Drilling down the Bakken Learning Curve

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North Dakota Wells Spudded

North Dakota Wells (2000-2005)

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Motivation

- Learning-by-Doing (LBD)
  - Greater experience $\rightarrow$ lower unit cost (or higher productivity)
  - Experience $\approx$ cumulative output

- LBD Relevance
  - Understanding economic growth and trade (Arrow, 1962; Lucas, 1988; Krugman, 1987)
  - Implications for pricing and output decisions, industry concentration (Thompson, 2010)

- LBD in Oil & Gas Extraction
  - Productivity offsets effects of resource depletion
  - Impact of low oil prices on U.S. drilling activity
Evidence for LBD in Many Industries
- Aircraft (Benkard, 2000), semiconductors (Irwin and Klenow, 1994), shipbuilding (Thornton and Thompson, 2001), agriculture (Conley and Udry, 2010)

Oil & Gas Drilling
- Kellogg (2011)
  - Texas, 1991-2005, vertical wells
  - Relationship-specific learning between operator and rig
- Osmundsen et al. (2012)
  - Norwegian Continental Shelf, 1968-2008
  - Limited evidence for learning
Research Question and Contributions

- **Research Questions**
  - Is there learning-by-doing in well drilling in the Bakken?
    - Productivity: rate of drilling (thousand feet/day)
    - Experience: cumulative wells drilled
  - Is there evidence for organizational forgetting?

- **Contributions**
  - Analyze horizontal drilling in a shale play
  - Estimate effects of forgetting
Background
Background

Operator
Background

Operator

Designs and Owns Well
(e.g. Continental or Hess)
Background

Operator

Drilling Contractor
Background

Operator

Drilling Contractor

Rig
Background

Operator

Drilling Contractor

Rig

Drills Well
(e.g. H&P or Nabors)
Background

Operator

- Directional Driller
- Drilling Contractor

Rig
Background

Operator

Directional Driller

Drills Lateral (e.g. Halliburton)

Drilling Contractor

Rig

Other Contractors
Background

- Operator
  - Directional Driller
  - Drilling Contractor
  - Other Contractors
  - Rig
## Data

<table>
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<th>Obs</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
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</table>

Sample includes wells drilled between 2005 and 2014.
326 rigs, 85 operators, 48 directional drillers, and 327 fields.
Estimation

\[ \text{LnRate}_{rodft} = \alpha_0 \text{Ln}E_{rt} + \alpha_1 \text{Ln}E_{oft} + \alpha_2 \text{Ln}E_{dft} + \alpha_3 \text{Ln}E_{ft} + \beta x_{rodft} + \phi_r + \psi_o + \zeta_d + \kappa_f + \lambda_t + \epsilon_{rodft} \]
Estimation

\[ \text{LnRate}_{rodft} = \alpha_0 \text{Ln}E_{rt} + \alpha_1 \text{Ln}E_{oft} + \alpha_2 \text{Ln}E_{dft} + \alpha_3 \text{Ln}E_{ft} + \beta x_{rodft} + \phi_r + \psi_o + \zeta_d + \kappa_f + \lambda_t + \epsilon_{rodft} \]

Rate_{rodft} depth divided by drilling days for well drilled by rig \( r \), operator \( o \), and directional driller \( d \) in field \( f \) at date \( t \)
\[
\text{LnRate}_{rodft} = \alpha_0 \text{Ln}E_{rt} + \alpha_1 \text{Ln}E_{oft} + \alpha_2 \text{Ln}E_{dft} + \alpha_3 \text{Ln}E_{ft} + \\
\beta x_{rodft} + \phi_r + \psi_o + \zeta_d + \kappa_f + \lambda_t + \epsilon_{rodft}
\]

Rate\text{}_{rodft} depth divided by drilling days for well drilled by rig \(r\), operator \(o\), and directional driller \(d\) in field \(f\) at date \(t\)

\(E_{rt}\) is experience of rig \(r\) at date \(t\)
Estimation

\[
\text{LnRate}_{rodft} = \alpha_0 \text{LnE}_{rt} + \alpha_1 \text{LnE}_{oft} + \alpha_2 \text{LnE}_{dft} + \alpha_3 \text{LnE}_{ft} + \\
\beta x_{rodft} + \phi_r + \psi_o + \zeta_d + \kappa_f + \lambda_t + \epsilon_{rodft}
\]

\(\text{Rate}_{rodft}\) depth divided by drilling days for well drilled by rig \(r\), operator \(o\), and directional driller \(d\) in field \(f\) at date \(t\)

\(E_{rt}\) is experience of rig \(r\) at date \(t\)

\(E_{oft}\) is experience of operator \(o\) in field \(f\) at date \(t\)
\[ LnRate_{rodft} = \alpha_0 \ln E_{rt} + \alpha_1 \ln E_{oft} + \alpha_2 \ln E_{dft} + \alpha_3 \ln E_{ft} + \beta x_{rodft} + \phi_r + \psi_o + \zeta_d + \kappa_f + \lambda_t + \epsilon_{rodft} \]

Rate_{rodft} depth divided by drilling days for well drilled by rig \( r \), operator \( o \), and directional driller \( d \) in field \( f \) at date \( t \)

\( E_{rt} \) is experience of rig \( r \) at date \( t \)
\( E_{oft} \) is experience of operator \( o \) in field \( f \) at date \( t \)
\( E_{dft} \) is experience of directional driller \( d \) in field \( f \) at date \( t \)
\[ 
\ln \text{Rate}_{rodft} = \alpha_0 \ln E_{rt} + \alpha_1 \ln E_{oft} + \alpha_2 \ln E_{dft} + \alpha_3 \ln E_{ft} + \\
\beta x_{rodft} + \phi_r + \psi_o + \zeta_d + \kappa_f + \lambda_t + \epsilon_{rodft} 
\]

\( \text{Rate}_{rodft} \) depth divided by drilling days for well drilled by rig \( r \), operator \( o \), and directional driller \( d \) in field \( f \) at date \( t \)

\( E_{rt} \) is experience of rig \( r \) at date \( t \)

\( E_{oft} \) is experience of operator \( o \) in field \( f \) at date \( t \)

\( E_{dft} \) is experience of directional driller \( d \) in field \( f \) at date \( t \)

\( E_{ft} \) is experience in field \( f \) at date \( t \)
Estimation

\[\text{LnRate}_\text{rodft} = \alpha_0 \text{LnE}_{rt} + \alpha_1 \text{LnE}_{oft} + \alpha_2 \text{LnE}_{dft} + \alpha_3 \text{LnE}_{ft} + \]
\[\beta x_\text{rodft} + \phi_r + \psi_o + \zeta_d + \kappa_f + \lambda_t + \epsilon_{\text{rodft}}\]

\(\text{Rate}_\text{rodft}\) depth divided by drilling days for well drilled by rig \(r\), operator \(o\), and directional driller \(d\) in field \(f\) at date \(t\)

\(E_{rt}\) is experience of rig \(r\) at date \(t\)
\(E_{oft}\) is experience of operator \(o\) in field \(f\) at date \(t\)
\(E_{dft}\) is experience of directional driller \(d\) in field \(f\) at date \(t\)
\(E_{ft}\) is experience in field \(f\) at date \(t\)
\(x_{rodft}\) control variables: depth, temperature, wind, and others
\[ \text{LnRate}_{\text{rodft}} = \alpha_0 \text{LnE}_{rt} + \alpha_1 \text{LnE}_{oft} + \alpha_2 \text{LnE}_{dft} + \alpha_3 \text{LnE}_{ft} + \beta x_{\text{rodft}} + \phi_r + \psi_o + \zeta_d + \kappa_f + \lambda_t + \epsilon_{\text{rodft}} \]

\( \text{Rate}_{\text{rodft}} \) depth divided by drilling days for well drilled by rig \( r \), operator \( o \), and directional driller \( d \) in field \( f \) at date \( t \)

\( E_{rt} \) is experience of rig \( r \) at date \( t \)
\( E_{oft} \) is experience of operator \( o \) in field \( f \) at date \( t \)
\( E_{dft} \) is experience of directional driller \( d \) in field \( f \) at date \( t \)
\( E_{ft} \) is experience in field \( f \) at date \( t \)

\( x_{\text{rodft}} \) control variables: depth, temperature, wind, and others
\( \lambda_t \) includes year-qtr and month-of-year fixed effects
Sources of Variation
- Fluctuations in oil prices
- New fields discovered or becoming economic
- Changes in rigs and directional drillers employed by operators

Endogeneity Issues
- Endogeneity arising from serial correlated shocks
- Measurement error
Organizational Forgetting

- Estimate organizational forgetting from breaks in drilling
- Include variable for log duration of a rig’s break in between drilling wells

\[
\text{LnRate}_{rodft} = \gamma \text{LnBreak}_{rt} + \alpha_0 \text{LnE}_{rt} + \alpha_1 \text{LnE}_{oft} + \alpha_2 \text{LnE}_{dft} + \alpha_3 \text{LnE}_{ft} + \\
\beta x_{rodft} + \phi_r + \psi_o + \zeta_d + \kappa_f + \lambda_t + \epsilon_{rodft}
\]

\(\text{LnBreak}_{rt}\) is logged number of days between finishing last well and beginning next well
- Instrument for break using oil price, U.S. rig count, and month-year rig finished last well
## Results

<table>
<thead>
<tr>
<th></th>
<th>No Controls</th>
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<td>LnRate</td>
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<td><strong>LnE&lt;sub&gt;rt&lt;/sub&gt;</strong></td>
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<tr>
<td>(Rig)</td>
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<td>(0.014)</td>
<td>(0.017)</td>
<td>(0.014)</td>
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<tr>
<td><strong>LnE&lt;sub&gt;oft&lt;/sub&gt;</strong></td>
<td>0.026**</td>
<td>0.021**</td>
<td>0.017*</td>
<td>0.017*</td>
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<tr>
<td>(Operator-Field)</td>
<td>(0.008)</td>
<td>(0.008)</td>
<td>(0.008)</td>
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<td>(Dir.-Field)</td>
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<td><strong>N</strong></td>
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<td>4625</td>
<td>4328</td>
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</table>

Standard errors clustered on field in parentheses

+ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Column 4: Cragg-Donald Wald F stat is 41.34 and Kleibergen-Paap Wald rk F Stat (weak identification) is 18.46; Overidentification test p-value = 0.29
Typical well cost $7.5MM (KLJ, 2015); Typical rig drills 8 wells per year; Average drilling time 27 days; Rig Day Rate $25,000 (RigData, 2012)
Typical well cost $7.5MM (KLJ, 2015); Typical rig drills 8 wells per year; Average drilling time 27 days; Rig Day Rate $25,000 (RigData, 2012)
Learning Curve

Typical well cost $7.5MM (KLJ, 2015); Typical rig drills 8 wells per year; Average drilling time 27 days; Rig Day Rate $25,000 (RigData, 2012)

2nd Year
Time Savings: 1 day/well
Cost Savings: $25,000/well
(0.3% of total well cost)
Learning Curve

Typical well cost $7.5MM (KLJ, 2015); Typical rig drills 8 wells per year; Average drilling time 27 days; Rig Day Rate $25,000 (RigData, 2012)
Conclusions

- Evidence for learning
  - by rigs and operators within a field
  - however, cost reductions from learning are relatively small

- Evidence for organization forgetting
  - by rigs
  - implies productivity negatively impacted when (if?) drilling rebounds
References


