Link Air Pollution to Human Welfare

An Application of Concentration Response Function in working paper "Air Pollution Impacts of Shale Gas Development in Pennsylvania"

September 11, 2020

What is environmental economics?

Environmental economics researches consist of three topics

1. How do human's economic activities change the environment? (externalities)

2. How do such changes in the environment affect human welfare as the consequence? (health impact)

3. By considering the consequences of changing the environment, what are our best moves? (cost-benefit analysis)

This paper: 75% on topic 1, 25% on topic 2.

An interdisciplinary study

This paper involves the knowledge from

- Geology (GIS, coordinates projection)
- Remote Sensing (Using satellite based remote sensing data)
- Meteorology (Related to PM concentration)
- Physics (Pollution dispersion)
- Chemistry (Formation of PM, primary and secondary sources)
- Atmospheric Science (Converting remote sensing data to PM2.5)
- Epidemiology (Causality of PM2.5 concentration on mortality)
- Economics and Statistics

Air Pollution Impacts of Shale Gas Development in Pennsylvania

The bottom line of this paper

Motivation

Well Site in Loyalsock State Forest, PA.

Summit Elementary School near Well Site, Powell, PA.

Visible Air Emission, John Day Unit, PA.

Dust from Truck Traffic at Well Pad.

Sources: www.fractracker.org

Shale Gas Wells Location

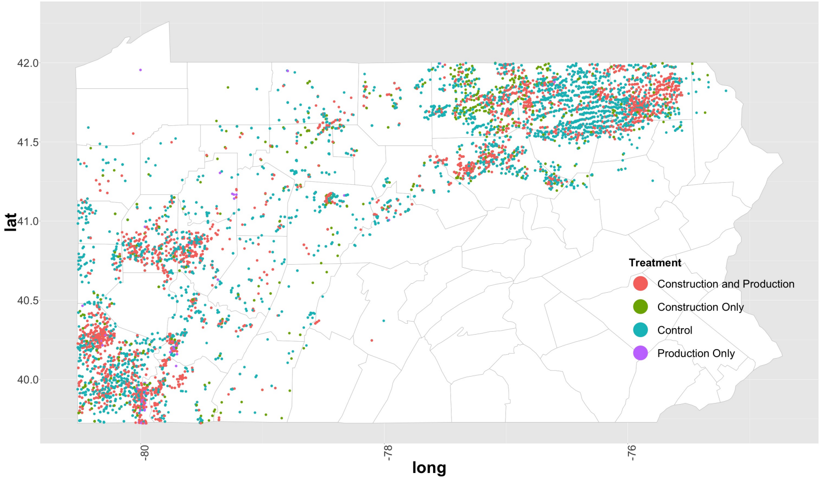


Figure 1: Unconventional Well Location by Group

Findings

- Shale gas industry has significant impact on local PM concentration through fracking and natural gas production activities.
- From 2010 to 2017, the PM 2.5 emission from shale gas industry causes extra 20 deaths in communities with 840,000 population.

Air Pollution Impacts of Shale Gas Development in Pennsylvania

Part 2: negative welfare impact of air pollution from shale gas industry

Data, Welfare Analysis

- EPA monitor data

  PM 2.5 data by monitors and days (https://www.epa.gov/outdoor-air-quality-data/download-daily-data)

- NASA MODIS AOD data

  AOD is satellite based remote sensing data of air quality. It is a good predictor of PM concentration (https://earthdata.nasa.gov/)

- ACS (American Community Survey) 5-years estimates data

  Census block group population (https://factfinder.census.gov/)

- CDC WONDER (mortality data)

  Death count by county and causes/diseases (https://wonder.cdc.gov/)

Preliminary results

On average, the impacts of a shale gas well on local air quality are

- Fracking stage increases local AOD by 2.10%
- Production stage increases local AOD by 1.35%
- The pollution disperses up to 10km (6.25 miles) by wind

Welfare Analysis

- 3 steps linking AOD to PM 2.5 by using a statistical model (Lee et al., 2011):
  - Step 1: Estimate the overall AOD impact of shale gas industry.
  - Step 2: Estimate the statistical model by using a sample of PM 2.5 monitors within Pennsylvania.
  - Step 3: Use step 2's result to predict the overall PM 2.5 impact of shale gas industry based on estimated overall AOD impact.
- Use the concentration-response models to estimate mortality impacts of PM 2.5. We use the relative mortality rate coefficients given by Lepeule et al. (2012).
  - Death of all causes
  - Death of cardiovascular disease (major cardiovascular diseases, I00-I78)
  - Death of COPD (chronic lower respiratory diseases, J40-J47)

PM 2.5 Monitors Locations in PA

There are 41 PM 2.5 monitors in PA.

Cox propotional-hazard model

$$ln(\text{Mortality Rate}) = \alpha + \beta X + \gamma PM_{2.5}. \quad (1)$$

X: Local characteristics presumably affecting mortality.

$PM_{2.5}$: PM 2.5 concentration.

α: Baseline mortality rate.

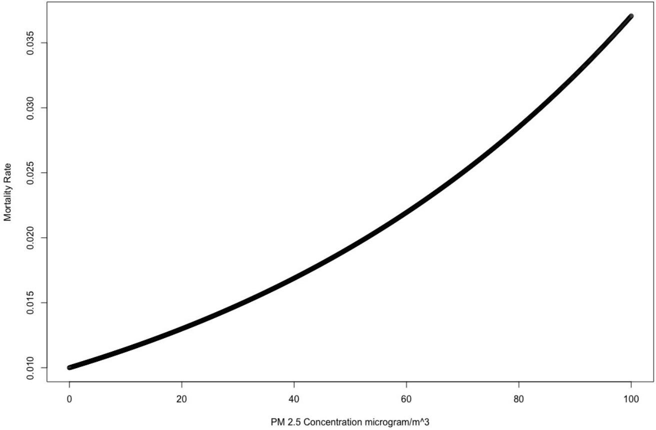
β: Relationship between X and mortality rate.

γ: effect of a unit change in PM2.5 concentrations on mortality rate.

Estimation results from Lepeule et al. (2012):
$\hat{\gamma}_{\text{all death}} = 0.0131$, $\hat{\gamma}_{\text{cardio}} = 0.0231$, $\hat{\gamma}_{\text{COPD}} = 0.0157$.

Examples

Figure 3: Mortality rate of all causes death in response to PM 2.5 concentration



In 2016, Beijing's yearly-average PM2.5 was $73\ \mu g/m^3$.

Cox propotional-hazard model

Impact on mortality rate

$$RR = \frac{\text{True mortality rate}}{\text{Mortality rate as if no fracking}} = exp(\hat{\gamma}(PM'_{2.5} - PM''_{2.5})). \quad (2)$$

RR: Estimated impact on mortality rate.

$\hat{\gamma}$: Estimation result from equation 2, done by Lepeule et al. (2012).

$PM'_{2.5}$: True PM 2.5 concentration.

$PM''_{2.5}$: PM 2.5 concentration as if no fracking.

$PM'_{2.5} - PM''_{2.5}$: Overall PM 2.5 impact of fracking.

Examples

In 2015, Washington County's annual PM 2.5 concentration is increased by 0.0556 $\mu g/m^3$ due to fracking, so $PM'_{2.5} - PM''_{2.5} = 0.0556\ \mu g/m^3$.

All causes mortality rate in Washington County is 1.2740%.

$$RR = exp(\hat{\gamma}_{\text{all death}}(PM'_{2.5} - PM''_{2.5})) = exp(0.0131 \times 0.0556) = 1.0007$$

The mortality rate of all causes in Washington County is 1.2740%. Therefore, the mortality rate of all causes as if no fracking is $\frac{1.2740\%}{RR} = 1.2731\%$.

The population under the effect of fracking in Washington County is 91,202. We estimate fracking causes extra $91202 \times (1.2740\% - 1.2731\%) = 0.8457$ death.

Mortality Impact

Table 1: Mortality Impact, 671 census block groups containing shale gas wells

Year	Cardio	COPD	All Death	Population
2010	0.69 (3,104.83)	0.09 (555.43)	1.22 (9,522.19)	841,848
2011	1.16 (3,084.53)	0.15 (568.97)	2.10 (9,765.50)	845,607
2012	1.32 (3,022.89)	0.17 (543.39)	2.42 (9,670.84)	843,169
2013	1.11 (3,090.76)	0.15 (579.48)	2.04 (9,912.32)	845,133
2014	1.35 (3,053.58)	0.18 (555.91)	2.53 (9,866.78)	843,801
2015	1.96 (3,122.42)	0.28 (589.06)	3.70 (10,159.49)	838,444
2016	1.48 (3,111.75)	0.19 (553.01)	2.73 (10,074.72)	833,749
2017	1.78 (3,133.03)	0.23 (592.83)	3.36 (10,488.52)	828,150
Total	10.85 (24,723.80)	1.44 (4,538.08)	20.11 (79,420)	

Numbers in parentheses describe the total death count.

Potential Extension

Moving to topic 3, we can calculate the mortality cost of PM 2.5 pollution from shale gas industry using the value of a statistical life (VSL).

EPA estimate $VSL = 7.4$ million per statistical life (2006 dollars),

Total cost: 7.4 million $\times$ 20.11death $= 148.814$ million.

Remember, this is only one part of the total externality cost of shale gas industry. More researches are needed to perform a complete cost-benefit analysis.

References I

Lee, H. J., Y. Liu, B. A. Coull, J. Schwartz, and P. Koutrakis (2011). A novel calibration approach of modis aod data to predict $pm_{2.5}$ concentrations. *Atmospheric Chemistry and Physics 11*(15), 7991–8002.

Lepeule, J., F. Laden, D. Dockery, and J. Schwartz (2012). Chronic exposure to fine particles and mortality: an extended follow-up of the harvard six cities study from 1974 to 2009. *Environmental health perspectives 120*(7), 965.