Model the relation between oil/gas production and beta radiation

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News

- Colorado Proposition 112, the minimum distance requirements for new Oil, gas, and fracking projects initiative is on the ballot in Colorado as an initiated state statute on November 6, 2018. If approved, a mandatory setback distance of 2500 feet from occupied and vulnerable areas will be applied for new drilling site. The current minimum setback distance is 500 feet for residential building and 1000 feet for highly-occupied building.
- Approximately 60% voter said no. Fun facts: the committess supporting this initiate raised 1.6 million while the committees opposing it raised over 30 million.

Introduction

In this report, we'll try to explore the correlation between β with oil/gas drilling.

Background

- Thanks to the breakthrough of drilling techniques (directional drilling and hydraulic fracking), the production cost of domestic oil has dropped remarkably in the past decade. This makes drilling profitable at lower oil price, thus booming this industry. By Sep,2018, U.S has passed Saudi Arabia and Russia as the top crude oil producer.

- These technique have existed for decades and were applied widely on off-shore drilling where cost of pad construction is high. Directional drilling enables harvesting hydrocarbon from formations unaccessible by vertical drilling. Fracking improve the absorption area thus has higher productivity.
- Both conventional and unconventional drilling may influence the local environment and public health through multiple channels. Possible route includes: methane leakage from wellhead, aquifer contaminated by fracking fluid, air pollutant emitted by drilling/production activities, radioactive waste from drilling/production activities.
- Radon is a ubiquitous noble radioactive gas. It's the progeny of Thoronim-232 and Uranium-238. Radon represents a far smaller risk for lung cancer than cigarette smoking , but it is the second leading cause of lung cancer in the United States. Radon decays quickly, giving off tiny radioactive particles. When inhaled, these radioactive particles can damage the cells that line the lung. Long-term exposure to radon can lead to lung cancer, the only cancer proven to be associated with inhaling radon.
- Currently, most studies about fracking-related radioactiviy focus on the radon level in drinking water. A small number of studies correlated indoor radon level with nearby fracking activities in Marcellus Shale. This study will be the first one to correlate conventional/unconventional drilling with radon. Since ambient radon is not measured directly onsite, we use the gross β of particles as a proxy to the ambient radon.

Data

Study period: from 2007 to 2017.

Study Extent: lower 48 states.

β radiation data: To measure the background radiation level, 130+ RadNet monitors were constructed across the U.S. In every RadNet monitor, gross β radiation from the particles on the filter is measured every 5 days. We downloaded this data directly from EnvrionFacts run by EPA. To match the frequency of well production data, this is aggregated by month.

Drilling data: We collected drilling information from drillinginfo.com. From the database, we extracted the monthly gas/oil production during the study period, both unconventional and conventional drillings are included.

Background radon data: We downloaded the EPA radon map data and join it to the assumed location of RadNet monitor. All counties of the U,S are categorized into three classes ranging from 1 with the highest radon level and 3 with the lowest. The background radon level is calculated based on soil type, weather and other information.

Uranium-238 and Thorium-232 map: U.S. Geological Survey used aerial gamma-ray data to quantify and describe the radioactivity of surface rocks and soils. Equivalent uranium (eU) is calculated from the counts received by the gamma-ray detector in the energy window. The same technique is also used for thorium. These two background map helps us control for the large-scale spatial trend.

Methods

Inverse Distance Weighted Production.

We assume that the contribution of conventional/unconventional drilling to local radon level is production-dependent. Possible mechanisms include: open air storage of sludge, scale and produced water, low-pressure leaking in the cases, leakage during transportation and storage. In addition, the contribution is negatively related with the distance due to diffusion.

So the contribution of a single well is:

$$C_{i,k} = \frac{Prod_i}{Dist(i,k)^x}$$

where i and k are index of well and RadNet monitor, and x is the power for set. The larger the power, the faster the contribution decline alonr distance. In this study, we calculate the first-order and second-order contribution. For a RadNet monitor, the sum of these contribution within a radius is a proxy of the oil/gas production nearby.

$$P_k = \sum_{i=1} nC_{i,k}, Dist(i,k) < 50km$$

In this study, we calculate the sum contribution of oil production nearby with the unit of $\frac{bbl}{km}$ or $\frac{bbl}{km^2}$ and the contribution of gas production nearby with tin the unit of $\frac{mcf}{km}$ or $\frac{mcf}{km^2}$. Then we disaggregate the contribution based on their drill type and get the contribution from conventional oil production, unconventional oil production, conventional gas production and unconventional gas production.

Generalized Additive Model

GAM models with random intercepts for each RadNet monitor are fit here to correlate β radiation with local oil/gas production. The basic model is:

$$m_0 = Rn + Ur + Th + s(Month) + s(Year) + (1|city)$$

For every variable of interest,for example first order inverse distance sum of conventional oil production ,we can fit another model:

$$m_1 = Rn + Ur + Th + V_Oil_Prod + s(Month) + s(Year) + (1|city)$$

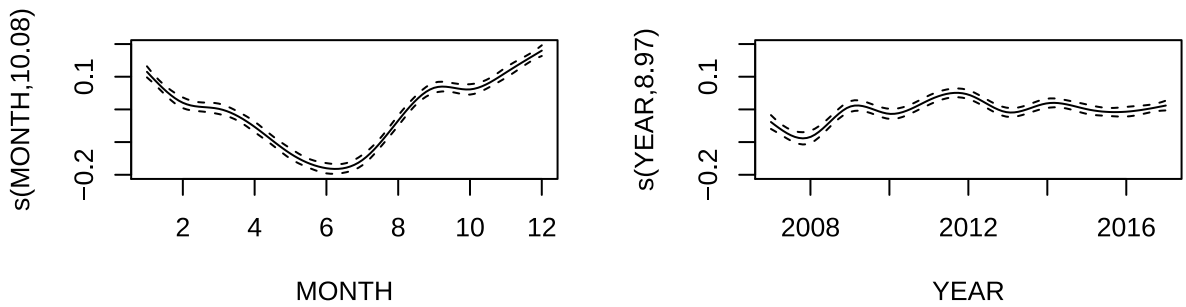
Then we can compare two models with ANOVA, if m_1 is remarkably better than m_0, we can conclude the variable of interest is correlated with β radiation level.

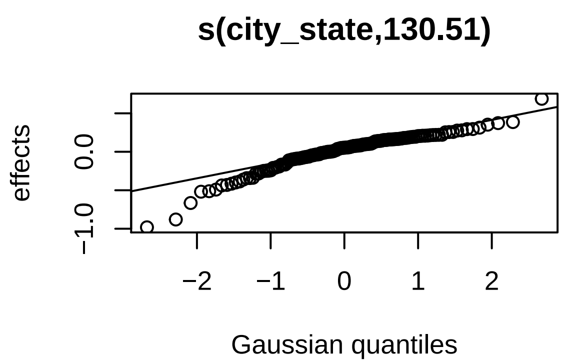
Results

The splines of month of year in basic model shows the seasonal trend of β radiation. This matches the research result that ambient radon is higher in the winter due to lower HPBL and weaker diffusion.

Of the 8 models, we detected 4 significant effects. In the first order inverse distance production cases: Conventional oil production, unconventional gas production are positively correlated with local β level. In the second order inverse distance production cases: conventional oil production and unconventional gas production are positively correlated with local β. So, conventional oil production and unconventional gas production maybe risky.

```
dataset=rad_all
g0<-gam(lbeta~radon+mass+Thmeans+s(MONTH,k=12)+s(YEAR,k=10)+s(city_state,bs="re"),data=dataset)
plot(g0,page=1)
```






```
## Analysis of Deviance Table
##
## Model 1: lbeta ~ radon + mass + Thmeans + s(MONTH, k = 12) + s(YEAR, k = 10) +
##     s(city_state, bs = "re")
## Model 2: lbeta ~ radon + mass + Thmeans + V_Fst_Oil_Prod + s(MONTH, k = 12) +
##     s(YEAR, k = 10) + s(city_state, bs = "re")
##   Resid. Df Resid. Dev      Df Deviance      F  Pr(>F)
## 1     13155     1098.0
## 2     13154     1097.6 0.93224  0.47007 6.0442 0.01574 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

## V_Fst_Oil_Prod
##   1.557815e-06

## Analysis of Deviance Table
##
## Model 1: lbeta ~ radon + mass + Thmeans + s(MONTH, k = 12) + s(YEAR, k = 10) +
##     s(city_state, bs = "re")
## Model 2: lbeta ~ radon + mass + Thmeans + H_Fst_Gas_Prod + s(MONTH, k = 12) +
##     s(YEAR, k = 10) + s(city_state, bs = "re")
##   Resid. Df Resid. Dev      Df Deviance      F   Pr(>F)
## 1     13155     1098.0
## 2     13159     1099.6 -3.9954  -1.5229 4.5673 0.001104 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

## H_Fst_Gas_Prod
```

```
##   3.334319e-08
```

```
## Analysis of Deviance Table
##
## Model 1: lbeta ~ radon + mass + Thmeans + s(MONTH, k = 12) + s(YEAR, k = 10) +
##     s(city_state, bs = "re")
## Model 2: lbeta ~ radon + mass + Thmeans + V_Snd_Oil_Prod + s(MONTH, k = 12) +
##     s(YEAR, k = 10) + s(city_state, bs = "re")
##   Resid. Df Resid. Dev      Df Deviance      F    Pr(>F)
## 1     13155       1098
## 2     13154       1097 0.78532   1.0778 16.461 0.0002058 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

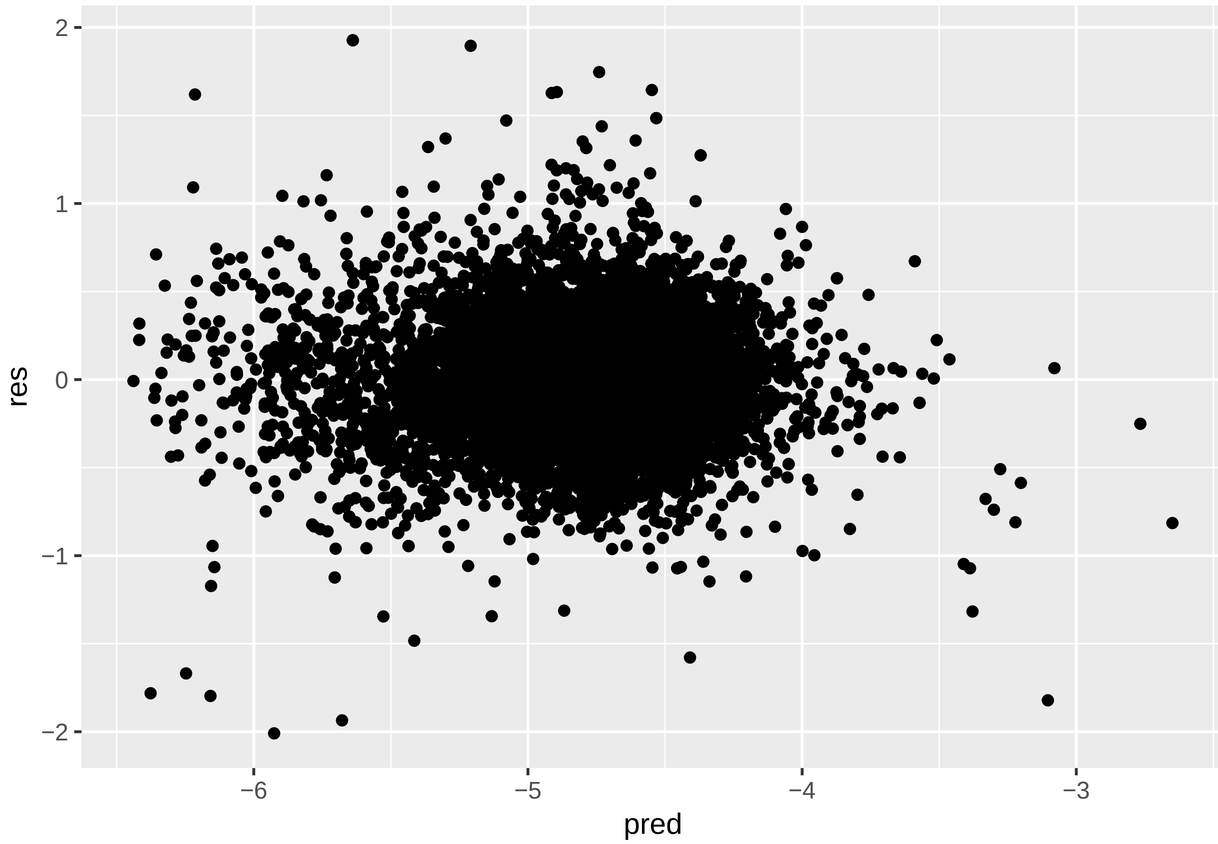
```
## V_Snd_Oil_Prod
##   2.514051e-05
```

```
## Analysis of Deviance Table
##
## Model 1: lbeta ~ radon + mass + Thmeans + s(MONTH, k = 12) + s(YEAR, k = 10) +
##     s(city_state, bs = "re")
## Model 2: lbeta ~ radon + mass + Thmeans + H_Snd_Gas_Prod + s(MONTH, k = 12) +
##     s(YEAR, k = 10) + s(city_state, bs = "re")
##   Resid. Df Resid. Dev       Df Deviance      F   Pr(>F)
## 1     13155     1098.0
## 2     13155     1097.7 0.078752  0.36282 55.223 0.001616 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

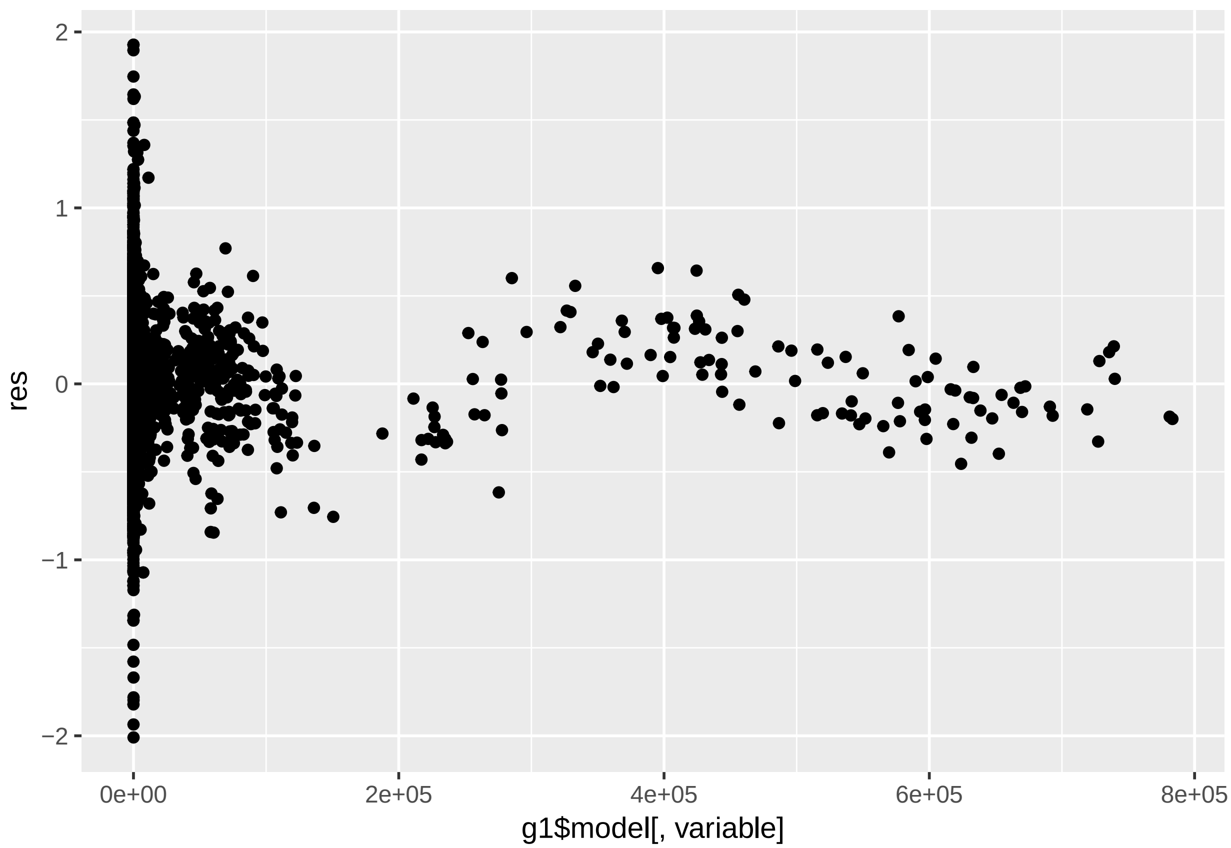
```
## H_Snd_Gas_Prod
##   3.219418e-07
```

Diagnosis

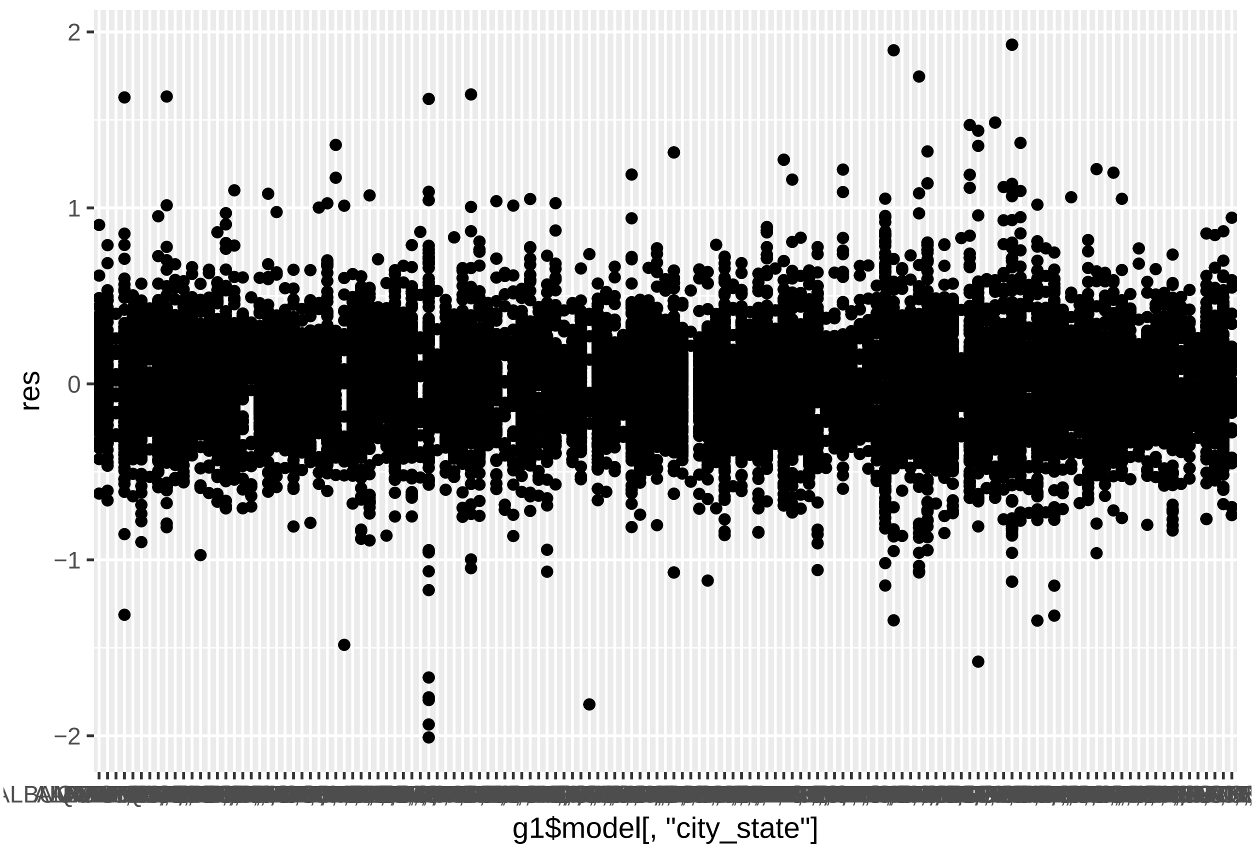
```r
ggplot(data=cbind.data.frame(res=resid(g1),pred=fitted(g1)),aes(x=pred,y=res))+geom_point()
```




```
ggplot(data=cbind.data.frame(res=resid(g1),g1$model),aes(y=res,x=g1$model[,variable]))+geom_point()
```




```
ggplot(data=cbind.data.frame(res=resid(g1),g1$model),aes(y=res,x=g1$model[,"city_state"]))+geom_point()
```



Limitations:

- In this study, a strong assumption of the GAM model is that the relationship between oil/gas production parameters and β radiation is linear. There's no study to back this assumption. It's probably oversimplistic. But if we used some non-linear method, such as the spline term in GAM, the interpretion is not straightforward anymore.
- In this study, the straightline distance is used as a proxy to the contribution of a single well to the RadNet monitor. The diffusion depends not only on distance but also on wind field. A better way is to take wind velocity/direction into account.