Flaring of Associated Natural Gas in the Bakken Shale

Timothy Fitzgerald\textsuperscript{1} and Case Stiglbauer\textsuperscript{2}

\textsuperscript{1}Texas Tech University
\textsuperscript{2}Continuity

USAEE North American Conference
Pittsburgh, PA 28 October 2015
Natural gas flared at the wellhead accounts for 30% of natural gas production volume in North Dakota.

Annual foregone revenue is over $1 billion.

$CO_2$ emissions from flaring are up to 905 tons per year.
Bakken Flaring
Widespread, Persistent, Increased

Figure: Natural Gas Flared in Bakken Region, Jan 2000 – Dec 2013
OIL AND GAS CO-PRODUCED

GAS IS LESS VALUABLE BYPRODUCT

Figure: Value of Oil Sold and Natural Gas Flared
Historical Context
Figure: Natural Gas Flared or Vented, Selected States 1967–2013

Source: EIA
RESEARCH QUESTIONS

- Why freely dispose?
- What determines the decision to connect to infrastructure?
- Why not connect every well?
**Why Flare?**

**Options for Produced Gas**

1. collect and market  
   ▶ requires investment in gathering and processing
2. reinject  
   ▶ requires sufficient pore space
3. “on-lease” use  
   ▶ electric generation; rich gas may pose problems
4. flare  
   ▶ safety issue; preferable to venting from GHG standpoint
GATHERING AND PROCESSING

Co-produced gas is a mix of methane ($CH_4$) and associated compounds (NGLs)

- NGLs often important share of economic value

Collecting and marketing methane and NGLs requires specific infrastructure investment

1. gathering lines
   - move raw gas from wellhead to gas plant
2. gas processing
   - separate methane from NGLs
3. transmission capacity or access to storage
   - transport to consumer (intra- or inter-state)

Natural Gas System Schematic (EPA)
ORGANIZATION

CONTRACTS

Most gathering and processing is not owned by operators
- specialized midstream firms
- ONEOK, Kinder Morgan: ~ 750 MMcfd
- Whiting, Hess, XTO, Petro Hunt, True: ~ 485 MMcfd

Contracts between operator (well) and processor (plant):
- share
- “keep whole”
- cash
- hybrids of above
MODEL I

Two resources are co-produced with exponential decline.

\[ y_t = (1 - \alpha) y_{t-1} \]
MODEL I

Two resources are co-produced with exponential decline.

\[ y_t = (1 - \alpha) y_{t-1} \]

Separable infrastructure investments for the two products determine potential regimes for profit maximization.

\[
\Pi = \begin{cases} 
(p_1 - c_1) y^1 & I_1 = 1, I_2 = 0 \\
(p_1 - c_1) y^1 + (p_2 - c_2) \frac{y^1}{\xi} & I_1 = 1, I_2 = 1 
\end{cases}
\]
**Model I**

Two resources are co-produced with exponential decline.

\[ y_t = (1 - \alpha) y_{t-1} \]

Separable infrastructure investments for the two products determine potential regimes for profit maximization.

\[ \Pi = \begin{cases} (p_1 - c_1) y^1 & I_1 = 1, I_2 = 0 \\ (p_1 - c_1) y^1 + (p_2 - c_2) \frac{y^1}{\xi} & I_1 = 1, I_2 = 1 \end{cases} \]

This yields an investment rule for the second product.

\[ \sum_{t=\tau}^{T} \left\{ \beta^t (p_{2t} - c_{2t}) \frac{y_{1t}}{\xi} \right\} \geq I_2 \]
**Variable Revenues**

Specific infrastructure investments
- Might not be such a good idea when output prices vary
- Steep decline in production may not justify connection
  - connect immediately or not at all

Use binomial option model
- observed history of price variation
- proxy for connection cost
- calculate value of waiting to connect
- use calculations to assess behavior
OPTION TREE

COMPOUND DECLINE & PRICE UNCERTAINTY

\[ t = 1 \quad t = 2 \quad t = 3 \quad t = 4 \]
Figure: Study Region
Figure: Location of Wells and Gas Plants in Bakken Region

- Associated Wells
- Processing Plants
**FLARING**

40x flaring in ND vs. MT
6.5x wells in ND vs. MT
### Table: Summary Statistics

<table>
<thead>
<tr>
<th>Variable (units)</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flared Gas (Mcf)</td>
<td>826.11</td>
<td>2847.29</td>
<td>0</td>
<td>90938</td>
</tr>
<tr>
<td>Gas Produced (Mcf)</td>
<td>2999.23</td>
<td>4401.85</td>
<td>0</td>
<td>133550</td>
</tr>
<tr>
<td>Gas Sold (Mcf)</td>
<td>2077.47</td>
<td>3390.21</td>
<td>0</td>
<td>77348</td>
</tr>
<tr>
<td>Nearest Well (mi)</td>
<td>1.02</td>
<td>2.11</td>
<td>0</td>
<td>36.26</td>
</tr>
<tr>
<td>Nearest Plant (mi)</td>
<td>14.58</td>
<td>8.32</td>
<td>0.22</td>
<td>65.24</td>
</tr>
<tr>
<td>Age at Connection (months)</td>
<td>7.2</td>
<td>8.5</td>
<td>2</td>
<td>99</td>
</tr>
</tbody>
</table>
Estimate simple decline rates from production histories:

- Oil: 4.5 percent per month
- Natural Gas: 4.0 percent per month

- Comparable to Covert (2014) and Fitzgerald (2015)
- Gas-oil ratio increases over time

Can forecast remaining recovery for each well in each month

- conditional on well-specific initial production and decline
- have tried time-varying decline rates
What is the Opportunity Cost of Flaring?

Foregone revenues depend on price variation

- composition: raw/wet vs. dry
- time
- spatial basis

We construct a Bakken-specific raw gas price estimate

- Stiglbauer (2015)

Account for NGL content, time variation, constant spatial basis
May 2007 – December 2013

Value remaining revenue at current price

- Estimated gross benefits of connection
Costs

We do not observe connection investments directly

We do observe:

- Euclidean distance to nearest well connected to network
- Euclidean distance to nearest gas plant that is operational
- Identity of nearest gas plant and its operator

1. use observed connections to predict average relationship between connection and distance to nearest connected well
2. use panel of connection distances for unconnected wells to predict connection costs
3. construct estimated net benefit of connection: estimated remaining revenue - estimated connection cost
Estimated Costs

At mean distance: 0.75 miles to nearest well, 13 miles to nearest plant
$88,500 – 202,700 (well – plant)
This does not account for the cost of the plant
THREE MODELS

1. Flaring Tobit
   - Validate comparative statics of theoretical model
   - Have compared to well fixed effects linear regression

2. Connection Duration
   - Identify factors associated with decision to connect

3. Dynamics of Decision
   - Treat connection as a potentially valuable option
## Tobit Results

Table: Tobit Coefficients: Log Flared Gas

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log Age Months</td>
<td>-2.369***</td>
<td>-2.369***</td>
<td>-2.216***</td>
<td>-2.529***</td>
</tr>
<tr>
<td></td>
<td>(0.045)</td>
<td>(0.243)</td>
<td>(0.189)</td>
<td>(0.270)</td>
</tr>
<tr>
<td>Log Raw Price</td>
<td>-3.527***</td>
<td>-3.527***</td>
<td></td>
<td>-3.048***</td>
</tr>
<tr>
<td></td>
<td>(0.140)</td>
<td>(0.975)</td>
<td></td>
<td>(1.066)</td>
</tr>
<tr>
<td>Log Dry Price</td>
<td></td>
<td></td>
<td>-7.326***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(1.094)</td>
<td></td>
</tr>
<tr>
<td>Log Distance Well</td>
<td>2.170***</td>
<td>2.170***</td>
<td>2.180***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.105)</td>
<td>(0.513)</td>
<td>(0.549)</td>
<td></td>
</tr>
<tr>
<td>Log Distance Plant</td>
<td></td>
<td></td>
<td></td>
<td>0.390</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.422)</td>
</tr>
<tr>
<td>Constant</td>
<td>15.011***</td>
<td>15.011***</td>
<td>16.688***</td>
<td>14.302***</td>
</tr>
<tr>
<td></td>
<td>(0.388)</td>
<td>(2.299)</td>
<td>(1.536)</td>
<td>(2.530)</td>
</tr>
<tr>
<td>σ</td>
<td>5.610***</td>
<td>5.610***</td>
<td>5.837***</td>
<td>5.749***</td>
</tr>
<tr>
<td></td>
<td>(0.042)</td>
<td>(0.365)</td>
<td>(0.346)</td>
<td>(0.395)</td>
</tr>
</tbody>
</table>

Notes: Dependent variable is logarithm of flared gas, measured in Mcf per month. Distance to nearest connected well is distance to nearest well that is selling gas. Distances are measured in miles.
## Duration Results

Table: Duration to Connection Coefficients

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Gas Price</td>
<td>-0.079***</td>
<td>-0.016*</td>
</tr>
<tr>
<td></td>
<td>(0.015)</td>
<td>(0.0094)</td>
</tr>
<tr>
<td>Wet Gas Price</td>
<td></td>
<td>-0.016*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0094)</td>
</tr>
<tr>
<td>Production Month</td>
<td>0.095***</td>
<td>0.094***</td>
</tr>
<tr>
<td></td>
<td>(0.0088)</td>
<td>(0.0085)</td>
</tr>
<tr>
<td>Distance Well</td>
<td>0.53***</td>
<td>0.56***</td>
</tr>
<tr>
<td></td>
<td>(0.050)</td>
<td>(0.053)</td>
</tr>
<tr>
<td>Distance Plant</td>
<td>-0.0025</td>
<td>-0.0038</td>
</tr>
<tr>
<td></td>
<td>(0.0044)</td>
<td>(0.0051)</td>
</tr>
<tr>
<td>N</td>
<td>57,053</td>
<td>52,896</td>
</tr>
<tr>
<td>BIC</td>
<td>17377.5</td>
<td>16180.8</td>
</tr>
</tbody>
</table>

Notes: Dependent variable is binary indicator of connection to gas infrastructure. Hazard rate is specified as complementary log-log function. Distance to nearest connected well is distance to nearest well selling gas in same month, coded zero if a well is connected itself. Distances are measured in miles. * 0.10 ** 0.05 *** 0.01
EXPECTED GAINS FROM INVESTING IN INFRASTRUCTURE

![Density plots comparing Unconnected and Connected estimated gain from connection.](image)
DECISIONS

Estimate value of connection in each month for each unconnected well

▶ estimate value of remaining recovery (upper bound at current price)
▶ from connected well, estimate connection cost per mile (average cost)
▶ estimate difference for each well
<table>
<thead>
<tr>
<th></th>
<th>Connected</th>
<th>Not</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>In Money</td>
<td>948</td>
<td>468</td>
<td>1,416</td>
</tr>
<tr>
<td>Out of Money</td>
<td>1,414</td>
<td>2,946</td>
<td>4,360</td>
</tr>
<tr>
<td></td>
<td>2,362</td>
<td>3,314</td>
<td></td>
</tr>
</tbody>
</table>
Value Declines Over Time

![Graph showing proportion of observations in money over production month]

- **Proportion Observations In Money**
- **Production Month**

The graph illustrates the decline in the proportion of observations in money over a period of production months.
ECONOMIC IMPLICATIONS

Flaring in Bakken is a big deal compared to rest of U.S.
- not such a big deal when compared to rest of world
Costs of connection may outweigh gains from marketing gas in some cases
- this is an argument for “rational free disposal”
- CNG transport from wellpad depends on NGL margin
Very little unitization to this point
- would allow for optimal infrastructure investment (w/in unit)
- unconventional resources \(\Rightarrow\) unitization
POLICY IMPLICATIONS

- Political and policy issue in North Dakota
  - Not as much Montana, but also other states (PA, OH, TX)
- Impose constraint for “gas capture plans”
  - Intended to reduce flaring by 2019
Figure: ND Processing Capacity and Gas Sales
Figure: Flaring by Connection Status
Figure: North Dakota Gas Plants and Interstate Transmission, March 2015