Isolating the Impacts of the Shale Revolution on the U.S. Energy Mix: Evidence from Natural Gas Pipeline Network

Matt Butner ¹  Jonathan Scott ²

¹Policy Integrity at NYU School of Law
²Energy Institute at UC Berkeley

Presented at USAEE
Nov 5th, 2019
The Shale Revolution: Hydraulic Fracturing and Horizontal Drilling

Figure 1. Production by Drill Type

Figure: From Feyrer et al., 2017
One of the Biggest Stories in the Electric Power Sector

Figure: The Shale Revolution Depresses the Natural Gas Price

Natural Gas Price ↓ ➞
- Electricity Price ↓
- ↓ Coal Generation
- ↑↓ Renewables ?
- ↑↓ CO₂ ?
- ↑↓ GHG ?
A Contentious Dialog: Shale Gas and Carbon Emissions

A. Natural Gas is Cleaner Than Coal

- “The drop in CO2 emissions [since 1990] is largely the result of low natural gas prices, which have contributed to natural gas displacing a large amount of coal used for electricity generation” — Former EIA Administer

B. Natural Gas is a Fossil Fuel

On my first day as president, I will sign an executive order that puts a total moratorium on all new fossil fuel leases for drilling offshore and on public lands. And I will ban fracking—everywhere.

4:26 PM · Sep 6, 2019 · Twitter Web App
Research Question and Method

How did the Shale Revolution affect the U.S. Fuel Mix?

- Our goal is to present a *counterfactual*.
  - What would the fuel mix look like today if the Shale Revolution had never happened?
  - There have been some simulation studies, but those rely on assumptions.
    (Newell and Raimi, 2014; Shearer et al., 2014; Gillingham and Huang, 2019).

- This is kind of hard to do...
  - A naive approach won't get the right number.
  - We can't do a randomized control trial.
  - Ideally we would be able to randomize exposure of states to the Shale Revolution.

- Our contribution is to use the legacy inter-state natural gas pipeline network infrastructure as a measure of quasi-random exposure to the Shale Revolution.
What Would This Look Like Absent the Shale Revolution?
What are We Trying to Estimate?

A lot of papers have looked at how lower natural gas prices affect...

- **marginal emission rates**
  (Holladay and LaRiviere, 2017; Cullen and Mansur, 2017; Knittel, Metaxoglou, and Trindade, 2016; Johnson, LaRiviere, and Wolff, 2019)

- **coal-to-gas switching**
  (Knittel, Metaxoglou, and Trindade, 2019; Kaffine and Fell, 2019; Linn and Muehlenbachs, 2018; Brehm, 2019).

We are interested in the direct relationship between quantities:

$$\text{Generation Share}^{\text{fuel}} = f(\text{Quantity Natural Gas Produced})$$

However, it is hard to determine if changes in $\text{Generation Share}^{\text{fuel}}$ is driven by $\text{Quantity Natural Gas Produced}$ and not by some other factor.
How to Get a Good Control Group

1. We look at individual states in a year:
   - This gives us cross-sectional variation in our outcome
   - Our explanatory variable will be natural gas deliveries

2. We take into account state-specific factors and general trends over time

3. We isolate which states are more exposed to the Shale Revolution
   - States connected to shale gas producing areas, via pipelines, benefit more from the shale revolution than states that are not.
   - Which states produce more shale gas changes over time.
   - Out of state production is plausibly not determined by in state demand.
   - Use pre-existing pipelines, from 1990, so not determined by induced demand from the Shale Revolution.
Using Interstate Pipeline Infrastructure to Quantify Shale Exposure

Map of U.S. interstate and intrastate natural gas pipelines

Legend
- Blue: interstate pipelines
- Red: intrastate pipelines

Source: U.S. Energy Information Administration, About U.S. Natural Gas Pipelines
Using Interstate Pipeline Infrastructure to Quantify Shale Exposure
Using Interstate Connections as Proxy for Shale Exposure

Measure interstate connectedness with outflow capacity weights, from state $j$ to $i$. Share of natural gas from state $j$ going to state $i$ in 1990:

$$S_{ji} = \frac{1990\text{EffectiveCapacity}_{ji}}{\sum_{k\neq j} 1990\text{EffectiveCapacity}_{jk}}$$

Effective Capacity is defined as average of iterative linkages.

Calculate exposure of state $i$ to natural gas from Shale Revolution:

1. Predicted gas deliveries:
   $$PredictedGas_{it} = \sum_{j} S_{ji} \cdot GasProduction_{jt}$$

2. Potential gas from exposure to shale rock:
   $$ShaleExposure_{it} = NationalProduction_{t} \sum_{j} S_{ji} \cdot Shale_{j}$$
Pipeline Weights for Some Key States

Figure: Examples of $S_{ji}$ from 1990
Visual Result: Treatment is Above Median Shale Exposure
Visual Result: Treatment is Above Median Shale Exposure

Estimate the coefficient $\beta^{\text{fuel}}_0$ in:

$$\text{Generation Share}^{\text{fuel}}_{it} = \beta^{\text{fuel}}_0 \text{Natural Gas Deliveries}_{it} + \beta^f_1 \text{Natural Gas Production}_{it} + \gamma^f_i + \delta^f_t + \varepsilon^f_{it}$$

Where $\text{Natural Gas Deliveries}_{it}$ is predicted from $\text{ShaleExposure}_{it}$ or $\text{PredictedGas}_{it}$

- Two-stage least squares estimation.
- Variation in $\text{Natural Gas Deliveries}$ is determined by pre-existing infrastructure.
  - Not changes in demand for natural gas.

In practice, we decompose $\text{Natural Gas Deliveries}_{it}$ into $\text{DeliveryShares}_{it} \cdot \text{NationalProduction}_t$ to estimate the effects of national production.
One Result: Effect of National Production on Fuel Share

Estimate of 10 bcf/day Nat. Gas Production

- Natural Gas
- Coal
- Wind
- Solar
- Hydro
- Nuclear

OLS
2SLS: Predicted Gas
2SLS: Shale Exposure

Estimate of 10 bcf/day Nat. Gas Production
The Implied Counter-factual:

\[ \text{Counterfactual}_{it}^{\text{fuel}} = \text{Generation Share}_{it}^{\text{fuel}} - \hat{\beta}_0 \cdot (\text{Natural Gas Deliveries}_{it} - \text{Natural Gas Deliveries}_{2005}) \]
The Implied Counter-factual:

\[
\text{Counterfactual}_{it}^{\text{fuel}} = \text{Generation Share}_{it}^{\text{fuel}} - \hat{\beta}_0^{\text{fuel}} \cdot (\text{Natural Gas Deliveries}_{it} - \text{Natural Gas Deliveries}_{2005})
\]

The graph shows the share of total generation from natural gas, coal, and wind from 1995 to 2015. The counterfactual calculation is represented by the line with a dashed pattern above the natural gas line, illustrating the hypothetical scenario without the influence of the factor represented by the counterfactual.
The Implied Counter-factual:

$$\text{Counterfactual}_{it}^{\text{fuel}} = \text{Generation Share}_{it}^{\text{fuel}} - \hat{\beta}_0 \cdot (\text{Natural Gas Deliveries}_{it} - \text{Natural Gas Deliveries}_{2005})$$
The Implied Counter-factual:

Counterfactual_{fuel}^{it} = \text{Generation Share}_{fuel}^{it} - \hat{\beta}_{0}^{fuel} \cdot (\text{Natural Gas Deliveries}_{it} - \text{Natural Gas Deliveries}_{i2005})
Mechanisms

Overall:
- Low natural gas prices makes gas more attractive than wind or coal
  - Think of a competitive tech-neutral request for proposals

Coal’s decline absent shale boom:
- Natural Retirements
- Environmental policies
  - Mercury Air Toxics Standard
  - Cross-State Air Pollution Rule
  - Regional Greenhouse Gas Initiative
- Replacement with renewable generation.

Wind’s growth absent shale boom:
- PPAs would be easier to secure without abundant natural gas (avoided cost↑).
- RPSs would be easier to pass without abundant natural gas.
Implications for Carbon Emission

Estimate a similar effect on $CO_2$, $\eta_1$

Calculate counterfactual (CF), compare to EIA’s CF
Implications for Carbon Emission

Estimate a similar effect on $CO_2, \eta_1$
Calculate counterfactual (CF), compare to EIA's CF

![Graph showing CO2 Emissions from Gas and Coal](image_url)
Implications for Carbon Emission

Estimate a similar effect on $CO_2$, $\eta_1$

Calculate counterfactual (CF), compare to EIA’s CF
Break-even Methane Leakage

Per unit of natural gas production,

\[
\text{Marginal Benefits} = \text{Marginal Costs} \\
\downarrow \text{CO}_2 \text{ from electricity} = \uparrow \text{CH}_4 \text{ upstream leaks} \\
\eta_1 = \mu \cdot p
\]

- We estimate \( \eta_1 \) as 5.77 million metric tons \( \text{CO}_2 \) per 1 bcf/day
- \( \mu \) is *Natural Gas* to \( \text{CH}_4 \) to \( \text{CO}_2 \) equivalence conversion
  - Natural gas is 87% Methane
  - Methane 33 times as potent as \( \text{CO}_2 \) (100-year window, IPCC)
- \( p \) is the leakage rate

Our results imply natural gas is net beneficial if leakage <3.3%
- Current estimated leakage rate is 2.3% (Alvarez et al, 2019)
- Little room for error
Concluding

The Shale Revolution transformed the U.S. electric power sector.

More natural gas production decreases electricity generation from coal and wind.

Absent the Shale Revolution...  
- coal would have declined by some amount anyway.  
- there would have been more renewables (replacing coal)

Overall the Shale Revolution reduced GHG emissions,  
- but not as much as EIA suggests,  
- and a leakage rate >3.3% obliterates these benefits.
Appendix
Subsample: no high wind growth

Excluding Texas, Oklahoma, Kansas, Iowa, South Dakota, North Dakota, Idaho, Colorado, Minnesota, Michigan, Oregon, California

![Graph showing generation share percentage points for different energy sources.](image-url)
Subsample: no zero wind potential states

Excluding Florida, Georgia, Alabama, South Carolina, Alabama, Tennessee, North Carolina, Mississippi, Virginia, West Virginia, Kentucky.

![Graph showing generation share percentage points for Natural Gas, Coal, Wind, Solar, Hydro, and Nuclear. The graph indicates an estimate of 10 bcf/day national production with error bars for each resource type marked with a dot labeled "2SLS: Predicted Shale".](image-url)