The Price Elasticity of US Shale Oil Reserves
Dr. James L. Smith
Southern Methodist University, Dallas TX

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Research Objectives

- Estimate price elasticity of the volume of US shale oil reserves, by play.
- Estimate price elasticity of the number of viable shale oil drilling sites, by play.
- Estimate potential for infill drilling to augment the volume of reserves.
- Estimate the economic threshold for completing investment in DUCs.
- Estimate sensitivity of production from mature shale oil wells to low prices.
This Paper is not About the Breakeven Price of US Shale Oil

- 80% of potential U.S. tight oil capacity additions in 2015 remain resilient at price as low as $70/barrel.
  - *IHS Online, Nov. 20, 2014.*

- Breakeven price for “some” US shale oil is $30/bbl.

- US shale oil costs are around $50/barrel at present.
  - *Mike Winter, Societe Generale, PIW, Oct. 12, 2015*

- Bone Spring, Wolfcamp, & Scoop: breakeven = $40/barrel, Eagle Ford: breakeven = $50/barrel
  - *WoodMackenzie, PIW, Aug. 8, 2016.*

- Breakeven cost now under $30 in Permian’s Delaware and Midland basins.
  - *Wells Fargo, PIW, Sept. 19, 2016*
Breakeven Price Varies Across Shale Oil Plays

KLR Group, reported by Oil & Gas 360, May 23, 2016.
There is no Single Breakeven Price, Not Even Within a Single Play

It is perhaps better to think of break-even as a bell-shaped curve, where some wells in a shale play can break even at $30, 50% break even at <$60/bbl (for example), but then some small fraction on the far side of the curve don’t even break even when oil prices are at $100/bbl.

Heterogeneous Well Productivity Within a Play

Bakken Core Lognormal EUR Distribution

mean = 0.725
The “Average” Well is not “Typical”

Bakken Core Lognormal EUR Distribution

- Mean = 0.725
- Median = 0.402
At $90, Any Well Above the B/E EUR is Viable

Bakken Core Lognormal EUR Distribution

- Mean = 0.725
- Median = 0.402
- B/E @ $90 = 0.504
Average Size of Those Wells is 1.406 mmb
But Only 42% of Potential Drill Sites Meet the Criterion

Bakken Core Lognormal EUR Distribution

mean = .725
median = .402
B/E @$90 = .504
E[EUR|EUR>.504] = 1.406
Pr[EUR>.504] = 42%
81% of Recoverable Resources are Viable at $90

Bakken Core Lognormal EUR Distribution

- B/E @$90 = .504
- median = .402
- mean = .725

E[Reserves @ $90] = 42% \times 1.406 / 0.725 = 81%

Pr[EUR > .504] = 42%

E[EUR | EUR > .504] = 1.406
Breakeven Well Productivity, EUR\textsubscript{p}

![Graph showing breakeven EUR (1000 barrels) vs. WTI ($ per barrel) for 2016 Cost, 2014 Cost, and Dynamic Cost.

- **Bakken Core**

SMU COX
Goal #1: Chart Reserves as Function of Price

Percent of Recoverable Resources that are Economic (Dynamic Cost scenario)

\[ \%_{resources} = \Phi \left( \sigma - \frac{\ln EUR_P - \mu}{\sigma} \right) \]

- Bakken Core

$0\text{/barrel, WTI}$

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
Goal #2: Chart the Number of Viable Drill Sites

Viable Drill Sites as Percent of Total
(Dynamic Cost scenario)

$\text{%wells} = 1 - \Phi \left( \frac{\ln EUR_p - \mu}{\sigma} \right)$

Bakken Core
Related Studies of Shale Oil Supply

- Browning, et al., 2014-2016 (UT Bureau of Economic Geography)
  - Process-oriented model tied to specific geology of resource base and variation in productivity of wells.

- Newell, Prest, and Vissing, 2016 (NBER)

- Lasky, 2015 (CBO)

- Kleinberg, et al., 2016 (MIT CEEPR)
  - No “model” but an explicit discussion of variation in productivity of wells.
Scope of the Analysis: Oil Plays

<table>
<thead>
<tr>
<th>Basin/Gas Field</th>
<th>Play</th>
<th>Uniform Coef Var</th>
<th>Specific Coef Var</th>
<th>Well Cost (Smm)</th>
<th>EUR (mboe)</th>
<th>IP Rate (boe/d)</th>
<th>Oil (%)</th>
<th>Gas (%)</th>
<th>NGL (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anadarko/MidCont</td>
<td>Springer</td>
<td>1.500</td>
<td>1.991</td>
<td>9.0</td>
<td>904</td>
<td>720</td>
<td>68%</td>
<td>16%</td>
<td>17%</td>
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<td>1.991</td>
<td>3.1</td>
<td>201</td>
<td>720</td>
<td>55%</td>
<td>25%</td>
<td>20%</td>
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<td>28%</td>
<td>17%</td>
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<td>Bakken</td>
<td>Bakken Core</td>
<td>1.500</td>
<td>1.970</td>
<td>7.5</td>
<td>725</td>
<td>851</td>
<td>85%</td>
<td>13%</td>
<td>2%</td>
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<td>Bakken</td>
<td>Bakken Non Core</td>
<td>1.500</td>
<td>1.970</td>
<td>6.5</td>
<td>558</td>
<td>655</td>
<td>88%</td>
<td>9%</td>
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<td>Denver/Julesburg</td>
<td>N Wattenberg</td>
<td>1.500</td>
<td>1.082</td>
<td>4.0</td>
<td>357</td>
<td>400</td>
<td>71%</td>
<td>20%</td>
<td>10%</td>
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<tr>
<td>Denver/Julesburg</td>
<td>N Wattenberg XL</td>
<td>1.500</td>
<td>1.082</td>
<td>6.6</td>
<td>727</td>
<td>722</td>
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<td>13%</td>
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<td>S Wattenberg</td>
<td>1.500</td>
<td>1.082</td>
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<td>395</td>
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<td>Eagle Ford</td>
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<td>515</td>
<td>915</td>
<td>71%</td>
<td>15%</td>
<td>14%</td>
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<td>801</td>
<td>1,387</td>
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<td>Other</td>
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<td>12%</td>
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<td>Permian</td>
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<td>745</td>
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<td>19%</td>
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<td>1.500</td>
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<td>75%</td>
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<td>0%</td>
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<td>Uinta</td>
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<td>1.500</td>
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<td>700</td>
<td>1,290</td>
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</table>
## Scope of the Analysis: Combo Plays

<table>
<thead>
<tr>
<th>Basin</th>
<th>Play</th>
<th>Uniform Coef</th>
<th>Specif Coef</th>
<th>Well Cost Smm</th>
<th>EUR mboe</th>
<th>IP Rate boe/d</th>
<th>Oil %</th>
<th>Gas %</th>
<th>NGL %</th>
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<td>Anadarko/MidCont</td>
<td>Cana Woodford</td>
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<td>1.991</td>
<td>7.0</td>
<td>1,826</td>
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<td>5%</td>
<td>63%</td>
<td>32%</td>
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<td>979</td>
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<td>29%</td>
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<td>Anadarko/MidCont</td>
<td>SCOOP Condensate</td>
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<td>1.991</td>
<td>9.6</td>
<td>1,952</td>
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<td>10%</td>
<td>50%</td>
<td>40%</td>
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<td>Anadarko/MidCont</td>
<td>STACK</td>
<td>1.500</td>
<td>1.991</td>
<td>8.5</td>
<td>940</td>
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<td>30%</td>
<td>30%</td>
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<td>Anadarko/MidCont</td>
<td>Meramec</td>
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<td>1,338</td>
<td>1,425</td>
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<td>47%</td>
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<td>50%</td>
<td>30%</td>
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<td>Anadarko/MidCont</td>
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<td>1.500</td>
<td>1.991</td>
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<td>232</td>
<td>400</td>
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<td>45%</td>
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<td>Appalachia</td>
<td>SW PA Wet Gas</td>
<td>1.500</td>
<td>1.500</td>
<td>5.9</td>
<td>2,933</td>
<td>2485</td>
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<td>50%</td>
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<td>Appalachia</td>
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<td>1.500</td>
<td>5.9</td>
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<td>46%</td>
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<td>Appalachia</td>
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<td>1.500</td>
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<td>30%</td>
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<tr>
<td>Appalachia</td>
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<td>1.500</td>
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<td>1,186</td>
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<td>48%</td>
<td>24%</td>
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<td>Eagle Ford Combo</td>
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<td>5.5</td>
<td>898</td>
<td>1,085</td>
<td>21%</td>
<td>45%</td>
<td>34%</td>
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<tr>
<td>Permian</td>
<td>Culberson LL Wolfcamp</td>
<td>1.500</td>
<td>0.805</td>
<td>11.9</td>
<td>1,955</td>
<td>2,450</td>
<td>20%</td>
<td>50%</td>
<td>30%</td>
</tr>
<tr>
<td>Permian</td>
<td>S Midland Basin Wolfcamp</td>
<td>1.500</td>
<td>0.805</td>
<td>4.8</td>
<td>500</td>
<td>525</td>
<td>48%</td>
<td>27%</td>
<td>25%</td>
</tr>
</tbody>
</table>
Estimation of the Lognormal Parameters

• Coefficient of variation (mean/std.dev) is based on USGS lognormal estimates.
  – This immediately determines $\sigma$.
  – Hypothesis: $\sigma$ has not changed despite technological progress.

• The mean EUR is based on expert industry judgment.
  – Given the $\sigma$ from above, this determines $\mu$.
  – Hypothesis: $\mu$ has increased due to technological progress.
The Impact of Low Prices on Reserves

Figure 6: Reserves as % of Technically Recoverable (Dynamic Cost)

- Midland Spraberry
- San Juan Gallup
- N Delaware Bone Spring
- Midland Wolfcamp
- S Delaware Wolfcamp
- Springer
- Eagle Ford Condensate
- Greater Monument Butte
- N Wattenberg
- Eagle Ford Oil
- Bakken Core
- S Wattenberg
- Bakken Non Core
- Tuscaloosa Marine Shale
- Wasatch SXL
- Tonkawa
- Marmaton
- Uteland Butte SXL

@ $30/barrel @ $60/barrel @ $90/barrel
The Price Inelasticity of Shale Oil Reserves

Figure 5: Reserve Elasticity, by Play and Price (Dynamic Cost)
The Impact of Price on Viable Drill Sites

Figure 10: Viable Drill Sites as % of Total (Dynamic Cost)
The Price Elasticity of Viable Drill Sites

Figure 9: Drill Site Elasticity, by Play and Price (Dynamic Cost)

Shale Oil Plays

- @ $90/barrel
- @ $60/barrel
- @ $30/barrel
Breakeven Prices for Mean vs. Median Wells

Figure 14: Breakeven Price for Mean vs. Median Well Productivity: 2014 Cost Scenario

Shale Oil Plays

<table>
<thead>
<tr>
<th>Mean</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>$-</td>
<td></td>
</tr>
<tr>
<td>$40</td>
<td></td>
</tr>
<tr>
<td>$80</td>
<td></td>
</tr>
<tr>
<td>$120</td>
<td></td>
</tr>
<tr>
<td>$160</td>
<td></td>
</tr>
<tr>
<td>$200</td>
<td></td>
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</tbody>
</table>

Midland Spraberry
San Juan Gallup
N Delaware Bone
Midland Wolfcamp
S Delaware Wolfcamp
Springer
Eagle Ford Condensate
N Wattenberg XL
Eagle Ford Oil
Greater Monument
Bakken Core
S Wattenberg
Bakken Non Core
Tuscaloosa Marine
Wasatch SXL
Tonkawa
Marmaton
Uteland Butte SXL
Figure 17: Percent of Recoverable Resources that are Economic
(elasticities at right, Dynamic Cost scenario)

SW PA Wet Gas
Infill Drilling Constitutes Play within a Play

Primary wells: \[ EUR \sim \Lambda(\mu, \sigma) \]

Infill wells: \[ EUR_{infill} = \delta \times EUR \]

Infill performance: \[ \delta \sim \Lambda(\mu_{infill}, \sigma_{infill}) \]

Thus: \[ EUR_{infill} \sim \Lambda(\mu + \mu_{infill}, \sqrt{\sigma^2 + \sigma_{infill}^2}) \]

To illustrate, assume: \[ mean_\delta = 0.4, stdev_\sigma = 0.2 \]
Potential Contribution of Infill Drilling

Reserves as % of Technically Recoverable Resources
(Dynamic Cost scenario and Variable Infill Performance)

Midland Basin: Spraberry

Primary Reserves
Primary + Infill Reserves

$/barrel, WTI
Infill Drilling Hardly Affects Elasticity

Impact of Infill Drilling on Elasticity of Reserves (Dynamic Cost scenario and Variable Infill Performance)

Midland Basin: Spraberry

Elasticity

Primary Wells
Primary + Infill Wells

Primary Wells
Primary + Infill Wells
Thank You
## Play-Specific Coefficients of Variation

<table>
<thead>
<tr>
<th>Petroleum Basin</th>
<th>Basin Average Coefficient of Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anadarko/MidContinent</td>
<td>1.991</td>
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<tr>
<td>Bakken</td>
<td>1.970</td>
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<tr>
<td>Denver/Julesburg</td>
<td>1.082</td>
</tr>
<tr>
<td>Eagle Ford</td>
<td>1.620</td>
</tr>
<tr>
<td>Permian</td>
<td>0.805</td>
</tr>
<tr>
<td>Overall Average</td>
<td>1.500</td>
</tr>
</tbody>
</table>
Figure 23: Percent of Recoverable Resources that are Economic (Dynamic Cost scenario)
Impact of Coefficient of Variation: Bakken Core

Figure 25: Percent of Recoverable Resources that are Economic (Dynamic Cost scenario)

- Average EUR Variability
- Play Specific EUR Variability

Bakken Core
Impact of Coefficient of Variation: Eagle Ford Oil

Figure 27: Percent of Recoverable Resources that are Economic (Dynamic Cost scenario)

Eagle Ford Oil Region

$/barrel, WTI

Average EUR Variability

Play Specific EUR Variability
Figure 31: Percent of Recoverable Resources that are Economic (Dynamic Cost scenario)

Midland Basin: Spraberry

$/barrel, WTI

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Average EUR Variability
Play Specific EUR Variability
Resilience of DUCs vs. New Wells (mean EUR)

Figure 21: Breakeven Price, Full Cycle vs. DUC (2014 Cost)
Resilience of DUCs vs. New Wells (median EUR)

Figure 22: Breakeven Price, Full Cycle vs. DUC (2014 Cost)