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## ABSTRACT

The use of long-term contracts in the procurement of coal for electricity generation is common. The data that is observed from contracts and their transactions are from different levels of the pricing process. Contracts contain the parameters by which all future deliveries are structured, specifying the length of the agreement and acceptable coal attributes. Based on these parameters, a price is later determined for successive coal deliveries and the transaction occurs. This data structure fits well into multi-level models, where each level of the process is empirically estimated. A random intercept model is estimated where the first level is a hedonic model of coal prices. The contract that initiates the delivery is used to connect the two levels of the model. In the second level, contract coefficients from the first level are regressed on contract parameters to determine their impact on how coal is priced. Results find that many contract parameters are statistically significant in the price of coal.

JEL Codes: Q48; Q53; L51: L22
Keywords: Tradable Permits; Contracts; Coal; Sulfur Dioxide

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The use of long-term contracts (>1 year) in the procurement of coal for electric generation is common. Power plants, railroads (or other options for transport) and mines negotiate the parameters of a contract and then transact based on the terms established over time. Some of the parameters that are often agreed upon in a contract are minimum quantity, acceptable coal attributes (quality), and length of the contract.

The nested structure of these transactions can be used to determine how contract parameters affect the price of coal. The determination of the price of a coal delivery depends upon data that are at two different levels; the delivered quality of the coal and the parameters of the contract for the coal. Multi-level models (also known as hierarchical models) fit contract data well. In this analysis, each level of the contract process is analyzed separately using a random intercept model. In the first level, a hedonic price regression is estimated using data on coal deliveries, controlling for the delivered coal attributes and contract fixed effects. In the second level, these estimated contract (fixed effects) coefficients are regressed on the contract parameters. This will allow for the estimation of the effect of contract parameters on the price of coal controlling for the delivered quality of coal.

Data from U.S. coal contracts for electricity generation from 1979-1999 are used to estimate the multi-level model described above. Second level results show that longer contracts are associated with a higher price. One contract parameter of interest is the allowable sulfur content upper bound. During the sample period, environmental regulation of sulfur dioxide ($SO_2$), an emission that is a by product of coal combustion, changed from an emissions standard to a tradable permit system. As a result, plants would value marginal changes in the sulfur content. Indeed, the results show that the allowable upper bound on sulfur content was statistically insignificant prior to this change in regulation and statistically significant afterwards.

## Background

Power plants, railroads and mines are endowed with characteristics that fit well with the transactions cost theory originated with Coase (1937) and expanded upon by Williamson (1985) and Klein *et al* (1978). Plants are fixed in location and may have asset specificity. Rail firms can service only mines and plants their tracks connect. Coal has many attributes that are easily measured. As a result, contracts for the procurement of coal seem to be driven by transaction cost theory rather than asymmetric information issues[1].

Transactions cost theory predicts that contracts are written with parameters that minimize contracting costs. This prediction is reasonable because repeated bargaining between firms is expensive and leaves them open to ex-post opportunistic behavior or the “hold up” problem in which one firm makes an investment whose value is largely determined through the use of the other firm’s product and subsequently finds that the other firm tries to take advantage by raising the price of the product.[2] A contract is written that specifies the terms of future transactions. The terms serve to minimize the expected costs of

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[1] This is belief is confirmed by the economics literature on coal contracts, discussed below, which are exclusively based on transaction cost theory.

[2] One alternative to contracting in the face of opportunistic behavior is vertical integration. However, state and federal regulators of plants strongly discourages this, even under restructured electricity markets. However, most of our sample is from pre-restructuring.

transacting. Firm characteristics will partially determine the expected transactions costs, thus these characteristics will explain the contract's parameters.

Transaction cost theory has been empirically tested in a number of economic fields and has been applied in many other social sciences (Richman and Macher, 2006). Transaction cost theory has been discussed in a number of energy and resource markets. Crocker and Matsen (1991) use natural gas contract data to show that longer contracts have more flexible pricing arrangements. Additionally they demonstrate that those contracts with less flexible pricing arrangements have more flexibility in the other contract parameters. Neumann and von Hirschhausen (2006) show that the duration of natural gas contracts falls as the market becomes more competitive but that contracts with higher degrees of asset specificity are longer. Dahl and Matson (1998) discuss qualitatively how transactions costs have shaped the natural gas market in the U.S. Saussier (2000) evaluates coal transportation contracts in France to show that the number of unspecified or vague obligations, defined as completeness, in a contract varies with the asset specificity of the contracting parties.

Some of the early empirical tests of transaction cost theory come from coal contracts. The most common empirical test is the relationship between asset specificity and duration. The most well known are the seminal works of Joskow (1985, 1987, 1988, 1990). Joskow (1987) finds that minemouth plants write longer contracts due to their higher asset specificity and lack of alternative suppliers. Joskow (1988) reviews the price adjustment mechanisms used in these contracts as they relate to transaction cost theory. Joskow

(1988 and 1990) discusses when certain types of price adjustment mechanisms perform better than others. Kerkvilet and Shogren (2001) study the effect of a large set of transaction cost variables on the duration of a contract. They show that asset specificity increases the length of contract but that previous interaction shortens the length.

Empirical work investigating the how the tradable permit system altered rent distribution generally find that mines and rail firm took advantage of this regulation to increase their share of the gains from trade. Keohane and Busse (2007) sketch a model of price discrimination in coal transactions based on where the plant is located relative to the Western coal basin. They find that railroads altered their pricing to plants subject to the tradable permit system based on how close the plant was to the Western coal basin, as this defined the alternative available. Lange and Bellas (2007) argue that contracts of different vintages can provide information on future permit prices through the implied sulfur premium. Results show that the sulfur premium increased after the announcement of a tradable permit system for $SO_2$ emissions but that the sulfur premium in these contracts were much lower than predictions available at that time.

Crocker and Matsen (1991) and Goldberg (1985) discuss a relational perspective to contract parameter determination. It is argued that contract should not been seen as fixed and inflexible mandates on behavior. Contracts are an imperfect instrument for protecting against “ex-post” rent seeking given that contract language and court enforcement are imperfect. Contracts should rather be seen as setting the structure for future negotiations. This perspective is utilized in the analysis presented here.

A coal contract involves three parties: the mine, a transporting firm(s), and the plant. The Energy Information Administration (EIA) estimates that over 70% of coal is shipped by rail exclusively. We will use the term rail firm to imply the transportation firm unless noted. However, the distribution of rents between the mine and rail firm are unknown. Thus we will consider the mine and rail firm to be one entity when discussing how gains and loses are determined. A higher price would just give the mine and rail firm a bigger pie to split; a lower price a smaller pie.

Coal is a product with many attributes that determine its quality and thus price. As a result, most contracts specify allowable levels of coal attributes. The most common attributes specified by contracts for which data are available, are quantity, British Thermal Units (Btus), sulfur, ash, and moisture content.[3] Higher Btus are a good attribute to have, while higher sulfur, ash, and moisture are not.

Coal attributes can vary substantially by region. There are three major U.S. coal basins that power plants use to meet their demand. The first one is the Western basin. It includes Wyoming, Montana, and Colorado. The second one is the Interior Basin, which includes Illinois, Indiana, and Kentucky. Last is the Appalachian Basin, which includes West Virginia, Pennsylvania, and Tennessee. Coal mines are endowed with coal of a certain quality; however variability exists within a coal mine (often referred to as a seam or bed). The American Society for Testing and Materials (ASTM) warn that sampling a coal

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[3] There are other coal attributes that plants may value for which data is not available though they are often correlated with the observable attributes. For example, grindability is largely a function of BTU, ash, and moisture content. As a result, these unobserved attributes are likely to be similar within contract deliveries.

seam/bed for its quality may not be representative of the entire coal seam/bed due to this variability (ASTM, 2007).

Due to the inherent variability in coal seams/beds a mine would find it advantageous to have greater flexibility in the allowable levels of coal attributes for delivery in its contracts. Contracts that specify a higher (lower) allowable upper bound on ash/sulfur/moisture (Btu) provide the mines with greater flexibility to meet the contract but potentially provide the plant with a lower quality coal.

In essence, the allowable levels of coal attributes specified in a contract acts as a quasi-forward contract. The mine hedges against higher (lower) than expected ash/sulfur/moisture (Btu) contents being found in a coal seam and accepts a price reduction to compensate. The plant exposes itself to risk of lower quality coal but is compensated with a lower coal price. Mines would be willing to accept a lower price for coal of a given quality due to the decreased risk of not meeting the contract. Plants would be willing to pay a lower price for coal of given quality due to the increased risk of burning lower quality coal. As a result, it is expected that increasing (decreasing) the allowable upper bound on ash/sulfur/moisture (Btu) in a contract would reduce the price of coal transacted (controlling for the actual delivered quality of the coal).

The cost to the plant of burning lower quality coal depends on which attribute is present in higher quantities. Ash and moisture generally do not lead to the emission of a regulated pollutant but would lower the efficiency of producing electricity. However, the sulfur content of the coal leads directly to emissions of $SO_2$. Some background on the history of $SO_2$ regulation is needed to set expectations for the direction of impact the allowable sulfur content upper bound would have on prices. Title IV of the 1990 CAAA created a system of tradable permits for $SO_2$ 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 $SO_2$ emissions, about 50 percent of 1985 emissions, by the year 2010. Phase I of the permit system began in 1995 with the inclusion of approximately 263 older boilers whose participation was mandated plus 174 newer boilers that would have been brought in under Phase II but voluntarily entered during Phase I. Previous regulation of $SO_2$ had been a mix of lax state regulation or emissions/technological federal standards. The relevant issue for this analysis is that previous to 1990, plants did not face a marginal cost of $SO_2$ emissions and thus it is expected that they would not price the sulfur content of coal. After 1990, the tradable permit program initiated a price per $SO_2$ emissions, thus plants would consider the cost of marginal changes to the sulfur content of coal.

In writing a contract, the plant and mine agree to an allowable upper bound on the sulfur content. Any increase in this allowable upper bound leaves the plant vulnerable to accepting higher than desired sulfur content in the coal. If a higher sulfur content coal is delivered, the plant must alter its compliance strategy to deal with the higher resulting $SO_2$ emissions. The tradable permit market provides plants with the flexibility to take higher sulfur content coal and provides a measure of the costs of these excess emissions through the permit price. Previous to the 1990 CAAA, plants were not priced at the margin for their emissions, thus they would be less concerned about the impact of a higher allowable upper bound for sulfur content and mines would be more likely to be able to sell coal with higher sulfur content.

In this analysis, coal contract data will be analyzed using multi-level or hierarchical models. Multi-level models allow for an estimation of data where observations may be correlated based on some shared circumstances between groups. Multi-level models are quite common in educational policy research (Raudenbush and Bryk, 2002; Goldstein, 1987). In an educational policy, the levels (shared circumstances) would be the schools/districts that set the subjects taught, the teacher that teaches the subject, and the students that are tested. Generally the levels used in educational policy research are students at the first, teachers at the second, schools at the third, and on.

In the economics literature, multi-level models are commonly used in health economics (Manca *et al,* 2005; Scott and Shiell, 1997). There is a small literature in environmental economics (Bateman and Jones, 2003; Carlsson and Martinsson, 2001; Langford et al, 1998) that revolves around contingent valuation studies where groups of people surveyed are similarly affected by the environmental outcome in question. Searches of economic literature database have yet to reveal use of multi-level models in the industrial organization literature.

Multi-level models are useful in analyzing many types of contract or industrial organization data. Contract formation, whether in traditional transactions cost theory or in the relational view, fits into the structure necessary for estimation with multi-level models. Coal contracts are nested in that the contract parameters influence the price and quality of coal transacted. The analysis given here will use multi-level models to determine how the contract parameters affect the pricing of coal.

## Data

The data come from the Coal Transportation Rate Database (CTRB), which is maintained by the Energy Information Administration (EIA). The EIA compiles the CTRB largely from the Federal Energy Regulatory Commission (FERC) Form 580 “Interrogatory on Fuel and Energy Purchase Practices,” a biennial survey of investor-owned, interstate electric utility plants with steam-electric generating stations of more than 50 megawatts. The dataset contains information on coal transactions for the years 1979-1999. This survey is more detailed than other surveys (FERC 423, for example) but it uses a smaller sample of plants.

The dataset can be thought of as two separate data sources merged. The first set of information is on the contracts. The contract characteristics given include year signed, duration, year renegotiated, year of each delivery, price adjustment mechanism and acceptable bounds on the coal attributes. These variables stay constant (unless the contract is renegotiated) across the deliveries. Each contract has a number of deliveries associated with it, though the data set is an unbalanced panel set as some contracts’ deliveries are more frequently reported than others. The second set is information on each delivery from a specified contract. Each delivery will specify the attributes of the coal delivered as well as the price paid. A discussion of contract characteristics is next, followed by coal delivery specifics.

The real delivered price per ton of coal is the dependent variable in the first level of this analysis. Prices were adjusted for inflation using the Producer Price Index for crude energy materials with 1982 as the base year (Economic Report of the President, Table B-66, 2004). The dependent variable in the second level is the estimated coefficient (from the first level) on each contract, which represents the impact the specific contract has on this real delivered price. The dependent variable in the third level is the estimated coefficient (from the second level) on each plant, which represents the impact of each plant on the real delivered price of coal through its impact on the contract.

The explanatory variables used in this analysis are separated into contract parameters and delivery variables. The contract parameters are used in the second level of the analysis. Contract parameters are the result of bargaining between mines, transportation firms, and plants. The first contract parameter is the price adjustment mechanism. As noted in Joskow (1988, 1990) each coal contract has its own price adjustment mechanism that may impact the price of a given delivery. We create an ordinal price adjustment mechanism variable that takes the value of 1 for the most completely specified/inflexible adjustment mechanism (fixed price) up to the value of 6 for the least completely specified/flexible (yearly negotiation). The second contract parameter is the duration of the contract. The data include the year that the contract was signed and the year that it is set to expire. Contract duration is created as the difference between the year signed and year expired. The third contract parameter is the acceptable sulfur content upper bound. The data give the sulfur content by weight of the coal and list the upper bound, with the understanding that the lower bound is zero for sulfur. The sulfur content was transformed into an amount of $SO_2$ per ton of coal using emissions factors given by the EIA (1999a) based on the coal's Btu content. The upper bound on $SO_2$ is interacted with a post-1990 variable (one for contracts signed or renegotiated in the years 1991-1999; otherwise zero) to determine if the switch to a cap-and-trade $SO_2$ permit system altered the manner in which the $SO_2$ bound impacted prices. The fourth and fifth contract parameters are the upper bounds on ash and moisture content. As with the sulfur content, data are given by weight of the coal and list the upper bound, with the understanding that the lower bound is zero. The sixth contract parameter is the acceptable Btu content lower bound. The lower bound is used because Btu is a good from the plants perspective while sulfur, ash, and moisture are bads. The seventh, and final contract parameter is the acceptable quantity lower bound.

The independent variables in the first level analysis (delivery variables) follow those of Lange and Bellas (2007). Delivered coal attributes (Btu, $SO_2$, ash and moisture) are the first four variables. Transportation costs are the next set of variables. Transportation variables include the total distance traveled and the total distance traveled squared to control for any non-linearities in the transportation pricing function. The final transportation variable is a number of modes variable, ranging from one to four, listing the number of modes of transportation and a dummy variable equal to one if multiple types of transportation (rail, truck, barge) are used and zero otherwise. Dummy variables for mine location are created for each of the 23 Bureau of Mines District. Year dummy variables are created as well as a year trend variable. The year trend is equal to 1 in 1979 up to 19 in 1999. A table of summary statistics for coal attributes can be found in Table I.

## Analysis

To determine how contract parameters impact the price of coal, multi-level modeling is used. First, a fixed-effect estimator grouped by contract was used to estimate the average effect of each contract on the price of coal controlling for the coal's attributes and the transportation costs.[4] The model estimated in the first level is:

$$P_{it} = \alpha_j + \beta_1 X_{it} + \beta_2 T_{it} + \beta_3 D_{it} + \varepsilon_{it} \qquad [1]$$

Where $P_{it}$ is the price of coal delivery i at time t, $a_j$ is a contract dummy, $X_{it}$ is a vector of delivered coal attributes, $T_{it}$ is a vector of transportation variables, $D_{it}$ is a vector of dummy control variables, and $\varepsilon_{it}$ is an error term.

The second level uses the first level estimated contract coefficients as the dependent variable. The variables in the second level relate contract parameters to the average effect of the contract on the price of coal. The model estimated in the second level is:

$$\hat{\alpha}_j = \beta_4 + \beta_5 CP_j + \nu_j$$

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[4] A Hausman test is performed on the first step to ensure that a fixed-effects estimator is the correct specification.

[2]

Where $\hat{\alpha}$ is the contract coefficient from the first level (Model 1) and $CP_j$ is a vector of contract parameters, and $v_j$ is an error term.

The multi-level model framework is used because it fits the structure of coal contract data well. There are other reasons multi-level models are used, rather than one estimation equation. First, only a fraction of the information listed in a contract is given in the data which implies that contract fixed effects are necessary to control for this unknown information. Since the known contract parameters generally don't vary within contract, if the model was estimated in one equation the known contract parameters would be perfectly collinear and thus dropped. Second, the allowable upper/lower bounds of coal attributes are highly correlated with actual delivered coal attributes. Estimating both variables in one level would be statistically difficult. Finally, Moulton (1990) discusses the negative implications of including variables from multiple levels in one equation, including downwardly biased standard errors.

The expected signs of the contract parameters should follow that of the expected effect on price. The effect of the completeness/flexibility of the price adjustment mechanism on the price of the coal is ambiguous. The effect of duration effect on price is ambiguous; plants presumably have a higher willingness to pay for longer contracts as they are assured the supply of coal necessary to meet demand. Mines would presumably have a lower willingness to accept with longer contracts as they are ensured a customer for their product.  Quantity lower bound is expected to have an ambiguous effect on price as large purchasers may expect a discount; however a higher lower bound on quantity would increase the chance of being unable to fulfill the contract due to their capital need maintenance or inclement weather.

The expected sign for the allowable coal attributes follows from the previous discussion of their use as quasi-forward contracts. The acceptable Btu content lower bound is expected to have a positive sign given that Btus are a good while the acceptable ash and moisture content upper bounds are expected to have negative estimated coefficients given ash and moisture are bads.  Acceptable sulfur content upper bound and its interaction with the post-1991 dummy is expected to have a negative sign.  Given that pre-1991 $SO_2$ regulation essentially put a price of zero on marginal changes in sulfur content and a cap-and-trade $SO_2$ system places a price on marginal changes in sulfur content, it is expected that the post-1991 interaction term will be larger (in absolute value terms) than the non-interacted $SO_2$ term.

For the reasons given above, the expected sign of Btu is positive and the expected signs of ash, sulfur, and moisture content are negative in the first level.  Distance travelled is expected to increase the price while the distance travelled squared is expected to be ambiguous.  The number of modes is expected to increase the price. The expected signs of the independent variables in the first and second levels are found in Table II.

Given the change in the form of sulfur regulation with the 1990 CAAA, it is expected that the relationship between the allowable upper bound of sulfur content and the delivered sulfur content may change. To investigate this, Table III gives the deviation of delivered sulfur content from allowable upper bound of sulfur content for the entire sample, pre-1991, and 1991 and beyond. A positive number implies that the delivered sulfur content is less than the allowable upper bound of sulfur content. Although not reported in the table, about 10% of the observations are negative, implying that the delivered sulfur content was higher than the allowable sulfur content. Table III shows that the deviation in sulfur content did shrink over the two time periods and that a t-test confirms that the two means are statistically different from each other.

## Results

The regression results for the two levels are given in Tables IV and V. Table IV shows the results from the first level, which is consistent with the expectations given in Table II. There are about 18,000 deliveries from 2421 contracts in the sample. A simpler sulfur specification is used here than in Lange and Bellas (2007) since dissecting the different sulfur premiums for different groups are not the main focus of the paper. Higher Btu content, greater distance traveled, and more transportation modes statistically increase the price. Ash and moisture content statistically reduce the price. The $SO_2$ coefficients are in line with Lange and Bellas (2007), around \$80 per ton of $SO_2$.

Table V shows the results for the second level. The dependent variable is the contract coefficient from the first level regression. Again, most coefficients are in line with the expectations give in Table II. The coefficients given reflect how the contract parameters affected the price of coal controlling for the delivery variables from the first level. Longer contracts, which have an ambiguous expected sign, are associated with a higher price. This implies that, in equilibrium, the higher plant willingness to pay exceeds the mines lower willingness to accept. A larger minimum quantity and allowable upper bound of moisture content is associated with a lower price. Higher allowable lower bound on Btu statistically significantly increases the price.

The variable of most interest for environmental policy is the allowable upper bound of sulfur content. The allowable upper bound of sulfur content is not statistically different from zero for contracts signed previous to the switch to a tradable permit system for $SO_2$ emissions. Contracts signed after the switch, show a roughly \$28 per ton (\$20 in 1995 dollars) premium. This implies that contracts priced the cost of potential excess $SO_2$ emissions from allowing higher sulfur content in the deliveries into their contracts, controlling for the actual delivered sulfur content. Mines evidently had enough bargaining power in the contracting process to capture more gains from trade once the tradable permit system was put into place.

## Conclusion

The nested structure of contract coal transactions can be used to determine how contract parameters affect the price of coal. Multi-level models (also known as hierarchical models) fit these types of data well. In this analysis, each level of the contract process is analyzed separately. In the first level, a hedonic price regression is run on the coal deliveries controlling for the delivered coal attributes and contract fixed effects. These contract coefficients are then used as a dependent variable in the second level. In the second level, contract coefficients are regressed on the contract parameters to determine how contract parameters affect the price paid for coal. This will allow for the estimation of the effect of contract parameters on the price of coal controlling for the actual delivered quality of coal.

Data from U.S. coal contracts for electricity generation from 1979-1999 are used to estimate the multi-level model described above. Given the natural variability of coal in a seam, it is expected that contracts whose parameters allow greater flexibility (a higher allowable upper bound for moisture for example) would show a price discount. Second level results generally support this hypothesis. Other results reveal that longer contracts are associated with a higher price. One contract parameter of interest is the allowable upper bound of sulfur content. During the sample period, environmental regulation of $SO_2$, an emission that is a by product of coal combustion, changed from an emissions standard to a tradable permit system. As a result, plants would value marginal changes in the sulfur content. Indeed, the results show that the allowable sulfur content was statistically insignificant prior to this change in regulation and statistically significant after the change in regulation.

## References

American Society for Testing and Materials. 2007. “Standard Practice for Collection of Coal Samples from Core” ASTM D5192-07.

Bateman, Ian and Andrew Jones. 2003. “Contrasting Conventional with Multi-Level Modeling Approaches to Meta-Analysis: Expectation Consistency in U.K. Woodland Recreation Values.” Land Economics 79(2), 235-258.

Carlsson, Fredrik and Peter Martinsson. 2001. “Willingness to Pay for a Reduction in Air Pollution: A Multilevel Analysis. 4(), 17-27

Coase, Ronald. 1937. “The Nature of the Firm” *Economica* 4(16) 386-405

Crocker, Keith and Scott Matsen. 1991. “Pretia ex Machina? Prices and Process in Long-term Contracts.” *Journal of Law and Economics*. 34 (1), 69-99.

Dahl, Carol and Thomas Matson. 1998. “Evolution of the U.S. Natural Gas Industry in Response to Changes in Transaction Costs.” *Land Economics*, 74 (3), 390-408.

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

Energy Information Agency. 2004. Annual Energy Review. Table 7.8.

Goldberg, Victor. 1985. “Price Adjustment in Long-Term Contracts.” *Bell Journal of Economics.* 7(), 45-61.

Goldstein, Harvey. 1987. Multilevel Models in Educational and Social Research. Charles Griffen Press, London.

Joskow, Paul. 1985. Vertical Integration and Long-Term Contracts: The Case of Coal-Burning Electric Generating Plants. *Journal of Law, Economics, & Organization*. 1(1), 33-80.

Joskow, Paul. 1987. “Contract Duration and Relationship Specific Investments: Empirical Evidence from Coal Markets.” *American Economic Review*. 77(1), 168-185.

Joskow, Paul.1988. “Price Adjustment in Long-Term Contracts: The Case of Coal.” *Journal of Law & Economics*. 31 47-83.

Joskow, Paul. 1990. “The Performance of Long-Term Contracts: Further Evidence from Coal Markets.” *RAND Journal of Economics*. 21(2) 251-274.

Keohane Nathaniel O. & Meghan Busse. 2007. Market Effects of Environmental Regulation: Coal, Railroads, and the 1990 Clean Air Act. *RAND Journal of Economics*, Vol. 38(4), pp. 1159-1179.

Klein, Benjamin, Robert Crawford & Armen Alchian.1978. “Vertical Integration, Appropriable Rents, and the Competitive Contracting Process” *Journal of Law and Economics*, 21(2) 297-326

Lange, Ian and Bellas, Allen S. (2007) "The 1990 Clean Air Act and the Implicit Price of Sulfur in Coal," *The B.E. Journal of Economic Analysis & Policy*: 7(1) (Topics), Article 41.

Mancaa, Andrea, Nigel Ricea, Mark J. Sculphera and Andrew H. Briggs. 2005. “Assessing Generalisability by Location in Trial-based Cost-effectiveness Analysis: The Use of Multilevel Models” *Health Economics*. 14(), 471-485.

Moulton, Brent 1990. “An Illustration of a Pitfall in Estimating the Effects of Aggregate Variables on Micro Units.” *Review of Economics and Statistics*. 72(2):334-338

Neumann, Anne and Christan von Hirschhausen. 2006. “Long Term Contracts and Assest Specificity Revisited-Am Empirical Analysis of Producer-Importer Relations in the Natural Gas Industry”. MIT Center for Energy and Environmental Policy Working Paper 06-010.

Raudenbush, Stephen and Anthony Bryk. 2002. *Hierarchical Linear Models: Applications and Data Analysis Methods*. Sage Publications, London

Richman, Barak D. and Macher, Jeffrey. 2006. "Transaction Cost Economics: An Assessment of Empirical Research in the Social Sciences". Duke Law School Legal Studies Paper No. 115 Available at SSRN: http://ssrn.com/abstract=924192

Saussier, Stephane. 2000. “Transaction costs and contractual incompleteness: the case of Electricite de France.” *Journal of Economic Behavior & Organization*. 42(2), 189-206.

Scott, Anthony and Allen Shiell. 1997. “Analyzing the Effect of Competition on General Practitioners’ Behavior Using A Mulit-Level Modeling Framework*.” Health Economics*. 6(6), 577-588

Williamson, Oliver. 1985. *The Economic Institutions of Capitalism*. New York, NY The Free Press.

**Table I: Summary Statistics**

| Variable | Mean | S.D |
|---|---|---|
| Delivered Price, $ per ton | 45.99 | 15.30 |
| Btu, per pound | 11,603.00 | 1,541.00 |
| $SO_2$, tons per ton of coal | 0.02 | 0.02 |
| Ash, % by weight | 9.40 | 3.10 |
| Moisture, % by weight | 9.09 | 8.30 |
| Distance, miles | 449.00 | 528.00 |
| # of modes of transport | 0.31 | 0.46 |
| Contract Completeness, Ordinal | 2.10 | 1.22 |
| Duration, Years | 7.80 | 9.10 |
| $SO_2$ Upper Bound, tons per ton of coal | 0.03 | 0.02 |
| Post-1991 $SO_2$ Interaction | 0.01 | 0.02 |
| Ash Upper Bound, % by weight | 10.80 | 4.15 |
| Moisture Upper Bound, % by weight | 11.40 | 7.50 |
| Btu Lower Bound, per pound | 11,613.00 | 2,000.00 |
| Quantity Lower Bound, 500 tons | 0.75 | 1.80 |

**Table II: Expected Signs, by Level**

| Variables | Expected Sign |
|---|---|
| *Delivered Coal Variables (1st Stage)* | |
| Btu | + |
| Ash | - |
| Sulfur | - |
| Sulfur-Post 1990 | - |
| Moisture | - |
| # of Modes of Transport | + |
| Total Distance | + |
| Distance Squared | +/- |
| *Contract Parameters (2nd Stage)* | |
| Contract Completeness | +/- |
| Duration | +/- |
| $SO_2$ Upper Bound | - |
| Post-1991 $SO_2$ Interaction | - |
| Ash Upper Bound | - |
| Moisture Upper Bound | - |
| Btu Lower Bound | + |
| Quantity Lower Bound | +/- |

+/- = Ambiguous

## Table III: Delivered Sulfur Content & Allowable Sulfur Content Variation

Allowable Sulfur Content - Delivered Sulfur Content

| Sample | All Contracts | Pre-1991 | Post-1991 |
|---|---|---|---|
| Mean | 0.32 | 0.35 | 0.25 |
| Median | 0.19 | 0.21 | 0.14 |
| S.D. | 0.01 | 0.012 | 0.008 |

T-test (Mean Pre-1991 ≠ Mean Post-1991) = 6.6

Percentage Difference in Delivered and Allowable Attribute

Contract Fixed Effects Regression

| Attribute:<br>Variable | Sulphur<br>Coefficient | Ash<br>Coefficient | Moisture<br>Coefficient | Btu<br>Coefficient |
|---|---|---|---|---|
| Phase 1 Plant | -0.01 | 0.04** | 0.06** | 0.01 |
| | (0.02) | (0.01) | (0.02) | (0.01) |
| Post-1990 | 0.05* | 0.03 | -0.01 | -0.01 |
| | (0.02) | (0.02) | (0.05) | (0.01) |
| Phase 1 * Post 1990 | -0.03 | -0.01 | -0.03 | -0.01 |
| | (0.02) | (0.02) | (0.03) | (0.01) |

Region Dummies Not Shown for Brevity

Serially Correlation Corrected Standard Errors in Parenthesis

* indicates 5% signifiance, ** indicates 1% significance

**Table IV: First Level Results**

Dependent Variable: Price of Coal Per Ton in Dollars

Estimator: Fixed Effects Grouped by Contracts

| Variable | Coefficient | S.E. |
|---|---|---|
| Btu** | 2.57 | 0.07 |
| Ash** | -23.79 | 3.60 |
| $SO_2$** | -59.43 | 6.34 |
| $SO_2$-Post 1990** | -37.79 | 10.63 |
| Moisture** | -8.24 | 1.80 |
| # of Modes of Transport** | 1.80 | 0.10 |
| Total Distance** | 4.40 | 0.50 |
| Distance Squared | -1.9E-06 | 5.00E-07 |

Year & Mine District Dummies Included

Price of Distances in Mils

* indicates 5% signifiance, ** indicates 1% significance

**Table V: Second Level Results**

Dependent Variable: First Level Contract Dummies

| Variable | Coefficient | S.E. |
|---|---|---|
| Contract Completeness** | -0.27 | 0.07 |
| Duration*** | 0.11 | 0.01 |
| $SO_2$ Upper Bound | 5.29 | 5.45 |
| Post-1991 $SO_2$ Interaction** | -28.49 | 10.00 |
| Ash Upper Bound | 0.04 | 0.04 |
| Moisture Upper Bound** | -0.08 | 0.03 |
| Btu Lower Bound** | 0.00 | 0.00 |
| Quantity Lower Bound** | 0.19 | 0.08 |

* indicates 5% signifiance, ** indicates 1% significance