prices</td>
<td>(16.99)</td>
<td>3.67</td>
<td>1.96</td>
<td>0.42</td>
<td></td>
</tr>
<tr>
<td>Sale date prices</td>
<td>1.60</td>
<td>(16.10)</td>
<td>4.01</td>
<td>(0.37)</td>
<td>(1.52)</td>
</tr>
</tbody>
</table>

*Dollar figures are in millions of 1982 dollars. Profit = Revenue – Cost – Bid – Royalty.
Competitive or Collusive Entry and Bidding?

The benefit of allowing firms to collude in exploration is greater efficiency: lower search costs, and all tracts with positive expected value are explored.

If 3-D signals are relatively informative, the social gains from more than one firm investing in a survey may be low.

Then coordination leads to more tracts being explored and more production.
The cost to the government is reduced revenues from less competition.
But, if tracts are marginal, the foregone revenues are likely to be small.
Then auctions may be a poor mechanism for allocating production rights, e.g., a more efficient mechanism may select via royalty rates.
   But royalties distort exploration and production at the margin.
Levels of competition in the 1990s were low, with approximately 1.3 bids per tract.
Under competition, the explanation for few, low bids is that most tracts are marginal.
Under collusion, the explanation is coordinated entry.
Question: are the entry/bidding/drilling patterns in offshore auctions in the 3-D sample period (beginning in the mid-1990s) consistent with competitive behavior?
Or are the patterns more consistent with firms coordinating their exploration and drilling activities?
Hypothesis I: Firms behave competitively

Consider a simplified model without joint bidding:
A tract is worth $V$ with probability $\alpha$, and zero otherwise.
There are two firms, which enter the auction only if they acquire and analyze seismic data at cost $C$.
Assume that 3-D is a perfectly informative signal, which reveals the true value of the tract.
The acquisition of a 3-D signal is private information (but verifiable).
The auction is FPSB with reserve price $R$.
Assume $\alpha V \leq R$ (don’t bid without signal)
and $\alpha (V-R) \geq C$ (if rival doesn’t bid, it pays to acquire a signal and bid $R$)
Firms play a two stage game:
Stage 1: They simultaneously decide whether to acquire a signal, $p_i = \Pr\{i \text{ acquires signal}\}$. This decision is private information.
Stage 2: They simultaneously decide how much to bid. If they observe a signal that the value is $V$, they bid according to the mixed strategy bid distribution function $G_i(b; \beta_j)$ where $\beta_j$ is firm $i$’s belief about the probability that its rival acquires a signal. Otherwise, they do not bid.
Competitive Equilibrium 1

Lemma: For any \((\beta_1, \beta_2)\) satisfying \(1 \geq \beta_1 > \beta_2 > 0\), or \(1 > \beta_1 = \beta_2 > 0\), there exists a unique mixed strategy BNE with
\[
G_1(b; \beta_2) = -\frac{(1-\beta_1)}{\beta_1} + \frac{(1-\beta_2)}{\beta_2} \frac{(V-R)}{(V-b)}
\]
and
\[
G_2(b; \beta_1) = \frac{(1-\beta_2)}{\beta_2} \frac{(b-R)}{(V-b)}
\]
for \(b \in [R, B]\), where \(B = R + \beta_2(V-R)\).
Then \(\pi_1 = \pi_2 = (1-\beta_2)(V-R)\).

If \(\beta_1 > \beta_2 = 0\), firm 1 bids \(R\) and firm 2 bids 0. But then 2 should enter.
If \(\beta_1 = \beta_2 = 1\), both firms bid \(V\), payoffs are \(-C\).

Proposition: There exists a unique BNE in which both firms enter with probability \(p = 1 - C/\alpha(V-R)\), hold beliefs \(\beta_1 = \beta_2 = p\), and randomize their bids if they observe tract value \(V\) on \([R, V - (C/\alpha)]\) according to:
\[
G(b; p) = \frac{(1-p)}{p} \frac{(b-R)}{(V-b)}
\]
Firms earn positive information rents in the bidding stage (because entry is private information), but compete away the rents in the entry stage.
Competitive Equilibrium 2

Predictions:
- Number of entrants is distributed binomial conditional on tract characteristics.
- Entry is not efficient: with probability $p^2$, entry costs are 2C instead of C; with probability $(1 - p)^2$, no one enters even though the expected value of doing so is positive. (The latter suggests positive resale value.)
- Entry rates are higher in the complete information game than in the game where signals are informative but noisy.
- A reduction in costs of a 3-D survey increases entry rates and bid levels.

Conjecture: these results also hold under the assumption that 3-D is not perfectly informative but more informative than 2-D seismic surveys. In this case, it is not clear how to define “more informative,” but the key idea is that information rents are lower with 3-D than 2-D.

Remark: If entry is observable, then the likely outcome is that only one firm (or consortium) enters in equilibrium and bids $R$, the reserve price. Here entry must be verifiable, e.g., acquisition of a 3-D survey.

Intuition: if two firms enter, they compete away any information rents and do not recover the costs of the 3-D survey. The model of observable entry leads to the prediction that entry rates are lower with 3-D and independent of entry costs.
Hypothesis 2: Firms behave cooperatively

There are two ways in which firms can cooperate.

1. Firms could coordinate their entry decisions, with each firm agreeing to bid only on the tracts that it is assigned. This case generates outcomes that are similar to those of a model in which entry is observable. But the zero profit entry condition is violated. Bids are not very informative of tract value. Note: need to appeal to repeated game arguments to enforce collusion.

2. Firms could compete in the entry stage but form a joint venture conditional on entry. HP have analyzed the effect of joint venture formation on entry in this model. Both entry and participation in the joint venture conditional on tract value exceeding the reserve price are randomized. Note: here collusion can be enforced by contract. Firms that participate in the joint venture agree not to bid against the cartel.

Consider a stylized model of joint venture formation.
Cooperative Equilibrium 1

Now suppose that, after the two firms decide whether to acquire a signal, they engage in joint bidding negotiations. They simultaneously announce “Yes” or “No.” (Y or N)
If both say Y, then they bid jointly.
   They bid R if at least one firm has acquired a signal that the tract value is V, and they do not bid otherwise.
If at least one firm says N, then they bid solo, given updated beliefs whether their rival is informed.
The competitive equilibrium is an equilibrium here, too, if both firms always say N to a joint bid.
But an N declaration by an uninformed firm is weakly dominated by Y. If an informed rival says Y, the uninformed firm shares its information rents.
A strategy for firm \( i \) now consists of:

\[
\begin{align*}
    p_i &= \Pr\{i \text{ acquires signal}\} & r_i &= \Pr\{i \text{ says } Y| \text{ uninformed}\} \\
    q_i &= \Pr\{i \text{ says } Y| \text{ informed, value } V\} & \text{solo bid d.f. } G_i(b; \beta_j)
\end{align*}
\]
Assume the firm always says N if it is informed and tract value is 0.
Cooperative Equilibrium 2

**Lemma:** Suppose both firms enter with probability \( p \). Then a symmetric equilibrium of the announcement game has \( r = 1 \) and

\[
q = 0 \quad \text{if } p < \frac{1}{3} \\
q = q(p) \quad \text{if } p \in \left[\frac{1}{3}, \frac{1}{2}\right] \\
q = 1 \quad \text{if } p > \frac{1}{2}
\]

where \( q(p) = \frac{\left((-1 + p) - \{2(-1 + p)(1 - 2p)\}^{1/2}\right)}{p} \).

Suppose \( p \) is low, and an informed firm on a productive tract says \( Y \), pretending to be uninformed. It gains \( (V - R) \) if its rival is informed, by bidding just above \( R \). It loses if its rival is uninformed, now having to surrender \( (V - R)/2 \), half the share of its rents.

It will not deviate if \( p(V - R) < (1 - p)(V - R)/2 \), or \( p < 1/3 \).

If \( p \) is high, suppose instead that an informed firm says \( N \). The firm no longer shares its rents. But it must now bid competitively, and earns \( (1 - p)(V - R) \), assuming an informed rival has belief \( \beta_i \geq p \). It would earn \( (V - R)/2 \) by saying \( Y \), and will not deviate if \( p > \frac{1}{2} \).
Cooperative Equilibrium 3

*Proposition*: The following is a sequential equilibrium:

(a) If $C/\alpha(V-R) > 2/3$,
   
   $p = 1 - C/\alpha(V-R) < 1/3$,
   
   $r = 1$, $q = 0$, and the competitive equilibrium obtains.

(b) If $C/\alpha(V-R) < 1/4$,
   
   $p = 1 - 2C/\alpha(V-R) > 1/2$,
   
   $r = 1$, $q = 1$, and competitive bidding $G(b;p)$.

(c) Otherwise,
   
   $r = 1$, $q = q(p)$, and competitive bidding $G(b;p)$.
   
   Here $p$ solves:
   
   $p(1+q(p)) = 1 - C/\alpha(V-R)]$

Observe only solo bids on low quality tracts, and only joint bids on high quality tracts.

On intermediate quality tracts, both joint and solo bids are submitted.

*Prediction*: As 3-D costs decline, entry rates are higher, and joint ventures are more likely.
Remarks

1. In this model, a ban on joint bids increases social welfare, as competitive entry rates are too high. (But the model ignores the benefits of risk sharing and information pooling.)

2. A second complicating feature may be bidder asymmetries. Spatial economies of scale in drilling wells (e.g., from a platform) may make it easier for firms to concentrate their exploration activity.

3. Drilling patterns in the 3-D era should differ from the 2-D era. The absence of any significant information externality reduces the incentive of firms to delay their drilling in hope of obtaining more information about the likelihood of finding oil. More tracts will be drilled and they will be drilled earlier (for constant prices). If tracts are marginal, the main determinant of drilling times is likely to be price volatility.