Demand for Sulfur at U.S. Power Plants
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Final Project 2
F&ES 720 Introduction to R

Question and hypothesis

Do U.S. power plants with emission abatement technologies such as flue gas desulfurization (FGD) have a higher demand for dirtier fuels? Is this demand driven purely by the ability of FGD-enabled plants to purchase dirtier, cheaper fuel while still in compliance with emission regulations, or does the FGD process itself matter, i.e. does FGD byproduct production incentivize the purchase of dirtier fuels which are its inputs? As null hypotheses, I have that the installation of FGD technology and production of a byproduct from the FGD process have no effect on the demand for the sulfur content of coal at U.S. power plants. The alternative hypothesis is then that each influences sulfur demand, specifically increasing it. I also test whether this relationship is constant (null hypothesis of no difference in a time trend) or differs relative to a no-FGD and no-byproduct base group.

Methods

Following from my first project which analyzed fuel purchase data in a hedonic price model, in this study I analyze how demand for the sulfur content of coal at U.S. power plants differs by plant characteristics. Specifically, I use a fixed effects model of U.S. power plants to analyze the role of FGD installation on sulfur demand. This specification, while providing a conservative estimate of sulfur demand, is simple in practice and leads to relatively robust results. I draw on Energy Information Administration (EIA) data from 2008 through 2014 which was collected through mandatory reporting requirements at U.S. power plants through forms *Annual electric generator report* (EIA-860) and *Power plant operations* (EIA-923) and is publicly available. I download it from the EIA website and merge the several separate EIA data files for use in R using another program. I use sub-plant consumption data at the boiler level on a monthly timescale for a large set of plants. It includes several hundred plants which have an enhanced monthly reporting requirement by the EIA and where each plant may contain one to several boilers each of which has consumption data that is reported separately.

Due to the fixed effect nature of my model- fixed at the plant level which is the level of decision making, and allowing a by-month time trend across the data, the model specification can be simple. In formulating model 1, I initially specified the monthly time trend as a set of 84 month-by-year factor variables but find little impact on the primary coefficient of interest when switching monthly to a linear time trend from factors. The primary coefficient of interest β_1 on *SO2controls*, indicates the impact on sulfur demand of a plant operating an SO_2 abatement technology:

$$lnadjsulfur = \beta_1 SO2controls + \beta_2 monthly \tag{1}$$

I next add to the model *SO2byproductproduction* which indicates as a dichotomous choice whether the plant produces any abatement technology byproduct. These have the potential to offset some of the operating expense of the abatement technology as a marketable input to agriculture and industry is produced in many cases. Noting that byproduct production only occurs at plants with SO_2 abatement controls installed, model 2 is simply specified as:

$$lnadjsulfur = \beta_1 SO2controls + \beta_2 SO2byproductprodn + \beta_3 monthly \tag{2}$$

Finally, I interact the monthly time trend with *SO2controls* and *SO2byproductprodn* to analyze how sulfur demand is changing over the period of observation. It is hypothesized that sulfur demand increases for plants with SO2 controls and byproduct production but not for plants without. Due to regulation and monitoring, plants without abatement technology have comparatively fixed demand for sulfur content while plants with controls can change their demand as abatement technologies become more efficient, cheaper to operate, or byproduct resale markets develop. The final specification then follows:

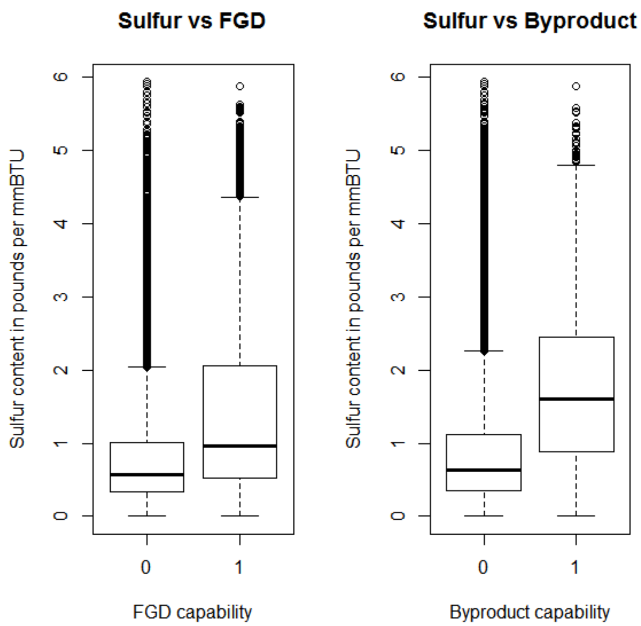
$$\begin{gathered} lnadjsulfur = \beta_1 SO2controls + \beta_2 SO2byproductprodn + \beta_3 monthly + \\ \beta_4 SO2byproductprodn * monthly + \beta_5 SO2byproductprodn * monthly \end{gathered} \tag{3}$$

where the two added covariates estimate how demand for sulfur diverges over time for the subset of power plants with sulfur abatement technology installed. Their comparison further suggests how the returns to plants with abatement technology are changing - whether accumulating to all plants equally or more so to plants that produce a byproduct.

Results

Figure 1 presents average sulfur demand for power plants with FGD installed and that produce a byproduct against plants that are not so equipped. In both cases, sulfur demand is higher for the non-baseline case. This would likely be even more pronounced if several outliers in the non-FGD case were not present which may indicate plants in nonattainment or not required to meet regulation for political purposes. The difference in sulfur demand for plants that produce a byproduct versus non- FGD is also particularly pronounced.

Figure 1. Sulfur demand by whether the power plant has FGD installed and whether it produces a marketable byproduct from FGD operation.



The results of models 1 through 3 are presented in table 1. Model 1 looks at the impact of SO_2 abatement technology, alternatively referred to as FGD, installation within a fixed effects model with the dependent variable in natural log form. It suggests, all else equal, FGD installation results in a 25-percent increase in sulfur content at power plants (sulfur demand). From final project 1, *A Hedonic Price Model of Coal Purchases in the U.S. Energy Sector*, the ability to purchase and consume higher sulfur content coal results in substantial savings, likely driving this result.

Model 2 further divides the group of electricity generators with FGD by whether they produced a marketable byproduct in the period. He & Lee (2016) claim railroads transporting coal price discriminate based on whether power plants produce a byproduct. While that is not tested in my model, FGD byproduct producers do appear to purchase higher sulfur coal indicating higher demand for sulfur and therefore may be susceptible to discriminatory pricing. While both FGD non-byproduct producers and FGD byproduct producers have higher sulfur demand, the demand of those producing a byproduct is markedly higher.

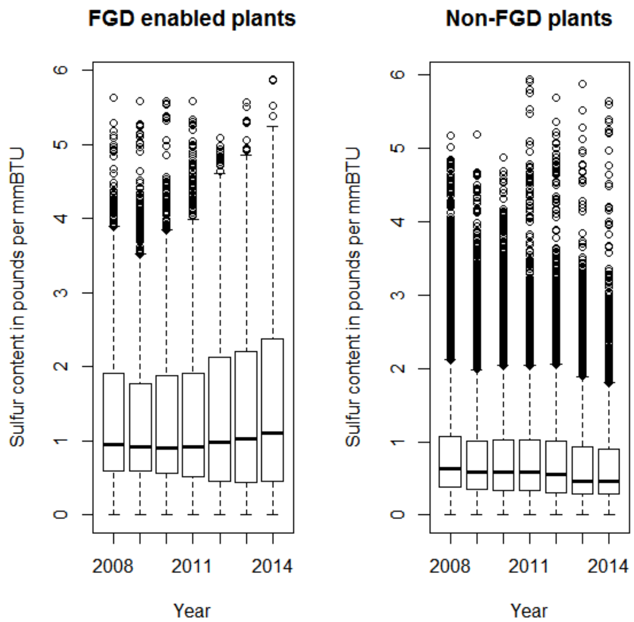
Model 3 then analyzes time trends across the data. In models 1 and 2, a decreasing trend for sulfur demand appears in the overall data, consistent with generally tightening sulfur regulation, at least without FGD improvements. Model 3, through interaction terms for FGD operation and byproduct production with the monthly time trend suggests industry divergence. Plants without FGD have generally decreasing sulfur demand, at a rate of 0.27-percent a month. Plants with FGD installed in comparison show an increasing trend of 0.2-percent per month and an additional 0.26-percent monthly increase for those producing a byproduct. This is consistent with national scale, aggregate sulfur demand data from the EIA which shows a general upward trend in sulfur content in some coal purchases (U.S. Energy Information Administration, 2016).

Table 1. Estimates of FGD installation and byproduct production on the demand for sulfur content in coal at U.S. power plants

lnAdjsulfur	Model		
	(1)	(2)	(3)
SO2controls	0.2556	0.1722	0.1023
	(0.0095)	(0.0102)	(0.0138)
SO2byproductprodn	-	0.3280	0.1885
	-	(0.0152)	(0.0209)
Monthly	-0.0013	-0.0015	-0.0027
	(0.0001)	(0.0001)	(0.0001)
Monthly:SO2controls	-	-	0.0020
	-	-	(0.0002)
Monthly:SO2byproductprodn	-	-	0.0026
	-	-	(0.0003)
Standard errors in parentheses			
Significance codes: 0 ‘***’, 0.001 ‘**’, 0.01 ‘*’, 0.05 ‘.’, 0.1 ‘ ’ 1			

Figure 2 presents the time trend for sulfur demand separately for FGD enabled and non-FGD plants. The FGD enabled plants show a general upward trend while the non-FGD plants show a downward trend as indicated in model 3. Plotting as annual box plots provides additional information. While the trend is generally upward for FGD enabled plants, the boxes suggest increasing variability- some plants are increasing sulfur consumption over time while others are not. Some of these may be plants that have begun producing a byproduct. In comparison, the boxes for non-FGD plants are shrinking over the period, indicating less variability in sulfur demand. Substantial outliers of high sulfur demanders remain across the period. These may indicate plants not in compliance, waived from doing so, or not operating under sulfur regulation due to being grandfathered in and suggest an avenue for further exploration.

Figure 2. Comparison of the general time trend in sulfur demand for plants with FGD installed against those without FGD. Presenting as annual boxplots provides additional information on the trends.



References

He, Q., & Lee, J. M. (2016). The effect of coal combustion byproducts on price discrimination by upstream industries. *International Journal of Industrial Organization*, *44*, 11-26.

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Data sources:

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Appendices:

Appendix A. Full regression results for the three model specifications.

Model 1:

lnAdjsulfur	Estimate	Std. Error	t-value	Pr(>|t|)	
SO2controls	0.2556	0.0095	27.0030	0.0000	***
Monthly	-0.0013	0.0001	-14.4640	0.0000	***
Signif. codes: 0 ‘***’, 0.001 ‘**’, 0.01 ‘*’, 0.05 ‘.’, 0.1 ‘ ’ 1					

Model 2:

lnAdjsulfur	Estimate	Std. Error	t-value	Pr(>|t|)	
SO2controls	0.1722	0.0102	16.8810	0.0000	***
SO2byproductprodn	0.3280	0.0152	21.5690	0.0000	***
Monthly	-0.0015	0.0001	-15.7670	0.0000	***
Signif. codes: 0 ‘***’, 0.001 ‘**’, 0.01 ‘*’, 0.05 ‘.’, 0.1 ‘ ’ 1					

Model 3:

lnAdjsulfur	Estimate	Std. Error	t-value	Pr(>|t|)	
SO2controls	0.1023	0.0138	7.3990	0.0000	***
SO2byproductprodn	0.1885	0.0209	8.9981	0.0000	***
Monthly	-0.0027	0.0001	-22.2700	0.0000	***
Monthly:SO2controls	0.0020	0.0002	9.1467	0.0000	***
Monthly:SO2byproductprodn	0.0026	0.0003	8.8137	0.0000	***
Signif. codes: 0 ‘***’, 0.001 ‘**’, 0.01 ‘*’, 0.05 ‘.’, 0.1 ‘ ’ 1					