Learning Where to Drill
Drilling Decisions and Geological Quality in the Haynesville Shale

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Learning has increased shale productivity

- Production process: *how* to drill
  - How does output respond to inputs, experience?
  - Improve well drilling, design
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- **Production process:** *how to drill*
  - How does output respond to inputs, experience?
  - Improve well drilling, design
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- **Geological quality:** *where to drill*
  - Which locations produce more?
  - Focus drilling on “sweet spots”
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► Production process: *how* to drill
  - How does output respond to inputs, experience?
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► Geological quality: *where* to drill
  - Which locations produce more?
  - Focus drilling on “sweet spots”
  - *Learning hastens depletion*
### How vs where matters for supply

<table>
<thead>
<tr>
<th></th>
<th>How</th>
<th>Where</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing output/well in SR</td>
<td>technology</td>
<td>targeting</td>
</tr>
<tr>
<td>All locations produce more</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>LR depletion</td>
<td>delayed</td>
<td>accelerated</td>
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- Ignoring that firms choose where to drill $\implies$ biased forecasts
  1. Underestimate depletion: drill best first
  2. Overstate technology: confound where & how
Research question: How bad could it be?

1) What do firms know about quality of locations they drill?
   – How does this affect their drilling decisions?
   – What do they learn by drilling?

2) Quantitative implications for supply
   – Short run: is learning sufficient to increase average output/well?
   – Long run: how severe are depletion effects?
Louisiana’s Haynesville shale (2003–2016)

Unit of observation: 1 sq. mile section

All parties in a section must participate in each well
Join data to form investment history
What firms know & learn affects 3 outcomes

- Leasing
- Drilling
- Production

Noisy signal $\psi_0$

Informativeness of signal:

Effects of information:

$\psi_0$, $\psi_1$

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What firms know & learn affects 3 outcomes

- Leasing (royalty)
- Noisy signal $\psi_0$
- Avg royalty rate $r_i$ section $i$
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- Leasing (royalty)
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Leasing (royalty) → Drilling Well 1 vs Wells 2–13 → Production

- Noisy signal \( \psi_0 \)
- Actual quality \( \psi_1 \)

Avg royalty rate \( r_i \) section \( i \)
Num wells drilled \( d_{it} \) section-month \( it \)
Production

\[ \log q_{iwt} \] section-well-month \( iwt \)

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Learning Where to Drill
What firms know & learn affects 3 outcomes

Leasing (royalty)

Drilling
Well 1 vs Wells 2–13

Production

Noisy signal $\psi_0$

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Informativeness of signal: $\rho$

1) Informativeness of signal: $\rho$
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1) Informativeness of signal: $\rho$

2) Effects of information: $\psi_0, \psi_1$
Econometric model: features & estimation

- **Goal**: recover firms’ information about quality
- **Challenge**: it’s not observable
Goal: recover firms’ information about quality

Challenge: it’s not observable

Drilling
  - Dynamic discrete choice: # wells to drill/month
  - Learning about quality
Econometric model: features & estimation

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- **Drilling**
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- **Royalty rate & Production**
  - Help measure unobserved information
Econometric model: features & estimation

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- **Royalty rate & Production**
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- **Estimation**: Maximimum Simulated Likelihood
  - Rust (1987) nested fixed point approach for drilling
  - 3 outcomes linked by information (unobserved)
  - Integrate out signal & quality to recover distribution
Simulation: mean productivity of wells drilled

2 phases

1) Learning: 15% growth over 2008–16
2) Depletion: -0.4%/yr decline over 2016–24
Simulation: well productivity with, without learning

\[ E[\gamma \psi_1 + \gamma g|d>0] \]

Simulation
- Fitted
- Max learning
- No learning

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Conclusion

▶ What’s new here

– Dynamic model of learning over space
– Aggregate implications of firms choosing where to drill
– Exploit regulatory structure in model, data
– Combine data on leasing, drilling, production

My questions

– Are companies learning about where to drill? Yes!
– They have noisy initial signals, and learn a lot from drilling
– Could this contribute to rising production/well? Yes!
– How bad are depletion effects? Moderate.
– Is Malthus slouching towards shale supply? No.
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