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Steam versus Coking Coal and the Acid Rain Program

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Abstract
The Clean Air Act of 1990 initiated a tradable permit program for emissions of sulfur dioxide from coal-fired power plants. One effect of this policy was a large increase in the consumption of low-sulfur bituminous coal by coal-fired power plants. However, low-sulfur bituminous coal is also the ideal coking coal for steel production. The analysis presented here will attempt to determine how the market responded to the increased consumption of low-sulfur bituminous coal by the electricity generation sector. Was there a decrease in the quality and/or quantity of coking coal consumption or did extraction increase? Most evidence suggests that the market for coking coal was unaffected, even as the extraction and consumption of low-sulfur bituminous coal for electricity generation increased substantially.

Keywords: Coal; Coke; Sulfur Dioxide

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Title IV of the U.S. Clean Air Act Amendments (CAAA) of 1990 initiated a tradable permit system to control sulfur dioxide emissions from coal-fired power plants. The flexibility inherent in a tradable permit program led to a significant increase in the use of low-sulfur bituminous and sub-bituminous coal along with a decrease in the use of high-sulfur bituminous coal. An alternative use for low-sulfur bituminous coal is to make coke, which is used in producing steel. The process of making coke requires coal with much more specific attributes (specifically low-sulfur, low-ash bituminous coal) than the coal used in electricity generation. Given that Title IV increased power plants' demand for the type of coal that is associated with coking, how was the market for coking coal affected? Specifically, did the increased consumption of low-sulfur bituminous coal for electricity generation reduce the consumption or quality of coking coal, or did the extraction of low-sulfur bituminous coal increase?

The answers are useful for general equilibrium economic modeling of the coal industry, which is used heavily in analyzing potential carbon dioxide policy. If the results suggest that the increase in low-sulfur bituminous coal consumption arose from new or increased development of low-sulfur bituminous coal, it would imply that the choice of coal mine development depends on the incentives of environmental policy. In this scenario, models that assume coal quality is fixed will overstate the costs of potential carbon dioxide policy. Further, it is possible that power plants increased consumption of low-sulfur coal caused a leakage of sulfur into the coking coal market. Would a similar scenario happen if certain boilers are excluded from potential carbon dioxide regulation? Given the policy and market similarities between sulfur dioxide and carbon dioxide, the effect of Title IV on coal markets can guide predictions of future carbon dioxide regulation on these same markets.

Background

Coal is generally differentiated into types by rank. Low rank coals, such as lignite and sub-bituminous, tend to have attribute qualities like low heat and high moisture content while high rank coals, bituminous and anthracite, have high heat and low moisture content. Within the rank of coal, other attributes (ash, sulfur and tar for example) can vary considerably. Coal sold to power plants, known as steam coal, is used to generate steam in a turbine for electricity production. Coal with a wide spectrum of attributes can be used as steam coal; bituminous and sub-bituminous coals being the most common rank of coal used. Coal-fired power plants currently consume 91% of all coal mined in the U.S. while a majority of the remaining coal is consumed by coking or industrial consumers (Energy Information Administration, 2005). Coal that is to be turned into coke, known as coking coal, is defined by the U.S. Energy Information Administration (EIA) as low-sulfur, low-ash bituminous coal. It is possible for a coking plant to use types of coal that a power plant normally uses and vice-versa although the coking process requires coal with more specific attributes than the coal used for power plants. It is this relative lack of substitutability that leads to the expectation that the coking coal market may be impacted by the increased demand for low-sulfur bituminous in the steam coal market. The EIA does not have an official definition of industrial coal.[1] As a result, there are no expectations as to how the increased demand for low-sulfur bituminous steam coal would affect the industrial coal market.

On the supply side, the mining industry consolidated during this time period. Mines throughout the 1990s operated at or near full capacity as the number of operating mines fell (EIA, 1999a). The supply side will be crucial in determining how the increased demand for low-sulfur bituminous coal affected the coke market. If the supply is inelastic (increased quantity leads to a larger changes in price), it is expected that the coke market would be affected through changes in price, quantity or quality. An elastic supply would predict little change to the coke market as extraction would increase according to demand.

Coal-fired power plants emit approximately 66% of all sulfur dioxide emissions in the U.S. Title IV of the 1990 CAAA created a system of tradable permits for sulfur dioxide emissions that would eventually apply to most coal-burning power plants in the U.S. The goal of the system was a 10 million ton reduction in sulfur dioxide emissions, about 50 percent of 1985 emissions, by the year 2010. Title IV was implemented in two phases, Phase I began in 1995 with the inclusion of 263 older boilers whose participation was mandated plus 174 boilers that would have been brought in under Phase II but voluntarily entered during Phase I. Phase II covers all coal-fired power plants above 25 megawatt generating capacity and began in 2000. Boilers included in Phase I were granted permits

[1] While the EIA does not have an official definition, it is likely that industrial coal is used to generate steam/heat for an industrial production process, similar to steam coal but on a smaller scale.

at the rate of 2.5 pounds of sulfur dioxide per million Btu of average annual heat input over 1985-87 (the baseline). Phase II granted permits at a rate of 1.2 pounds of sulfur dioxide per million Btu as measured over the baseline.[2]

A majority of Phase I plants complied with Title IV by switching to lower sulfur coal, rather than installing pollution control equipment (scrubbers) as had been expected (EIA, 1997). Sub-bituminous coal, specifically from the Powder River Basin in Wyoming, saw the largest increase in coal production at approximately 36%. Many of the Phase I boilers had been designed to burn high-sulfur bituminous coal that was generally available locally. The costs of modifying boilers to burn low-sulfur coal were expected to preclude substitution to low-sulfur coals. In fact, these costs ended up being much lower than expected, leading to the increased use of low sulfur-sub-bituminous and bituminous coal (Ellerman *et al* 2000).

Coking plants were not part of Title IV but were affected by other aspects of the 1990 CAAA. Considine *et. al*. (1993) estimate an engineering-economic model of the U.S. steel industry to predict the impact of the non-Title IV 1990 CAAA regulations on the use of coke in making steel. It is estimated that coking coal consumption would fall 20% in 1998 relative to the baseline, from 32 million tons per year to 25 million tons per year.

Data & Methods

[2] A good reference for information on Title IV is Ellerman *et al* (2000).

There are no disaggregated public datasets on the consumption of coking or industrial coal. The EIA published the Coal Industry Annual (CIA) between 1993 and 2000.[3] The CIA contains data at the U.S. State level on steam, coke and industrial coal consumption and prices in the United States. Tables 69, 71, and 73 of the CIA provide the total quantity of steam, industrial, and coking coal consumed in the U.S., respectively, for the years 1991-2000. Tables 92, 94, and 96 of the CIA give the average nominal prices of all steam coal, industrial coal and coking coal, respectively, for the years 1991-2000.[4] However, the CIA reports information on the quality of coking coal together with the quality of industrial coal. Table 107 of the CIA gives the average quality of fuels consumed by coke and industrial consumers in the U.S. for the years 1992-2000. Quality attributes given are the Btu, sulfur and ash content.

While information on all steam coal can provide reference, the research here focuses specifically on low-sulfur bituminous steam coal use. Data on this comes from the Federal Energy Regulatory Commission's Form 423 survey. It contains plant level observations of purchased coal quality, quantity, and cost for all power plants greater than 50MW capacity. The dataset compromises a large percentage of the total steam coal consumed. Low-sulfur bituminous coal is defined here as bituminous coal with less than 1.2 pounds of sulfur dioxide per million Btu, with the conversion of sulfur to sulfur dioxide made using EIA (1999b) emissions factors.

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[3] The CIA was preceded by Coal Production and followed by Annual Coal Report, both of which omit information that is available in the CIA. Though the CIA was published from 1993-2000, information available in it may include data from earlier years.

[4] Nominal prices are converted to real prices using the Producer Price Index for crude energy materials with 1982 as the base year (Economic Report of the President, 2001).

The high level of aggregation for coke and industrial coal data limit the ability to perform rigorous analysis of these coal markets. Information on the quantity, price and quality of coking and industrial coal will be compared to that of total steam coal and low-sulfur bituminous steam coal using graphs, t-tests to compare groups mean and standard deviations, and basic regressions. The question being tested is whether the quantity of coal exchanged in the coking and industrial coal market was adversely affected by the increased consumption of low-sulfur bituminous steam coal resulting from Title IV of the 1990 CAAA.

Results

Figure 1 gives the quantity of low-sulfur bituminous steam, coking, and industrial coal consumption for the years 1991-2000 in millions of tons. Total steam coal consumption varied between 775 and 900 million tons throughout this period, though no trend is evident. The movement of low-sulfur bituminous steam coal in this figure corresponds roughly to what one would expect given the timing of Title IV of the 1990 CAA. The consumption of low-sulfur bituminous steam coal increased by 30 million tons (15%) between 1993 and 1994 alone, and continued to increase once Title IV went into effect. Industrial coal consumption remained relatively unchanged as Title IV took effect, around 72 million tons, but fell in the late 1990s to 65 million tons in 2000. Coking coal consumption fell from 34 million tons in 1991 to 29 million tons in 2000; slightly less than the predictions given in Considine *et. al.* (1993) for the non-Title IV impact of the 1990 CAAA to coking consumption. Together, these figures imply that consumers of coke and industrial coal were not pushed out of the market by steam coal consumers' responses to Title IV.

Figure 1: Coal Quantities Consumed

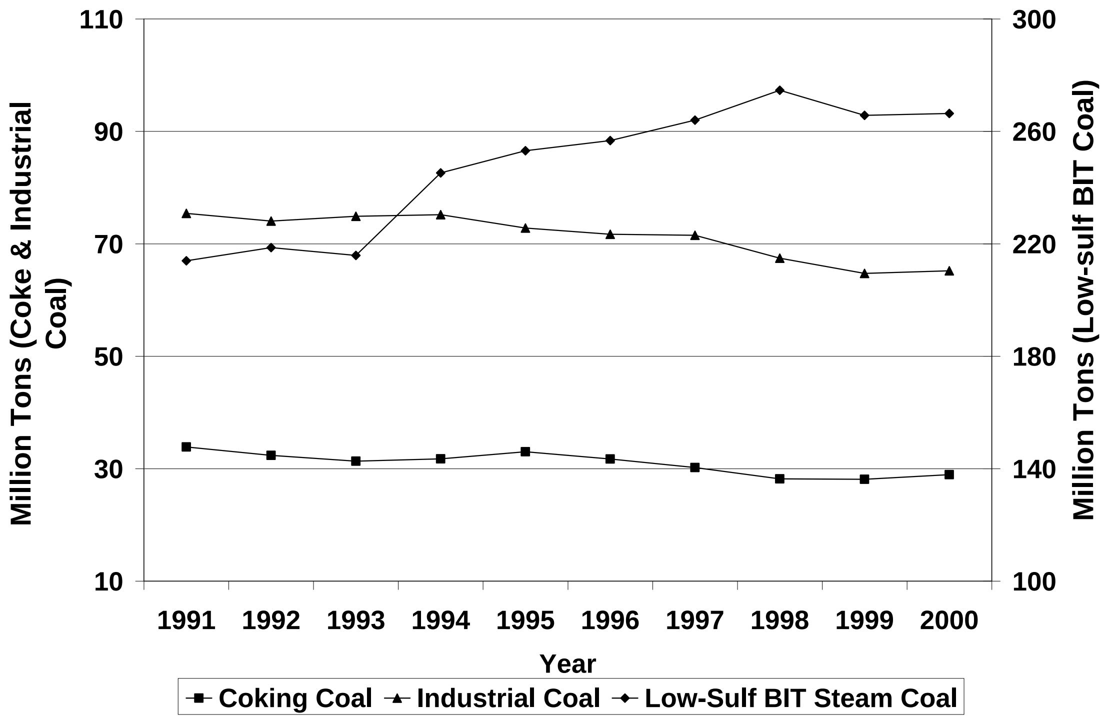

Figure 2 gives the average real prices from 1991-2000 for the four classes of coal. The prices seem to move together as their peaks and troughs are similarly timed. Indeed, the correlation between these series is above 0.94. Coking coal is more expensive than total steam coal; however there are different qualities of steam coal. High quality steam coal (low-sulfur bituminous) is the second most expensive coal of the group. Coking coal is the most expensive coal of all. Using EIA (1999b) emissions factors for bituminous coal to convert the sulfur to sulfur dioxide and the median sulfur content of low-sulfur bituminous coal, the sulfur premium would have to increase by roughly $1000 (there is already a sulfur premium built into these prices due to Title IV) for low-sulfur bituminous steam coal to equal the price of coking coal.[5] This would imply that mines would be unlikely to reduce the supply of coking coal in favor of low-sulfur bituminous steam coal.

Figure 2: Coal Prices

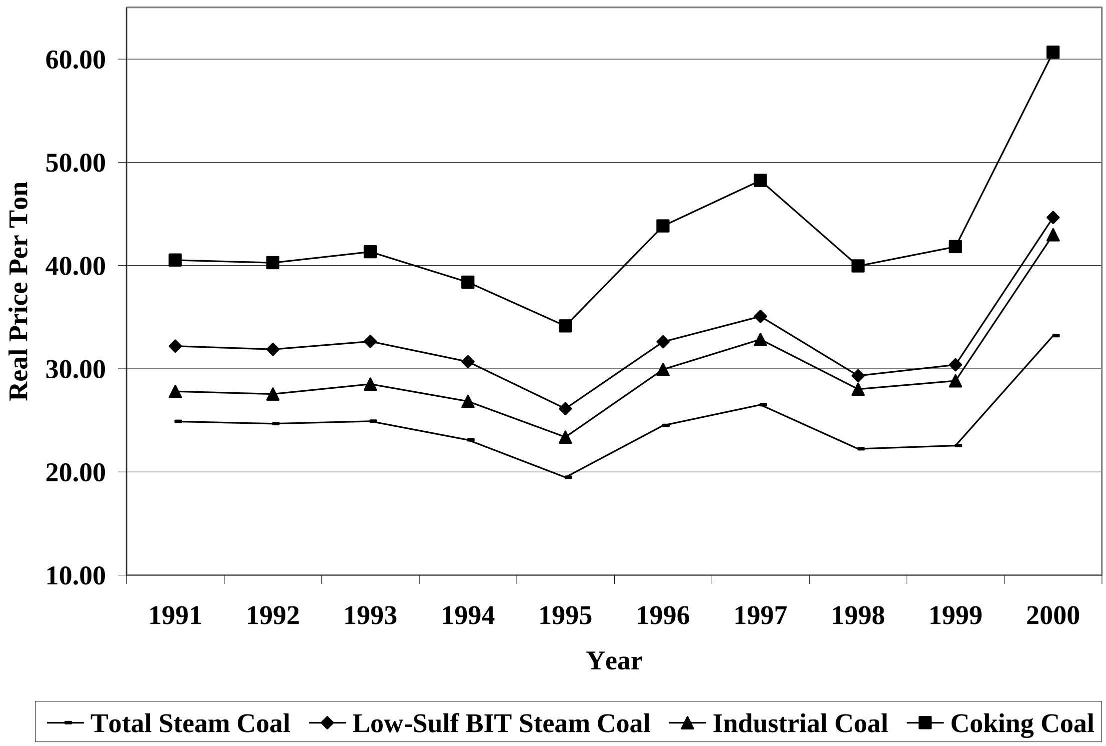

Table 1 shows data from 1992-2000 on the average quality of coking and industrial coal across the U.S. Again, the CIA does not separate the quality of coking coal from the quality of industrial coal; it only reports the combined quality. The raw data themselves provide little evidence that industrial and coking coal changed in quality over the decade.[6] The quality data are disaggregated to the U.S. State level, which allows for some basic statistical analysis. Table 2 shows the results of a two sample t-test with unequal variances to assess whether industrial and coking coal changed quality over the

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[5] $1000 is the quotient of $10 per ton and 0.01 tons of sulfur dioxide per ton of low-sulfur bituminous coal.
[6] It should, however, be noted that since these are combined qualities, changes within coking or industrial coal consumption could be masked by this level of aggregation.

sample period. Two specifications are used to test for changes; the first divides the sample by the implementation of Title IV in 1995 and the second omits the years 1994-1997 due to possible transition effects. Both samples show no significant change in any of the three coal attributes (Btu, sulfur and ash) over the two samples.

Table 1: Average Coking/Industrial Coal Quality

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000
Btu	11,096	11,303	11,316	11,367	11,405	11,407	11,583	11,245	11,218
Sulfur	1.07	1.23	1.16	1.15	1.17	1.17	1.15	1.13	1.08
Ash	7.45	6.34	7.63	7.61	7.58	7.62	7.71	7.42	7.44

Btus are per pound; sulfur and ash are percent by weight

Table 2: T-test of Coal Quality Differences

	Mean		Standard Deviation		T-Statistic	P-Value
	1992-1994	1995-2000	1992-1994	1995-2000	Mean (1992-1994) - Mean (1995-2000) $\neq 0$	
Btu	11556	11674	135	90	-0.71	0.47
Sulfur	1.077	1.081	0.58	0.33	-0.04	0.96
Ash	7.94	8.16	0.02	0.13	-0.90	0.36
	Mean		Standard Deviation		T-Statistic	P-Value
	1992-1993	1998-2000	1992-1993	1998-2000	Mean (1992-1993) - Mean (1998-2000) $\neq 0$	
Btu	11541	11671	167	127	-0.71	0.47
Sulfur	1.091	1.077	0.78	0.46	0.14	0.88
Ash	7.94	8.08	0.26	0.18	-0.46	0.64

T-test run assuming unequal variances

Finally, since the above t-tests do not control for state variation, multivariate regressions are run for each industrial and coking coal quality attribute to assess whether the quality changed over time. Two specifications are used; the first is a trend variable that takes the value of one in 1992 and increases by one each year and the second is a post-1994 dummy variable that takes the value of one for each year after 1994 and is zero for 1994 and before. There are two specifications for each of the three quality attributes for a total of six regressions. Coal quality attributes are regressed on the time factor described above and state dummy variables.

Results of the regression analyses are given in Table 3. They suggest that coking and industrial coal has increased in Btu content over time while the sulfur content remained statistically unchanged. The results for ash content are mixed as the trend variable is not statistically significantly different than zero but the post-1994 dummy is positive and statistically significant. Restricting the sample to the top 12 U.S. states in coking/industrial coal consumption does not alter the results for Btu or sulfur but does suggest a statistically significant increase in ash content over time.[7] Increasing ash content would imply a lower quality of coal, however the significance is mixed across specifications thus the result is not robust.

Table 3: Regression Results

Dependent Variable: Btu Content					
Variable	Coefficient	Std. Error	Variable	Coefficient	Std. Error
Trend	**20.56**	**9.50**	**Post-1994 Dummy**	**117.35**	**51.9**
Dependent Variable: Sulfur Content					
Variable	Coefficient	Std. Error	Variable	Coefficient	Std. Error
Trend	-0.01	0.01	Post-1994 Dummy	0.01	0.02
Dependent Variable: Ash Content					
Variable	Coefficient	Std. Error	Variable	Coefficient	Std. Error
Trend	0.02	0.02	**Post-1994 Dummy**	**0.22**	**0.10**

All Regressions Run with U.S. State Dummy Variables
Results in Bold Indicate Statistical Signficance at the 5% Level

[7] The top 12 states are based on 2000 coke consumption reported in the CIA are: Alabama, Illinois, Indiana, Iowa, North Dakota, Ohio, Pennsylvania, Tennessee, Texas, Virginia, and Wyoming.

Conclusions

Title IV of the 1990 CAAA initiated a tradable permit system to control emissions of sulfur dioxide from coal-fired power plants. The flexibility of this environmental policy allowed plants to choose their abatement option, which was overwhelmingly the consumption of low-sulfur coals. The consumption of low-sulfur bituminous coal for electricity generation increased considerably. However, low-sulfur bituminous coal is also the coal used to make coke. Whether the increased consumption of low-sulfur bituminous coal for steam generation came at the expense of coking coal consumers is the question addressed in this analysis.

Data on consumption of coking and industrial coal are not available at any disaggregated level, thus inferences are made based on more aggregated information for the years 1991-2000. Most results suggest that coking and industrial coal was not affected by the increased consumption of low-sulfur bituminous steam coal. Coking coal was (and still is) more expensive than low-sulfur bituminous steam coal, suggesting that a mine is unlikely to reduce their supply to coke customers to expand supply to low-sulfur bituminous steam coal customers. No evidence is found that coking and industrial consumers substituted into higher sulfur coals after Title IV was implemented, thus little sulfur leakage could have occurred.

These results would suggest that the large increase in consumption of low-sulfur bituminous steam coal after Title IV came from coal sources previously unused (an increase in quantity supplied in the steam coal market) rather than a substitution of suppliers out of the industrial or coking coal market. It is not surprising from an economic viewpoint that a sulfur dioxide tradable permit system would lead mines to increase their production of low-sulfur coals. If the coal market responds in a similar manner to the introduction of a carbon dioxide tradable permit system, it is likely that mines will increase development of low-carbon coal mines. Previous research on the carbon content of coals (Quick and Glick 2000) reveal that low-carbon coal are likely to be bituminous coals with low-sulfur and ash content.

References

Considine, T., G. Davis, and D. Marakovits. 1993. Technological Change under Residual Risk Regulation: The Case of Coke Ovens in the U.S. Steel Industry. Environmental and Resource Economics 3(5), 437-455

Ellerman A. Denny, P. Joskow, R. Schmalensee, J.P. Montero, and Elizabeth Bailey. 2000. Markets for Clean Air: The U.S. Acid Rain Program. Cambridge University Press, New York.

Quick, J. and D. Glick. 2000. Carbon dioxide from coal combustion: variation with rank of US coal. Fuel 79 (7), 803-812.

U.S. Council of Economic Advisors. 2004. Economic Report of the President, U.S. Government Printing Office, Washington D.C.

U.S. Energy Information Administration. Various Years. Coal Industry Annual. Washington DC

U.S. Energy Information Administration. 1997. The Effects of Title IV of the Clean Air Act Amendments of 1990 on Electric Utilities: An Update. Washington DC

U.S. Energy Information Administration. 1999a. The U.S. Coal Industry in the 1990's: Low Prices and Record Production. Washington, DC

U.S. Energy Information Administration. 1999b. Electric Power Annual 1998 Volume II. Washington DC

U.S. Energy Information Administration. 2005. Electric Power Annual Coal Report. Washington DC