The Effects of Royalties on Oil and Gas Production

Clinton J. Levitt
Department of Economics
Copenhagen Business School

BIEE 2010
Objective

- Understand the effect royalties have on oil and gas production:
  1. Tilting?
  2. High-grading?
  3. Government revenue?
  4. Exploration rates?
  5. Geographic distribution of exploration?

- In this presentation, I focus on exploration.
How?

- Estimate a structural model of oil and gas production that includes both exploration and extraction.
- Construct a firm-level panel consisting of decisions made 700 firms concerning over 350,000 wells.
  1. How much to explore.
  2. Where to explore.
- Construct a pool-level panel of over 40,000 pools.
  1. Construct Reserves estimates for each firm.
  2. Estimate field specific costs.
Firm’s Decision Problem

- The firm maximizes discounted future profits,

\[
\max_{q_t, w_t} \mathbb{E} \left[ \sum_{t=0}^{\infty} \beta^t [\tilde{p}_t q_t - c(q_t, R_t) - d(w_t)] \bigg| \Omega_t \right]
\]

subject to 2 transition equations:

1. Reserves:

\[
R_{t+1} = (R_t - q_t) + f(w_t, W_t).
\]

2. Wells:

\[
W_{t+1} = W_t + w_t.
\]

and a resource constraint

\[
q_t \leq R_t.
\]
The corresponding Bellman equation is

\[ v(p, R, W) = \max_{q,w} \{ \tilde{p}q - c(q, R) - d(w) + \beta E[v(p', R', W') | \Omega_t] \} \]

Subject to the law of motion for reserves,

\[ R' = (R - q) + f(w, W), \]

and the law of motion for the total number of wells drilled,

\[ W' = W + w. \]
Euler Equations

- Euler equation for extraction:

\[
\tilde{p} - \frac{\partial c(q, R)}{\partial q} = \beta E \left[ \left( \tilde{p}' - \frac{\partial c(q', R')}{\partial q'} \right) - \frac{\partial c(q', R')}{\partial R'} \right]_{\Omega_t}.
\]
Euler Equations

- Euler equation for reserve production

\[
\left( \hat{p} - \frac{\partial c(q, R)}{\partial q} \right) \frac{\partial f(w, W)}{\partial w} - \frac{\partial d(w)}{\partial w} \\
= \beta E \left[ \frac{\partial f(w', W')}{\partial w'} \left( \hat{p}' - \frac{\partial c(q', R')}{\partial q'} \right) - \frac{\partial d(w')}{\partial w'} \right]_{\Omega_t}.
\]
Empirical Model

- Reserve Production Function:

\[ f(w_t, W_t) = \Gamma \left[ 1 - \exp \left( -\gamma \frac{w_t}{1 + W_t} \right) \right] \]
Empirical Model

- **Lifting Costs:**

\[ c(q_t) = \alpha_0 q_t + \alpha_1 \frac{1}{2} q_t^2 + \alpha_2 R_t. \]

- **Drilling Costs:**

\[ d(w_t) = \tau_1 w_t + \frac{1}{2} \tau_2 w_t^2. \]

- **Prices:**

\[ p_{t+1} = a_0 + a_1 p_t + u_t \quad u_t \sim N(0, \sigma^2) \]
The empirical problem is to estimate the parameter vector for each of the $K$ fields:

$$\Phi = [\Gamma, \gamma, \tau_1, \tau_2, \alpha_0, \alpha_1, \alpha_2, a_0, a_1, \sigma^2]$$
The GMM estimates of $\Phi$ are obtained by choosing $\tilde{\Phi}$ that minimizes the vector function

$$
S = \left[ \sum_{i=1}^{N} z_i'M_i(X; \tilde{\Phi}) \right]' \tilde{\Omega}_i \left[ \sum_{1=1}^{N} z_i'M_t(X; \tilde{\Phi}) \right]
$$

where $\tilde{\Omega}$ is a weighting matrix and $M_t(X; \tilde{\Phi})$ is

$$
M_i(X_t; \Phi) = \begin{pmatrix}
m_{1t}(X_t;\Phi) & 0 \\
0 & m_{2t}(X_t;\Phi)
\end{pmatrix}.
$$
Preliminary Results: Lifting Costs

- Map illustrating estimated lifting costs evaluated at field-specific means
Preliminary Results: Drilling Costs

• Map illustrating estimated drilling costs evaluated at field-specific means
Policy Functions: Exploration Wells

Low Price

High Price
Policy Functions: Volume

Low Price

High Price
Policy Simulation: Mean of the Parameter Estimates

<table>
<thead>
<tr>
<th>Percent Increase</th>
<th>Number of Exp. Wells</th>
<th>Percentage Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>12663</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>12575</td>
<td>-0.88</td>
</tr>
<tr>
<td>2</td>
<td>12444</td>
<td>-1.73</td>
</tr>
<tr>
<td>4</td>
<td>11848</td>
<td>-6.44</td>
</tr>
<tr>
<td>6</td>
<td>11382</td>
<td>-10.12</td>
</tr>
<tr>
<td>8</td>
<td>11103</td>
<td>-12.32</td>
</tr>
<tr>
<td>10</td>
<td>11008</td>
<td>-13.07</td>
</tr>
</tbody>
</table>
## Policy Simulation: Low Cost and High Volume Fields

<table>
<thead>
<tr>
<th>Percent Increase</th>
<th>Number of Exp. Wells</th>
<th>Percentage Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>24212</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>22999</td>
<td>-5.01</td>
</tr>
<tr>
<td>2</td>
<td>24932</td>
<td>2.97</td>
</tr>
<tr>
<td>4</td>
<td>22575</td>
<td>-6.76</td>
</tr>
<tr>
<td>6</td>
<td>22667</td>
<td>-6.38</td>
</tr>
<tr>
<td>8</td>
<td>22635</td>
<td>-6.51</td>
</tr>
<tr>
<td>10</td>
<td>22316</td>
<td>-7.83</td>
</tr>
</tbody>
</table>
Policy Simulation: High Cost and Low Volume Fields

<table>
<thead>
<tr>
<th>Percent Increase</th>
<th>Number of Exp. Wells</th>
<th>Percentage Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>507</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>486</td>
<td>-4.14</td>
</tr>
<tr>
<td>2</td>
<td>508</td>
<td>0.20</td>
</tr>
<tr>
<td>4</td>
<td>516</td>
<td>1.78</td>
</tr>
<tr>
<td>6</td>
<td>541</td>
<td>6.71</td>
</tr>
<tr>
<td>8</td>
<td>488</td>
<td>-3.75</td>
</tr>
<tr>
<td>10</td>
<td>512</td>
<td>0.99</td>
</tr>
</tbody>
</table>
Policy Simulation: High Reserve Production Fields (high $\gamma$ and $\Gamma$)

<table>
<thead>
<tr>
<th>Percent Increase</th>
<th>Number of Exp. Wells</th>
<th>Percentage Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>15582</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>15580</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>15562</td>
<td>-0.001</td>
</tr>
<tr>
<td>4</td>
<td>15529</td>
<td>-0.003</td>
</tr>
<tr>
<td>6</td>
<td>15498</td>
<td>-0.005</td>
</tr>
<tr>
<td>8</td>
<td>15458</td>
<td>-0.008</td>
</tr>
<tr>
<td>10</td>
<td>15312</td>
<td>-0.017</td>
</tr>
</tbody>
</table>
Thanks for your attention