Do Firms Interact Strategically?
An Empirical Analysis of Investment Timing Decisions in Offshore Petroleum Production

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Petroleum Production

− Exploration
  ■ drilling rigs
Petroleum Production

- Exploration
  - drilling rigs

- Development
  - production platforms
Strategic considerations

- Information externality
Strategic considerations

- Information externality
- Extraction externality
Difference #1: sign

Strategic considerations

- Information externality: *positive*

- Extraction externality: *negative*
Difference #2: Geographical scope

Common geological features (information externality)
Difference #2: Geographical scope

Pool of Petroleum (extraction externality)
Difference #3: Relative importance

Large tracts: information externality
Small tracts: information and extraction externalities

Difference #3: Relative importance

Tract A  Tract B
Strategic considerations

- Information externality: *positive*
- Extraction externality: *negative*

Relative importance larger on small tracts than on large tracts
Research questions

- Do firms interact strategically?

- Do the externalities have any net strategic effect that may cause petroleum production to be inefficient?
Data

- U.S. federal lease sales in the Gulf of Mexico, 1954-1990
- Maximum tract size: 3 miles by 3 miles
- Up to 23 tracts can be located over a common field
- 57% - 67% fields have more than 1 tract
- 70% - 79% fields have 3 or fewer tracts
Motivation

 Theory
  - Do strategic interactions take place in practice?

 Methodology
  - How estimate strategic interactions?

 Policy
  - Is the federal leasing program inefficient?
Methodology

- Reduced-form discrete response model of a firm’s exploration investment timing decision
  - instrument for neighbors’ decisions

- Structural econometric model of the firms’ multi-stage investment timing game
Structural model

- Multi-stage investment timing game
  - exploration
  - development

- How does a firm’s profits depend on the exploration and development decisions of its neighbor?
Investment stages

1. exploration
2. development

solve backwards
Investment stages

1. exploration

2. development

solve backwards
Stage 2: Development

When to develop an explored tract?

Value of an explored but undeveloped tract $i$ in market $k$ at time $t$ is:

$$V^e(\Omega_{kt}, \epsilon_{it}; \theta) = \max\{\pi^d(\Omega_{kt}, \epsilon_{it}; \theta), \beta V^{ce}(\Omega_{kt}; \theta)\}$$

where

$$\pi^d(\Omega_{kt}, \epsilon_{it}; \theta) = \pi_0^d(\Omega_{kt}; \theta) + \epsilon_{it}$$

$$V^{ce}(\Omega_{kt}; \theta) = \mathbb{E}[V^e(\Omega_{kt+1}, \epsilon_{it+1}; \theta) \mid \Omega_{kt}, \epsilon_{it}=0]$$
Investment stages

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solve backwards
Stage 1: Exploration

When to explore an unexplored tract?

Value of an unexplored tract $i$ in market $k$ at time $t$ is:

$$V^n(\Omega_{kt}, \mu_{it}; \theta) = \max\{\pi^e(\Omega_{kt}, \mu_{it}; \theta), \beta V^{cn}(\Omega_{kt}; \theta)\}$$

where

$$\pi^e(\Omega_{kt}, \mu_{it}; \theta) = E_{\epsilon}[V^e(\Omega_{kt}, \epsilon_{it}; \theta) \mid \Omega_{kt}] - c^e(\Omega_{kt}; \theta) + \mu_{it}$$

$$V^{cn}(\Omega_{kt}; \theta) = E[V^n(\Omega_{k,t+1}, \mu_{i,t+1}; \theta) \mid \Omega_{kt}, \epsilon_{it}=0]$$
Econometric estimation

- Step 1: Estimate continuation values & predicted exploration and development probabilities
- Step 2: Use generalized method of moments (GMM) to match predicted probabilities with the actual probabilities in data
Pooled results from structural model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mu )</td>
<td>4.99</td>
<td>0.00</td>
</tr>
<tr>
<td>( \sigma_e )</td>
<td>4.86</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Coefficient \( \alpha \) in the exploration profit function on: discretized real drilling cost + 1
-10.01 0.00

Coefficients \( \gamma \) in the development profit function on:
- # tracts in market that have been explored
  0.03 0.02
- # tracts in market that have been developed
  0.16 0.02
- discretized average winning bid per acre
  5.10 0.01
- discretized real drilling cost
  -9.91 0.01
- discretized real oil price
  5.19 0.00
- constant
  5.01 0.02

Notes: There are 1041 observations spanning 87 markets. Standard errors are formed by bootstrapping 100 simulated panels of 87 markets each.
Reasons results do not support non-cooperative, strategic behavior during exploration

- Large tract size => no cross-tract externalities
- Firms cooperate to internalize externalities
- Positive information externality and negative extraction externality cancel
Strategic effects expected

<table>
<thead>
<tr>
<th></th>
<th>Large tracts</th>
<th>Small tracts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large tract size =&gt; no cross-tract externalities</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Firms cooperate to internalize externalities</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Positive information externality and negative extraction externality cancel</td>
<td>Y/N extraction externality less important</td>
<td>Y extraction externality more important</td>
</tr>
</tbody>
</table>
## Results for large tracts

<table>
<thead>
<tr>
<th>Acreage</th>
</tr>
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<tr>
<td>≥ 5000</td>
</tr>
</tbody>
</table>

Coefficients $\gamma$ in the development profit function on:

<table>
<thead>
<tr>
<th># tracts in market that have been explored</th>
<th>0.00</th>
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</thead>
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<tr>
<td></td>
<td>(4.24)</td>
</tr>
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</table>

<table>
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<th># tracts in market that have been developed</th>
<th>-0.00</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1.12)</td>
</tr>
</tbody>
</table>
# Results for small tracts

<table>
<thead>
<tr>
<th></th>
<th>&lt; 5000</th>
<th>&lt; 4000</th>
<th>&lt; 3000</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>coefficients $\gamma$ in the development profit function on:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># tracts in market that have been explored</td>
<td>-25.78</td>
<td>-25.99</td>
<td>-27.67</td>
</tr>
<tr>
<td></td>
<td>(0.15)</td>
<td>(0.56)</td>
<td>(0.00)</td>
</tr>
<tr>
<td># tracts in market that have been developed</td>
<td>3.15</td>
<td>4.00</td>
<td>4.06</td>
</tr>
<tr>
<td></td>
<td>(0.03)</td>
<td>(0.17)</td>
<td>(0.00)</td>
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## Results for small tracts

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<td>3.15</td>
<td>4.00</td>
<td>2.31</td>
</tr>
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<td>(0.00)</td>
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Externalities no longer cancel; negative extraction externality dominates
Results

**Importance of strategic interactions depends on tract size**

**Externalities do not have any net non-cooperative strategic effect on large tracts**

**During exploration, relative importance of extraction externality with respect to information externality is greater on small tracts**
Conclusion

Federal government’s choice of tract size has minimized additional inefficiencies that may have resulted from non-cooperative strategic interactions.
Thank you for coming
Investment stages

1. exploration

2. development

solve backwards
Investment stages

1. exploration

2. development

solve backwards
Stage 2: Development

When to develop an explored tract?

Value of an explored but undeveloped tract \( i \) in market \( k \) at time \( t \) is:

\[
V^e(\Omega_{kt}, \varepsilon_{it}; \theta) = \max\{\pi^d(\Omega_{kt}, \varepsilon_{it}; \theta), \beta V^{ce}(\Omega_{kt}; \theta)\}
\]

where

\[
\pi^d(\Omega_{kt}, \varepsilon_{it}; \theta) = \pi^0_d(\Omega_{kt}; \theta) + \varepsilon_{it}
\]

\[
V^{ce}(\Omega_{kt}; \theta) = E[V^e(\Omega_{k,t+1}, \varepsilon_{i,t+1}; \theta) | \Omega_{kt}, l_{it}^{d=0}]
\]
let $g^d(\Omega_{kt}; \theta) \equiv$ the probability of developing an explored but undeveloped tract at time $t$ conditional on the public information at $t$

then

$$g^d(\Omega_{kt}; \theta) = \exp\left( - (\beta V^{ce}(\Omega_{kt}; \theta) - \pi^d_0(\Omega_{kt}; \theta)) / \sigma_\varepsilon \right)$$
Stage 2: Development

let \( g^d(\Omega_{kt};\theta) \equiv \) the probability of developing an explored but undeveloped tract at time \( t \) conditional on the public information at \( t \)

then

\[
g^d(\Omega_{kt};\theta) = \exp\left( - \left( \beta V^{ce}(\Omega_{kt};\theta) - \pi_0^d(\Omega_{kt};\theta) \right) / \sigma_\varepsilon \right)
\]

Estimate non-parametrically in 1st step
Stage 2: Development

let $g^d(\Omega_{kt}; \theta) \equiv$ the probability of developing an explored but undeveloped tract at time $t$ conditional on the public information at $t$

then

$$g^d(\Omega_{kt}; \theta) = \exp \left( - \left( \beta V^{ce}(\Omega_{kt}; \theta) - \pi_0^d(\Omega_{kt}; \theta) \right) / \sigma_\epsilon \right)$$

Match predicted probabilities to data in 2nd step
Estimator of $V_{ce}(\Omega_{kt}; \theta)$

$$V_{ce}^t = \mathbf{M}^e \cdot (\beta \ V_{ce}^{t+1} + \sigma_\varepsilon \ g^d_{t+1})$$

where

- $\mathbf{M}^e$ = empirical transition matrix conditional on $I_t ^d = 0$
- $g^d$ = empirical probability of developing an explored tract

$t \geq T$: solve for fixed point
$t < T$: iterate backwards
Investment stages

1. Exploration

2. development

solve backwards
Stage 1: Exploration

- When to explore an unexplored tract?

- Value of an unexplored tract $i$ in market $k$ at time $t$ is:

$$V^n(\Omega_{kt}, \mu_{it}; \theta) = \max\{\pi^e(\Omega_{kt}, \mu_{it}; \theta), \beta V^c(n)(\Omega_{kt}; \theta)\}$$

where

$$\pi^e(\Omega_{kt}, \mu_{it}; \theta) = E_{\varepsilon}[V^e(\Omega_{kt}, \varepsilon_{it}; \theta) | \Omega_{kt}] - c^e(\Omega_{kt}; \theta) + \mu_{it}$$

$$V^c(n)(\Omega_{kt}; \theta) = E[V^n(\Omega_{k,t+1}, \mu_{i,t+1}; \theta) | \Omega_{kt}, I_{it=0}]$$
Stage 1: Exploration

\[ g^e(\Omega_{kt}; \theta) \equiv \text{the probability of exploring an unexplored tract at time } t \text{ conditional on the public information at } t \]

then

\[ g^e(\Omega_{kt}; \theta) = \exp\left( - (\beta V^{cn}(\Omega_{kt}; \theta) - (\beta V^{ce}(\Omega_{kt}; \theta) + g^d(\Omega_{kt}; \theta) \sigma_\varepsilon)) / \sigma_\mu \right) \]
Stage 1: Exploration

let \( g^e(\Omega_{kt}; \theta) \equiv \) the probability of exploring an unexplored tract at time \( t \) conditional on the public information at \( t \)

then

\[
g^e(\Omega_{kt}; \theta) = \exp(-\beta V^{cn}(\Omega_{kt}; \theta) - (\beta V^{ce}(\Omega_{kt}; \theta) + g^d(\Omega_{kt}; \theta) \sigma_\epsilon ))/ \sigma_\mu
\]
Stage 1: Exploration

let \( g^e(\Omega_{kt}; \theta) \equiv \) the probability of exploring an unexplored tract at time \( t \) conditional on the public information at \( t \)

then

\[
g^e(\Omega_{kt}; \theta) = \exp(- (\beta V^{cn}(\Omega_{kt}; \theta) - (\beta V^{ce}(\Omega_{kt}; \theta) + g^d(\Omega_{kt}; \theta) \cdot \sigma_\varepsilon ))/ \sigma_\mu)
\]

Estimate non-parametrically in 1\textsuperscript{st} step
Stage 1: Exploration

let \( g^e(\Omega_{kt};\theta) \equiv \text{the probability of exploring an unexplored tract at time } t \text{ conditional on the public information at } t \)

then

\[
\begin{align*}
g^e(\Omega_{kt};\theta) &= \exp\left(- (\beta V^{cn}(\Omega_{kt};\theta) - (\beta V^{ce}(\Omega_{kt};\theta) + g^d(\Omega_{kt};\theta) \sigma_\varepsilon))/\sigma_\mu \right)
\end{align*}
\]

Match predicted probabilities to data in 2\textsuperscript{nd} step
Estimator of $V^{cn}(\Omega_{kt}; \theta)$

\[ V^{cn}_t = M^n (\beta V^{cn}_{t+1} + \sigma \mu g^e_{t+1}) \]

$V^{cn}_{T-1} = 0$

where
- $M^n =$ empirical transition matrix conditional on $l^e_t=0$
- $g^e =$ empirical probability of exploring on an unexplored tract

$t \leq T$: iterate backwards
Additional results

Federal government cannot do better by making the 5-year lease term longer or shorter
previous lit extra slide
Forms of coordination

- joint venture in exploration
  - BUT, may not occur because:
    - negotiations contentious
    - fear of allegations of pre-sale anti-trust violations (esp. among Big 7)
    - prospective partners have incentive to free-ride on info-gathering expenditures

- consolidation of production rights through purchase or unitization
  - BUT, may not occur because:
    - negotiations contentious
    - relative or absolute tract values need to be determined
    - info costs
    - oil migration
Definition of Neighbors

A tract \( j \) is considered a neighbor of tract \( i \) at time \( t \) if:

- located within 5 miles
- lease began before time \( t \)
- has not been explored before \( t-1 \)
- owned by a different firm
Advantages of discrete response model

- leases of neighbors can begin on different dates
  - can use all available data

- reduced-form specification: simple

- can identify parameter of interest

- covariates can be continuous variables
Advantages of structural approach

- estimates structural parameters of the underlying dynamic game
- addresses endogeneity problems without the need for instruments
- determines how a firm’s profits are affected by the decisions of its neighbors
- explicitly models the multi-stage dynamic decision-making problem
Innovations to Pakes, Ostrovsky & Berry (2005)

- actual data
- sequential investments
- exploration is a finite-horizon dynamic optimization problem
- estimate parameters in profit function
Tracts used in structural analysis

Gulf of Mexico
Firms’ perceptions of neighbors

- depend only on the publicly observable market state variables $\Omega_{kt}$

- firms take expectations over neighbors’ private information (shocks)

- $\Pr(\text{neighbor invests}) = \Pr(\text{profits} > \text{continuation value})$
  - expectations taken over the private shocks
Estimator of $V^{ce}(\Omega_{kt}; \theta)$

$$V^{ce}_t = M^e \left( \beta V^{ce}_{t+1} + \sigma^e g^d_{t+1} \right)$$

where
- $M^e$ = empirical transition matrix conditional on $I^d_t = 0$
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$t \geq T$: solve for fixed point
$t < T$: iterate backwards
Estimator of $V^{cn}(\Omega_{kt};\theta)$

$$V^{cn}_{t} = M^n \triangleright \left( \beta V^{cn}_{t+1} + \sigma_\mu g^e_{t+1} \right)$$

$$V^{cn}_{T-1} = 0$$

where

- $M^n$ = empirical transition matrix conditional on $l_t^e=0$
- $g^e$ = empirical probability of exploring on an unexplored tract

$t \leq T$: iterate backwards
Modifying the leasing program

- change lease terms
- encourage unitization of exploration programs
  - Ex: limit the amount of nonunitized acreage that a firm can possess
- require firms to make their seismic reports publicly available
- change the quantity, size or location of the tracts offered in each lease sale
- use multi-unit auctions
- make contractual environment more conducive to coordination
- taxes/regulation
Possible effects of decreasing tract size

- increase # bidders
  - increase bid levels (competitive pressure)
  - decrease bid levels (winner’s curse)

- information & extraction externalities
  - decrease bid levels (government does not extract rents from internalizing externalities)

- other reasons why gov’t might prefer smaller tracts
  - political (why ban joint bids among large firms in 1975?)
  - other?
Efficiency of OCS wildcat leasing program

- **PROs:**
  - revenue maximization: gov’t captures a reasonable share (~77%) of the rents in wildcat auctions

- **CONs:**
  - information externalities
  - extraction externalities
  - environmental costs
  - domestic strategic needs
Reasons OCS wildcat leasing program is socially inefficient

1. Information externalities
   - firms learn information about their tracts when other firms explore or develop neighboring tracts
   - noncooperative war of attrition
     - Hendricks & Porter, 1993
     - Porter, 1995
   - too little exploration at the beginning of the lease term
   - duplicative drilling in the final period of the lease
Reasons OCS wildcat leasing program is socially inefficient

1. Information externalities (cont)

- optimal coordinated plan = sequential search
  - 1st period: drill one tract
  - if productive, drill neighboring tract in next period
Reasons OCS wildcat leasing program is socially inefficient

2. Extraction externalities

- marginal costs of extraction may vary with the quantity of oil remaining in a reserve

- a firm’s extraction affects extraction costs of
  - itself
  - firms owning neighboring tracts
Reasons OCS wildcat leasing program is socially inefficient

3. Environmental costs of production process

- Direct costs
  - ecosystem damage caused by exploratory drilling
  - pollutants emitted during reserve development
  - oil spillage during extraction
- Indirect costs
  - markets for renewable energy
  - incentives for technological innovation in energy industry
Reasons OCS wildcat leasing program is socially inefficient

4. Strategic
   - need for a domestic strategic oil reserve
   - socially optimal policy
     - involve less delay, or
     - tie the production rate to current political factors