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Working Paper Series

Working Paper # 07-10
December, 2007

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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. The effect of this enlightened policy on the coal industry was a large increase in consumption of low-sulfur bituminous and subbituminous coals. Low-sulfur bituminous coal is most attractive to coal-fired power plants as they have higher heat content and require less alteration to the boiler to burn as effectively the coal previously in use. However, low-sulfur bituminous coal is also the ideal coal for coking. The analysis presented here will attempt to determine whether the increased consumption of low-sulfur bituminous coal for electricity generation caused a decrease in the quality and/or quantity of coking coal consumption. Most evidence suggests that the market for coking coal was unaffected, even as the consumption of low-sulfur bituminous coal for electricity generation increased substantially. Implications of potential greenhouse gas regulation on this market are also discussed.

* The author wishes to thank Elaine Frey for her helpful comments and suggestions. The views expressed in this paper are those of the authors and do not necessarily reflect those of the Environmental Protection Agency.

Keywords: 1990 Clean Air Act; Coke; Input Substitution
Subject Area: Energy (33); Distributional Issues (60)

Title IV of the Clean Air Act Amendments (CAAA) of 1990 initiated a tradable permit system to control the emissions of sulfur dioxide 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 subbituminous coal and 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.[1] Given that Title IV increased the demand from electricity generation for the type of coal that is associated with coking, how was the market for coking coal affected? Specifically, did the increase in consumption of low-sulfur bituminous coal for electricity generation reduce the consumption and/or quality of coking coal?

Another coal consumer that might have been affected by the 1990 CAAA is the industrial consumers of coal. While industrial consumers preferences for coal quality are not as clear, a similar affect (a crowding out by electric utilites) as the one to the coke market is possible. Did the increase in consumption of low-sulfur bituminous coal for electricity generation reduce the consumption and/or quality of industrial coal? The answers are relevant for potential carbon dioxide regulation also. If the increase in low-sulfur bituminous coal consumption arose from new or increased development of low-sulfur bituminous coal mines, rather than crowd out the consumption of coking and industrial coal, it would imply that the choice of coal mine development depends on the

[1] A substitute for coke is the electric arc furnace which uses scrap steel as a feed stock. The use of electric arc furnaces have increased over the sample period (Crompton, 2001). How this trend has affected the coke market is not discussed here.

incentives of environmental policy. Perhaps new or increased development of low-carbon coals will occur once a carbon dioxide policy is in place.

Background

Coal-fired power plants currently consume 91% of all coal mined in the US while a majority of the remaining coal is consumed by coking or industrial consumers (Energy Information Administration, 2005). Coal sold to power plants, known from here on as steam coal, is used generate steam in a turbine for electricity production. Most types of coal can be used for steam generation, with a wide range of bituminous and subbituminous coals being the most common. Coal that is to be turned into coke, known from here on as coking coal, is defined by the Energy Information Administration (EIA) as low-sulfur, low-ash bituminous coal. The coking process requires coal with more specific attributes than the coal that can be used for steam generation. It is this relative lack of substitutability that leads to the expectation that the coking coal market would be impacted by the increased demand for low-sulfur bituminous steam coal. The EIA does not have an official definition of industrial coal.[2] As a result, there are no expectations that can be given as to how the increased demand for low-sulfur bituminous steam coal would affect the industrial coal market.

The majority of sulfur dioxide emissions come from coal-fired power plants. 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

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[2] 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 the steam coal but on a smaller scale.

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 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.[3]

A majority of Phase I plants complied with Title IV by switching to lower sulfur steam coal, rather than installing control equipment (scrubbers) as had been expected (EIA, 1997). Many of the Phase I boilers had been designed to burn higher sulfur bituminous coal that was generally available locally. The costs of adjusting the boiler to burn low-sulfur coal was expected to preclude substitution to lower sulfur subbituminous steam coal. In fact, these costs ended up being much lower than expected, leading to the increased use of subbituminous coal. More appealing to Phase I plants than subbituminous coal was low-sulfur bituminous coal due to the lower boiler adjustment costs associated with burning low-sulfur bituminous coal (Ellerman *et al* 2000).[4]

In a supply and demand framework, Title IV would shift the demand curve for low-sulfur bituminous steam coal out, as can been seen in Figure 1. The demand would shift from D to D', which increases the quantity consumed from Q to Q'. A goal of this paper is to determine whether the increased low-sulfur bituminous steam coal

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

[4] Boiler capital costs range from $5-$10 per kilowatt of generating capacity for low-sulfur bituminous coal compared to $15-$75 per kilowatt of generating capacity for subbituminous coal (Ellerman *et al* 2000).

consumption came from mines reducing the amount of coking coal sold or whether low-sulfur bituminous coal production increased.

A similar change in the coal market will occur when regulation of carbon dioxide emissions pushes coal-fired plants to look for lower carbon fuels. This is because bituminous coals in general have lower carbon contents than their main substitute for electricity generation, subbituminous coal. One study estimates that bituminous coal has on average 3% less carbon dioxide emissions per million Btu than subbituminous coal (205 vs 211 lbs of carbon dioxide per million Btu) (Hong and Slatick, 1994). Quick and Glick (2000) estimate that carbon dioxide emission increased by 7% due to the coal switching attributed to Title IV of the 1990 CAAA because of the movement from high-sulfur bituminous to low-sulfur submitominous coals. In a world where both sulfur dioxide and carbon dioxide emissions are capped, low-sulfur bituminous coal provides the lowest emissions of both pollutants. Further, the lower the sulfur and ash content the lower the carbon dioxide emissions as sulfur and ash provide little of the heat required for combustion. The affect of Title IV of the 1990 CAAA on low-sulfur bituminous coal markets can guide predictions of future carbon dioxide regulation on these same markets.

Data

There are no micro-level public dataset on the consumption of coking or industrial coal. The EIA published the Coal Industry Annual (CIA) between 1993 and 2000.[5] The CIA contains state level aggregated data on steam, coke and industrial coal consumption and prices in the U.S. Tables 69, 71, and 73 of the CIA provide the total quantity of

[5] The CIA was preceded by Coal Production and followed by Annual Coal Report, both of which omit information that is available in the CIA.

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.[6] 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 hypothesis 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 (1999) emissions factors.

Results

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. The hypothesis being tested is whether 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.

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[6] 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).

Figure 2 gives the quantity of low-sulfur bituminous steam, coking, and industrial coal consumption for the years 1991-2000 in millions of tons. The total steam coal consumption averaged approximately 800 million tons throughout this period. The movement of low-sulfur bituminous 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 between 1993 and 1994, and continued to increase once Title IV went into affect. The coke and industrial coal consumption remained relatively unchanged as Title IV took affect. This would imply that consumers of coke and industrial coal were not pushed out of the market by steam coal consumer's response to Title IV.

Figure 3 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. Steam coal is by far cheaper than coking or industrial coal. However, this masks the variance in quality of steam coal as low-sulfur bituminous steam coal is more expensive than industrial coal. The prices of low-sulfur bituminous steam coal and industrial coal seem to be converging, though the lack of information on qualities and type of coals industrial consumers demand makes it difficult to interpret this information. Coking coal is the most expensive coal of all. The relative prices of coking and low-sulfur bituminous steam coal suggest that mines would not want to reduce supply to the coking coal market to increase supply to the low-sulfur bituminous steam coal market. Using EIA (1999) 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.[7] This would imply that mines would be unlikely to reduce the supply of coking coal in favor of low-sulfur bituminous steam coal.

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. There is little evidence that industrial and coking coal combined changed in quality over the decade. 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.

The quality data are disaggregated to the state level, which allows for some basic statistical analysis. Table 2 shows the results of a two sample t-test with unequal variances to asses whether industrial and coking coal changed quality over the 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. The only pattern that is evident is that the variability of sulfur content in industrial and coking coal decreased after implementation of the Title IV.

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 asses whether the quality changed over time. Two specifications are used; the first is a trend variable

[7] $1000 is the quotient of $10 per ton and 0.01 tons of sulfur dioxide per ton of low-sulfur bituminous coal.

which 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 the 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 states in coking/industrial coal consumption does not alter the results for Btu or sulfur but does reveal that both specifications have a statistically significant increase in ash content over time.[8] Increasing ash content would imply a lower quality of coal while a higher Btu content implies higher quality coal; thus the result do not provide a clear indication of whether the quality of coking and industrial coal increased or decreased.

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

[8] 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.

bituminous coal is the coal used to make coke. Whether the increased consumption of low-sulfur bituminous coal for steam generation came at the expense of coking or industrial coal consumers is the question addressed in this analysis.

Data on consumption of coking and industrial coal are not available at the micro 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.

These results would suggest that the increased consumption of low-sulfur bituminous steam coal came from coal sources previously unused. 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. The results suggest that a carbon dioxide tradable permit system is likely to lead to increased development of low-sulfur bituminous coal mines, as it is also low in carbon content, rather than crowd out the consumption of coking coal.

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Figure 1: Market for Low-Sulfur Bituminous Steam Coal

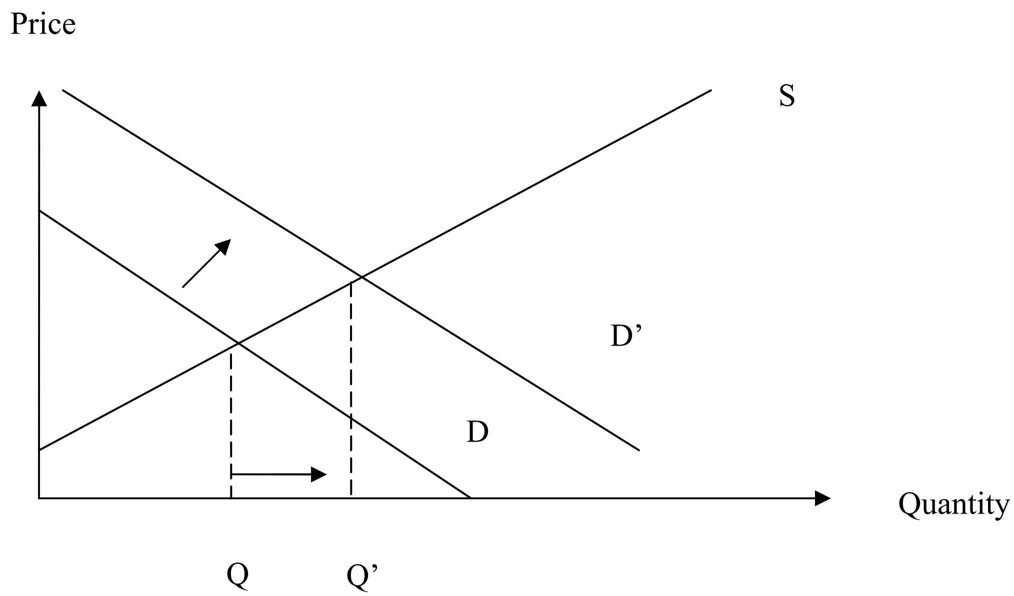

Figure 2: Coal Quantities Consumed

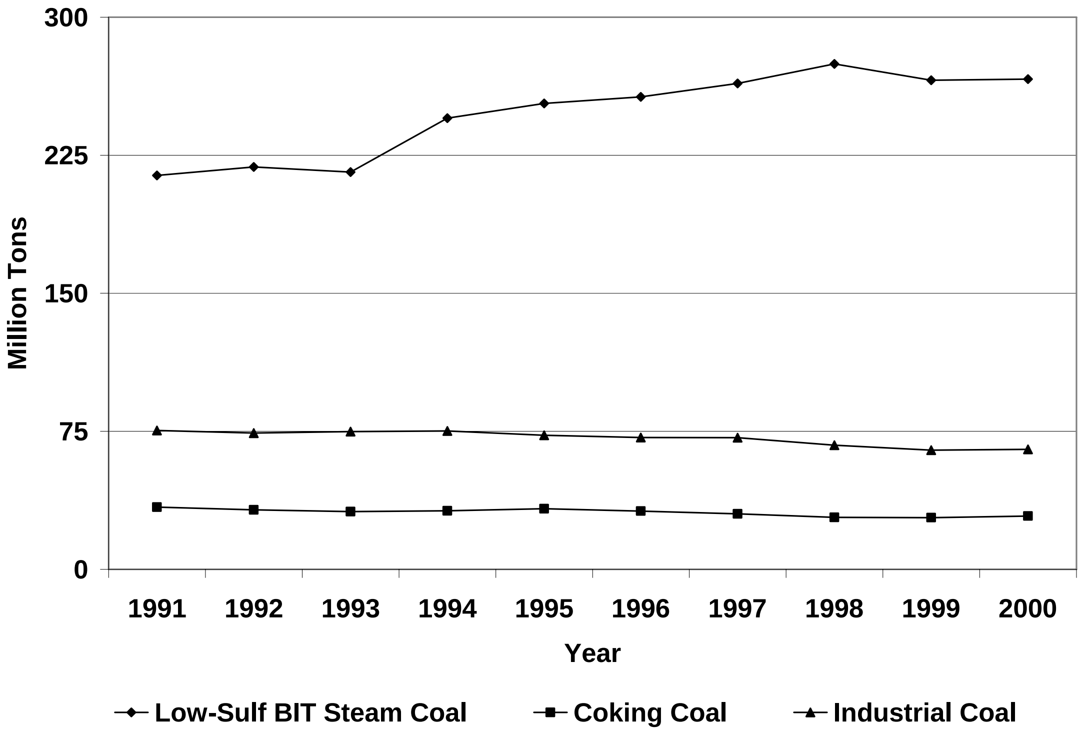

Figure 3: Coal Prices

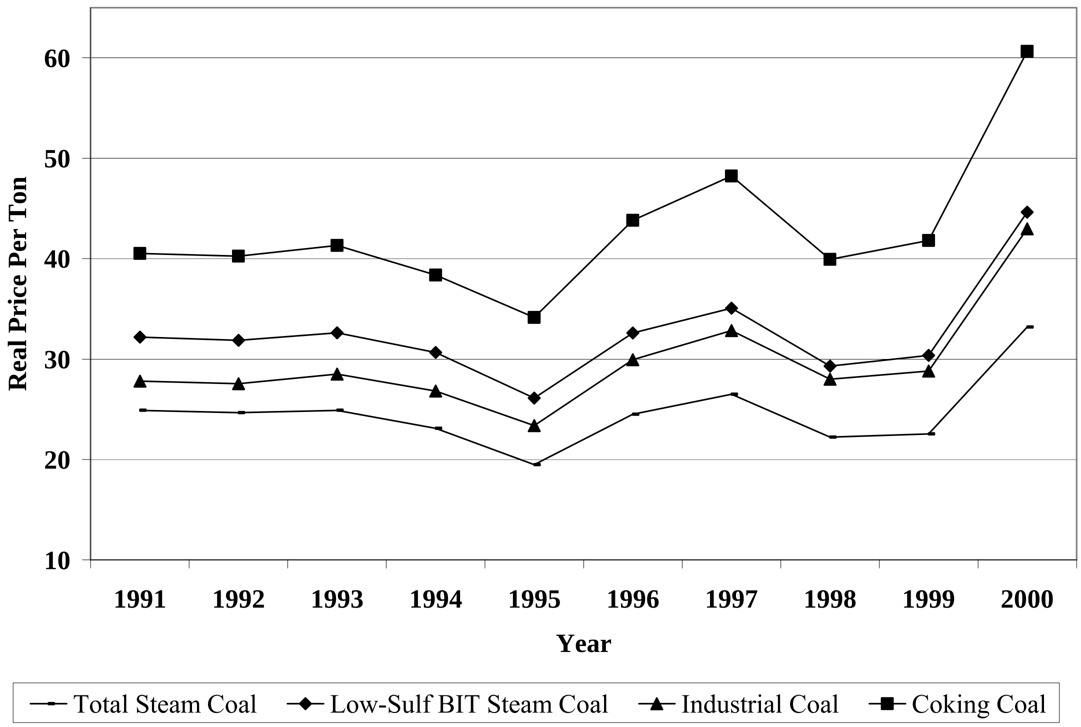

Table 1: Average Coking/Industrial Coal Quality

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

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

Table2: 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

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 State Dummy Variables

Table 4: Regression Results for Top 12 States in Coke Consumption

Dependent Variable: Btu Content					
Variable	Coefficient	Std. Error	Variable	Coefficient	Std. Error
Trend	62.33	20.05	Post-1994 Dummy	332.5	110.69
Dependent Variable: Sulfur Content					
Variable	Coefficient	Std. Error	Variable	Coefficient	Std. Error
Trend	-0.01	0.01	Post-1994 Dummy	-0.03	0.06
Dependent Variable: Ash Content					
Variable	Coefficient	Std. Error	Variable	Coefficient	Std. Error
Trend	0.04	0.02	Post-1994 Dummy	0.23	0.11

All Regressions Run with State Dummy Variables