FINAL TECHNICAL REPORT

September 1, 1987 through August 31, 1988

Project Title: The Utility Market for Desulfurized Coal
ICC Project Number: 87/3.1B-2
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ABSTRACT

The overall objective of the proposed research project is to determine current and future clean fuel needs in potential markets for Illinois coals, including international markets. In particular, the aim is to determine and quantify coal requirements and consumers' willingness to pay for different quality coals, including coals desulfurized by several processes being developed by the Illinois Center for Research on Sulfur in Coals (CRSC). The approach draws on two detailed data sets covering midwestern and southern electric utility fuel preferences which were obtained during a previous year's CRSC project. These data show utilities' willingness to pay premia for various grades of desulfurized coal. Using these data, statistical estimates of demand for desulfurized coal are developed and used to determine the willingness to pay for particular attributes of coal, especially sulfur content. Related work analyzes transportation market for coal. This objective is to determine whether the development of desulfurized midwestern coal might be countered with lower freight rates for western coal, which would reduce any price advantage for desulfurized coal. To supplement the information about domestic markets, data have been gathered in this project on overseas steam-electric generating capacity. This data will be helpful in assessing the foreign market for desulfurized coal.
EXECUTIVE SUMMARY

Analyses of survey and market data suggest that a premium would be paid for Illinois coal with low sulfur but few other modifications. Depending on the data source and other circumstances, the estimates range from $1/ton for small changes in the quality of coal that already meets federal sulfur standards to around $24/ton for average quality Illinois coal compared to compliance coal from western fields. It seems clear that the premium will be larger for changes that bring sulfur down to compliance levels than for changes beyond compliance requirements.

Any estimates of sulfur premia must take into account other changes that might accompany desulfurization. One is the effect on other coal attributes. Reductions in volatile matter content, associated with hydropyrolyzation, were explored in this research. The results suggest a clear and strong offsetting effect on price. Thus, it appears that desulfurization that is accompanied by devolatilization will accomplish little in boosting the electric utility demand for Illinois. It could even lead to lesser willingness to pay for the treated coal. A second factor is the extent to which western coals could be made less expensive in response to the competition from desulfurized Illinois coal. Conditions in the western coal freight sector appear ripe for lowering transport rates. Lower freight rates would diminish the low sulfur premia that have been paid in the past and further reduce the market gains to be had with desulfurization.

Other avenues for expanding markets for Illinois coal, desulfurized or not, are in foreign markets. Nearly 700 foreign utilities have been identified. Data on fuel needs have been gathered and inventoried for over 250 foreign utilities.
OBJECTIVES

The overall objective of this project is to determine current and future clean fuel needs in potential markets for Illinois coals, including international markets. In particular, the aim is to determine and quantify coal requirements and consumer’s willingness to pay for different quality coals, including coals desulfurized by several processes being developed by the Illinois Center for Research on Sulfur in Coal (CRSC).

The overall objective divides into two specific goals, one relating to the domestic market and the other concerning the international market for desulfurized coals. For the domestic portion, the goal is to complete the quantification of demand for desulfurized coal begun in the previous year of this project. Econometric analysis of the available data reveals estimates of the premium that desulfurized products can command on the market along with estimates of the market value of other changes that may accompany desulfurization. The following tasks are associated with this objective: 1) analyze survey data collected during year one of the project to determine the value of changes in sulfur and volatile matter content; 2) analyze fuel purchase data obtained from the federal government in order to understand how coal prices generally and sulfur and ash penalties particularly are determined; 3) cross validate the two approaches with respect to sulfur; and 4) extend the sample (noted in task 1) if appropriate.

The international portion of the project aims to determine the fuel use and needs of steam-electric utilities outside the U.S. The aim is to construct a unit-level inventory of major generating stations overseas including information appropriate to fuel choices, such as applicable sulfur regulations. The sole task associated with this objective is to implement a survey of overseas electric utilities and develop an inventory of the resulting information.

INTRODUCTION AND BACKGROUND

Illinois possesses a third of the nation's bituminous coal reserves, more coal (in thermal content) than any other state--nearly eight billion tons. Coal is an extremely valuable resource for the state--its reserves translate into $2.4 trillion at current prices.

Illinois coal generally has good burning characteristics and heat content, but contains sulfur in amounts that make it hard for many generating units to meet air pollution standards. There is a substantial interest in lowering the sulfur content of Illinois coal so that more electric utilities (which buy the great majority of coal) can use it. However, this makes sense only if the value to utilities of desulfurized coal exceeds the cost of mining and sulfur removal.

Illinois' Center for Research on Sulfur in Coal (CRSC) has been concerned with the cost-quality tradeoff. In a CRSC project conducted in 1986
and 1987, the present researchers began efforts to quantify the tradeoffs between volatility, sulfur content, and price in the utility market for Illinois coal. The research took a two-pronged approach. One was to collect data on real fuel transactions, including price and quality information. Massive data sets for 15 years were obtained from the federal government. Because market conditions differ across the country, analysis of these data requires the use of advanced quantitative techniques. These techniques could not be developed and implemented in year one. Rather, the preliminary analyses were limited to market conditions within Illinois in order to minimize the locational issues. The plan in year two was to develop methods of dealing with the locational issues and analyze more general conditions in the domestic market. Specifically, we are interested in the formation of prices in the domestic steam coal market and how Illinois coal, especially desulfurized coal, fits into this process.

The other prong of the previous research project involved surveying utility fuel buyers on their preferences regarding desulfurized fuel. Detailed questionnaires were sent to 55 companies that own a total of 72 power plants that utilize Illinois coal. The utilities were presented a description of a hypothetical desulfurized coal and a price and asked how much of the desulfurized coal they would buy relative to their overall coal purchases. By systematically varying the coal specifications and prices in the sample, data suitable for estimating the demand for key coal attributes were generated. The attributes of most interest were sulfur and volatile matter content. Preliminary analyses were performed in year one, but more complete analyses were scheduled for year two.

The two prongs of this research agenda were needed because the transactions data do not include information on certain characteristics that are of vital interest with respect to CRSC-sponsored desulfurization processes, especially volatile matter content. Hydropyrolysis (charring) is one of the processes being investigated with CRSC sponsorship, but it entails removing volatile matter as well as sulfur. The effect on the end-product value is a major concern. The survey was developed in order to generate data that could be used to study this effect.

Despite their differences, each of the two prongs allows investigation of the market value of sulfur reduction. One goal of the research in the present year was to determine whether the two approaches yielded similar estimates of the value of lower sulfur content.

The domestic market is the setting for the preceding analyses. However, the international market is increasingly viewed as a potential growth market for Illinois coals. It would be very useful to begin identifying the foreign potential and the role that desulfurization might play in the overseas market. Thus, a new initiative undertaken in year two was to begin an inventory of foreign electric utilities and their fuel requirements. This element of the project was aimed primarily at describing the foreign market potential, not at substantive
analysis of that potential. It entails developing and keeping track of data about foreign utilities and their fuel needs.

The following sections deal in turn with the major tasks identified above. In each section, we first report on the domestic parts of the project beginning with the analysis of the survey and then moving to the analyses of market transactions data. The international market research is discussed after the domestic research.

EXPERIMENTAL PROCEDURES

A. Coal Quality Values from Survey Data

This effort used econometric techniques to estimate electric utilities' willingness to pay for coal quality characteristics as indicated in responses to the Marketing Survey for Desulfurized Coal (see, Kolstad et al., 1987).

Coal quality is an important factor in coal procurement decisions. The modest decision rule of minimizing delivered cents per million Btu has given way to analysis of coal quality characteristics in engineering models of operating systems to assess a prospective coal's impact on the heat rate, capacity, availability, maintenance and emissions of a coal-fired electric power generating station. Procurement practices typically specify the levels of a number of key coal quality characteristics with known correlations to the operating performance of the plant. Adjustments for deviations from design characteristics are made by coal blending, capacity derating and equipment retrofit.

We collected unit level data on the coal quality specifications used by plants in the Marketing Survey sample. The list of coal quality specifications is given in Figure 1. The survey requested boundary specifications for a wide range of coal quality characteristics that affect materials handling, combustion and emissions for coal furnaces. The data were entered into a hierarchical microcomputer database.

We stratified the data by various groups of specifications and analyzed variations within and across groups using one- and two-way analysis of variance. We also analyzed the distribution of responses using graphical data analysis techniques and computed conditional probabilities of specific events using standard methods. The data and procedures are fully described in Woock (1988).

The next step was to apply econometric techniques to analyze the substantive content of the survey responses. This was based on an economic model of the technology of coal-fired electricity generation. In general, technology is modelled as a function that takes one or more inputs and transforms them into the desired output. In this case, we choose a short-run representation of technology that transforms inputs of coal quality characteristics (thermal, sulfur and volatiles content) in fixed proportions into megawatthours of electricity
Figure 1.

I. INFORMATION ABOUT REFERENCE GENERATING SYSTEM

1. For each UNIT of the REFERENCE GENERATING STATION please indicate your boundary (maximum or minimum) procurement specification for the following coal characteristics.

<table>
<thead>
<tr>
<th>(a) Minimum BTU/lb (moisture free)</th>
<th>Unit 1</th>
<th>Unit 2</th>
<th>Unit 3</th>
<th>Unit 4</th>
<th>Unit 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>(b) Maximum Sulfur Content (as received, measured lb/MMBtu)</td>
<td></td>
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<tr>
<td>(c) Maximum Moisture Content (as received) (%)</td>
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<tr>
<td>(d) Minimum Volatile Matter (by weight, moisture free)</td>
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<td></td>
<td></td>
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<tr>
<td>(e) Maximum Chlорine (by weight, moisture free)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>(f) Size Dispersion (Maximum 1 &lt; 1/2&quot;)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>(g) Minimum Hargrove Grindability Index</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>(h) Maximum Ash Content (by weight, moisture free)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(i) Minimum T250 (ash fusion)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (°F)</td>
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<tr>
<td>(j) Maximum T250 (Ash fusion)</td>
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<td>Temperature (°F)</td>
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<tr>
<td>(k) Minimum Ash Resistivity (ohms-cm)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(l) Maximum Base/Acid Ratio of Ash</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(m) Maximum Fouling Index Computed Using</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Na2O + K2O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n) Maximum Na2O as % of Ash Mineral Analysis</td>
<td></td>
<td></td>
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<tr>
<td>(o) Maximum % Alkaline as Na2O, Dry Basis</td>
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<tr>
<td>(p) Maximum Slinging Index</td>
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produced by generating stations. Duality theory allows the model of
technology to be cast in the form of a unit cost function. We represented
the technology as a unit cost function, \( c = F(W,Z) \) where \( c \) is the cost
of thermal input per megawatthour; \( W \) is a vector of prices of the
"reference" fuel (the plants current fuel) and desulfurized fuel in
cents/MMBtu; and \( Z \) is a vector listing the sulfur and volatile matter
content of both fuels in lbs/MMBtu.

We are specifically interested in measuring the willingness-to-buy
desulfurized fuels. The demand equation for the productive factor,
the desulfurized coal, can be derived by taking the partial derivative
of the unit cost function with respect to the price of the desulfurized
coal. This gives \( \partial c / \partial w_D = q_D = f(W,Z) \) where \( q_D \) is the quantity of
desulfurized product the firm is willing-to-buy in MMBtu; \( w_D \) is the
price of the desulfurized product; and \( W \) and \( Z \) are as before.

Having established an economic model, we needed a suitable functional
form with which to estimate the model's parameters using statistical
regression methods. The Generalized Leontief Cost Function (GLCF)
(Diewert and Wales, 1986) was chosen. This is one of several "flexible"
forms that have desirable econometric properties. A complete exposition
of this model is given in Braden et al. (1988).

Concerning statistical procedures, we estimated first the parameters
of an unrestricted GLCF using Ordinary Least Squares (OLS). This
model contains a large number of coefficients relative to sample
observations which severely hampers hypothesis testing. To contend
with this problem, we estimated a restricted version that deleted
higher order terms. Ordinary Least Squares were also used to estimate
parameter values of the restricted model. In addition to the degrees
of freedom problem, there is substantial multicollinearity in the data
being analyzed along with extreme outliers and influential observations.
Under these circumstances, robust regression methods are appropriate
(Koenker, 1982). So, in addition to the OLS models, robust regression
estimators were applied to the restricted model. A complete account
appears in Braden et al. (1988).

The next step utilized the respective parameter estimates to compute
the slope of the factor demand relationship and the elasticity of
demand with respect to the price and fuel quality. Then we calculate
the locus of relative price ratios at which demand is zero at various
levels of sulfur and volatile matter content. Finally, we totally
differentiate the factor demand equation and calculate elasticities of
desulfurized fuel price with respect to the sulfur and volatility
levels of the fuels. These elasticities are used to compute sulfur
and volatility premia for the desulfurized fuel.

B. Analysis of Coal Market Transactions Data

This area of research was approached in two ways. One involves resolving
spatial issues in coal markets in order to apply "hedonic" techniques
of price disaggregation. This allows discovery of the premia and penalties for coal attribute changes as revealed in the market place. The second approach consists of a detailed analysis of price formation in markets for low sulfur coal. This will provide insight into the market responses to competition from desulfurized Illinois coal.

1. Data. Before discussing the analyses, it will be useful to describe the data. Substantial effort was exerted in this project to put massive but obscure federal coal transactions data into a usable condition and provide easy accessibility to the data. This was undertaken to facilitate the quantitative work required to analyze the data.

Utility fuel transactions information is supplied to the federal government by electric generating utilities on Federal Energy Regulatory Commission (FERC) Form 423, "Monthly Report of Cost and Quality of Fuels for Electric Plants." (Energy Information Administration, 1987). All plants with a fossil-fuel steam-electric installed nameplate capacity of at least 50 megawatts are required to submit the form. For each transaction, the form records the quantity of coal purchased, its sulfur, ash, and heat content, the purchase price, the type of purchase, the type of mine, and the identification of the plant and the mine of origin. A typical year of transactions involves 1700 different mines and 380 different generating stations, yielding an average of 25,974 transactions for a given year. These data are made available to the public in the form of data tapes of the complete transaction set as well as published reports of aggregated quantities.

The transactions data for the period from July 1972 through December 1986 were taken from magnetic tape supplied by the EIA and installed on an IBM PS 2/80 microcomputer using the ORACLE relational database management program. The number of transactions occurring in a year ranges from 13,562 to 32,617 and totals 376,629 for the 15 years, requiring 27 megabytes of hard disk storage. Once represented within ORACLE, answers to a wide range of questions relating to the value and quality of coal are easily obtained through the use of a standardized interactive database language known as the Structured Query Language, or SQL. Designed to be easy to write and read, the SQL command language allows the user to create data tables, store and change information, and retrieve information in the desired form, performing calculations on it and combining it in new ways.

To extend the usefulness of the purchase transactions data in studying the role of mine location and transportation costs on coal values, latitude and longitude coordinate data have been included in the database for both generating plants and mines. These data were extracted from U.S. Energy Information Administration (EIA) Form 767.

2. Analysis of Transactions. We return now to the analysis of the transactions data. Measuring the response of price to a particular characteristic of coal such as sulfur content is an ideal application for the economic technique known as hedonics. The hedonic technique is used to estimate the implicit prices for characteristics of a good,
using these estimates to infer the value of a change in those characteristics (Rosen 1974). Its applicability to coal quality demand is discussed by Kolstad and Braden (1987). The demand function for a particular characteristic is obtained using a two step procedure in which the implicit price is estimated from the hedonic price equation, and then regressed on observed consumer attributes. Studies of the housing market pioneered the hedonic approach, in an attempt to infer the value of characteristics such as number of rooms, neighborhood, and pollution level.

The task of measuring the price premium for low sulfur coal divides into three parts: 1) developing a coal price model that captures the complexity of the market; 2) adjusting the model to address the dependence in price that occurs due to spatial proximity; and 3) performing the statistical estimation of the model.

A key distinguishing property of the coal market is that coal prices are space-dependent. A model that considers only quality characteristics as explanatory variables ignores the role of two additional spatial factors. First, the geographical origin of the coal partially determines the price that the coal will command. Second, the mine-to-plant distance influences transaction price, since recorded prices are for delivered coal and include all transportation costs. Incorporating these additional spatial influences yields the following price relationship:

\[ P = f(S, A, M, D, u) \]  

(1)

where \( P \) is the transaction price ($/million Btu); \( S \) is sulfur content (lbs/million Btu); \( A \) is ash content (lbs/million Btu); \( M \) is the coordinate location of the seller (coal mine); \( D \) is the mine-to-plant distance; and \( u \) is a statistical error term.

The choice of functional form is constrained by recognizing that coal quality characteristics can be "repackaged." For example, one ton of coal with 1/2% sulfur may be mixed with one ton of 1% sulfur coal to yield two tons of coal with 3/4% sulfur. This ability to repackage implies that the hedonic price function is convex in sulfur and ash content. The functional form proposed to accommodate this convexity is the quadratic Box-Cox flexible functional form. Using this procedure, the functional form is selected statistically by positing a general quadratic form and employing the data to locate the parameter values that provide the best fit. (Halvorsen and Pollakowski 1981).

Another issue that must be confronted in an analysis of spatial data is the dependent relationship that exists between price regimes at spatially adjacent markets. Neighboring generating plants tend to exhibit similar transaction price patterns, while distant plants follow essentially independent schemes. Failure to address this dependence introduces imprecision in the price premium estimates. Such dependence suggests a particular form for the error structure of the model, whereby errors are weighted by an appropriate function of
distance between plants (Cliff and Ord 1981). Statistical analysis of
the transactions data confirmed that spatial autocorrelation persists
in the data for plant-to-plant distances up to 300 miles.

The resulting coal price model takes the form

\[ P = Xb + (I-W)e \]  \hspace{1cm} (2)

where \( P \) is a vector of \( N \) observed transaction prices, \( X \) is the matrix
of characteristics and their second order combinations, \( b \) is the
vector of coefficients to be estimated, \( I \) is the identity matrix, and
\( W \) is the error weighting matrix, the typical element of which is the
inverse of the distance between plant \( i \) and plant \( j \). Using the Federal
Energy Regulatory Commission's (FERC) form 423 coal transactions data
that includes the delivered purchase price, sulfur content, ash content,
heat content, and locations of the purchaser and seller of a given
transacted quantity, estimation is performed statistically by finding
the value of \( b \) which maximizes the log likelihood function of equation
(2).

The estimation procedure involves performing a search on the three
parameters to maximize the likelihood function, and then solving for
the coefficient estimates directly. Employing standard statistical
packages for the first step is complicated by the unconventional error
structure and by the size of the square weighting matrix \( W \). To estimate
the price equation for the transactions at Illinois plants in 1983
involves only 158 observations, but the resulting \( W \) matrix exceeds the
microcomputer memory limitations of 64K. It is necessary to utilize a
nonlinear programming package on a mainframe computer to obtain an
efficient search.

3. Price Formation for Low Sulfur Coal. This research focuses on the
formation of delivered prices for low sulfur coal. Since transportation
costs make up the largest proportion of the delivered price of low
sulfur coal in the Midwest, we have investigated the effects of carrier
behavior on price formation. We want to determine whether the delivered
price differentials between imported low sulfur and indigenous high
sulfur coal represents abnormal rents to the carriers that can be
dissipated by increased competition. If the price differentials
largely represent abnormal rents to haulers, the prospects are dimmer
for the market viability of desulfurization. If, on the other hand, the
price differentials represent differences in the costs of providing
low sulfur fuel onsite in the Midwest, then those processes which
increase costs by less than the price differential may be economically
viable.

The market premium for desulfurized Illinois coal depends on the
delivered prices in Illinois steam coal markets for alternative low
sulfur coals. The existence of a price differential in the Midwestern
market is clear. Figure 2 shows average delivered prices for low and
high sulfur steam coals in the East North Central census region. This
region includes Ohio, Michigan, Indiana, Illinois and Wisconsin. The
Delivered Prices to Midwestern Plants for Steam Coal by Sulfur Content (constant 1982 dollars)

AVERAGE PRICE ($/MMBtu)

YEAR


low sulfur coal (under 0.6 lb/MMBtu)
high sulfur coal (over 1.5 lb/MMBtu)
price differential is significant, ranging from 50 to 100 cents per
MMBtu over the past decade. The source of the differential is the
subject of our research.

In order to investigate these issues, we developed a model of spatial
transportation pricing for bulk commodities. The model produces
spatial pricing policies that preserve quantity and distance tapers in
transportation prices. We then embedded the spatial transportation
price formation process in a model of distant competition between
small numbers of bulk commodity carriers. These models lead to behavioral
predictions and a measure of the market conduct of rail carriers in
coal transportation. With these models, it is possible to test the
behavioral hypotheses concerning price formation.

The model allows us to distinguish between two types of carrier behavior,
quantity-setting (contract transactions) and price-setting (spot
transactions). The model predicts price discrimination against nearer
customers in more competitive markets, and price discrimination against
more distant customers in monopolistic markets. The model shows
quantity-setting firms, when competitively balanced, tend to charge
uniform transportation prices in markets where they compete. When
competing carriers are dissimilar in their conduct, the less competitive
firm tends to practice a form of limit pricing. Price-setting firms
tend to be "less discriminatory" than quantity-setting firms.

In addition to the market model of coal transportation, we have inves-
tigated a game theoretic approach. There have been suggestions in the
literature that the railroads have been taking advantage of the favorable
market position of western low sulfur coal by charging unwarranted
freight rates. If this is the case, a substantial threat to the
position of western coal, in the form of desulfurized midwestern coal,
might simply be absorbed by lower railroad rents. That is, the development
of desulfurized midwestern coal at favorable prices might lead railroads
to lower their freight rates to reduce delivered prices for western
products. This would undercut the investment in desulfurization by
lowering the market premium for low sulfur coal.

The possibility that railroads charge excessive freight rates depends
on the existence of market power, the power to control prices. Hence,
our approach to this problem is a game theoretic entry deterring model
in order to measure the extent of market power in the freight market
for western coal. This effort began late in the project and progressed
to the point of identifying an entry-deterring game among duopolists as
appropriate to western coal circumstances. The game occurs in two
stages: capacity precommitment, then price setting under increasing
returns to scale. The first stage is relatively straight-forward.
The second is complicated by the presence of increasing returns.
Under this circumstance, it is not clear which pricing strategies make
sense. We are reviewing pertinent literature on this point. Once the
model is developed, we shall then develop testable hypotheses the
underlying structure of the market. Empirical tests of these hypotheses
will allow us to infer how western coal haulers will respond to competition from low sulfur coal produced in the Midwest.

C. The International Market for Utility Coal

The primary function of the foreign electric utilities database is to develop and maintain a unit-level inventory of major foreign sources of demand for coal. The database structure will include characteristics appropriate to fuel choice, such as applicable sulfur emission regulation and general operating statistics of plants and boilers.

The initial international power generation database was constructed following the guidelines of three tasks. These tasks included:

1. Collection of an address list of ministries of energy from which a request for addresses of power generation companies in their country was made.

2. Compilation of an address list of potential power generation companies from which a request for 1986 statistical information was made.

3. Organization of the data received by respondents into the database.

The first task required contacting foreign embassies in the United States for information of power generation in their country. As a supplementary reference, the Europa series\(^1\) was utilized to complete the list names and addresses energy ministries. A total of 105 letters were mailed to energy ministries requesting a list of power generation facilities from their country. Of these, 42 responses were received, a 40 percent response rate.

From these responses, and the Electric Utility World Directory 1972-1973 as a supplement, a list of potential power generation companies was compiled during the second task. This address list of potential generation companies was then mailed a request for their 1986 operation statistics. A total of 658 requests were mailed to utilities from 112 countries.

The final task of Phase I required keeping record of the responses received and organizing the operational statistics. A format consisting

\(^1\)This series includes:

of three tables was determined to best suit data storage needs. The first of these tables will provide a list of company names, addresses, contacts and general characteristics of electricity demand and supply including total generation in kWh, sales (final and resale) in kWh, generation capacity by total MW and by fuel (coal, petroleum, gas, LNG, uranium, water and others) and type (steam, internal combustion, gas turbine, geothermal, hydo-electric, nuclear, and others, and the total number of plants.\textsuperscript{2}

The second table provides general operating statistics on the plants of each power generation company accounted for in the database. Specifically, this table will include the plant's name, location, number of units, nameplate capacity in MW and fuel type (coal, lignite, bituminous, petroleum, natural gas, LNG, water, uranium, other). In addition, this table will provide supplementary comments including notes about plants under construction and shared facilities.

The third table supports specific unit-level data of each generating plant reported. Specifically, for each plant a capacity factor, equivalent availability, heat rate, maker of generator, year of first operation, year of expected retirement, maximum sulfur content, ash treatment type (wet or dry bottom), monthly net electrical generation in 1986, boiler information monthly and annual fuel consumption, annual average fuel quality, and environmental regulations standard (SO\textsubscript{2}, CO, NO\textsubscript{X} and particulates) will be recorded. This table will be key in providing users a better understanding of the markets for desulfurized, as well as untreated, Illinois coal.

The database structure is delineated in Figure 3. It is constructed using Oracle version 5.1 and will be completed in two phases. The first phase will result in the initial international power generation database and will consist of the first two tables, while the second phase will verify and update the data contained in these two tables and request unit-specific data for the third table.

The following discussion describes the procedures planned for completion of Phase II of the international power generation database. As indicated above, the primary purpose of Phase II is provide specific unit operating characteristics including fuel quality and environmental restrictions. This Phase will require two specific tasks: 1) development of a survey instrument; and 2) updating and augmenting the initial database.

The survey instrument to be developed under task one will report all of the data recorded in the initial database for verification purposes and request additional unit-level statistics. As described earlier,

\textsuperscript{2}The table also includes a record of the dates the data represent, documentation of the sources received from survey respondents and any other relevant comments about the power generation company.
Figure 3: Database Organization

INTERNATIONAL UNIT-LEVEL ELECTRIC UTILITY DATABASE

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>TABLE 2</th>
<th>TABLE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Generators</td>
<td>Plant Data</td>
<td>Unit-level Data</td>
</tr>
</tbody>
</table>

INITIAL INTERNATIONAL ELECTRIC UTILITY DATABASE
these statistics include individual operation information such as capacity factor, equivalent availability, heat rate, maker of generator, year of first operation, year of expected retirement, monthly net electrical generation, monthly and annual fuel consumption, annual average fuel quality and environmental regulations standard. This survey will only be sent to those utilities which were identified as electric utility generating companies in the initial database.

Once the initial database is updated and augmented with the Phase II responses, the international electric utility database will be suitable for users interested in international markets for Illinois coal. Specifically, the database will provide users with general information on the fuel requirements, generation capacity, operating characteristics of coal-fired plants and units, demand and supply relationships, and applicable environmental regulations.

RESULTS AND DISCUSSION

A. Coal Quality Values from Survey Data

The analyses of responses to the survey design identified no obvious defects or sources of bias in the survey design. We did find that most of the across sample variation in coal quality specifications was explained by stratification of the sample into "wet" and "dry" bottomed furnaces. This stratification was explicitly recognized in the construction of the survey instrument. We also found that the plants least "concerned" about volatility levels were those least "concerned" about compliance sulfur specifications. We discovered that plants willing to accept volatility levels below 30% had a sulfur requirement 25% above the sample average sulfur specification and 370% greater than the sample average sulfur compliance specification. Further we calculated that the conditional probability that a sulfur compliance unit would accept a low volatile (<25%) product is .02. The conditional probability that a sulfur compliance unit would accept a product with conventional levels of volatile matter content is .44.

The substantive analysis of survey responses is described in detail by Braden et al. (1988). In summary, the analysis revealed that a small decrease in the sulfur content of the desulfurized fuel induces a proportionately larger increase in demand for the desulfurized product, e.g. a 1% decrease in sulfur induces a 3% increase in demand. However a small increase in the reference fuel volatility produces a proportionately larger decrease in demand for the desulfurized fuel, e.g. a 1% increase in the volatile matter content of the plants' current burn implies a 10% drop in demand for the desulfurized fuel. At sample mean quality levels for the data, a decrease in the sulfur content of the offered fuel from .785 to .707 lbs/MMBtu increases the willingness-to-pay from $36.99/T to $37.91/T; a desulfurization premium of about $1/T. A decrease in volatile matter content from 17.8 to 16.02 lbs/MMBtu reduces the willingness-to-pay from $36.99/T to $36.01/T; a devolatilization penalty of about $1/T. Thus for a near-compliance desulfurized
coal product with conventional levels of volatile matter, the devolatilization penalty offsets the desulfurization premium.

Figure 4 plots the locus of price ratios at which demand for the desulfurized product becomes zero for given levels of sulfur and volatiles content. That Figure shows that high volatile matter levels induce demand at lower relative prices than low volatile levels throughout the range of sulfur content for the desulfurized fuels. A high price ratio indicates the price advantage rests with the desulfurized coal. Note that it is only at high levels of volatile matter and compliance sulfur that there is any non-zero demand for the desulfurized coal at a price greater that of the reference fuel.

In conclusion, based upon responses to the survey instrument, low volatile matter desulfurized products will have difficulty finding general acceptance in the steam coal market. Plants that are willing to take low volatile products do not specify low sulfur fuels. For plants that specify low sulfur fuels, their minimum volatile matter requirement is almost uniformly in the conventional range.

Since statistical results are weak, these results must be interpreted with caution. In general, these results indicate that caution must be exercised in market applications of clean coal technologies. Desulfurization techniques that change other characteristics of the coal, such as volatility, confront the very real possibility that the premium associated with reduced sulfur is offset by penalties associated with the degradation of other characteristics.

Utilities in the sample have a taste for high volatility as well as a taste for low sulfur. The plants in the sample are relatively unwilling to buy low volatile products, even if the sulfur content is reduced.

B. Analysis of Coal Market Transactions Data

1. Data. The rewards of establishing the database system to manage the massive coal transactions data sets are best understood by illustrating the ease with which complicated questions about coal prices and quality may be answered by a single query. Table 1 presents some examples of the system’s power and speed. The wait times noted are based on a microcomputer clock speed of 20 megahertz. The first two example queries employ a user’s own language pattern. The quick response to the final example clearly verifies the efficiency gains that are enjoyed by using the computerized database for more complex tasks. To assemble a similar table by hand would increase the time commitment by at least tenfold. This unique tool will play an invaluable role in future studies of coal quality.

2. Analysis of Transactions. Analyses of the fuel transactions data reveal that low sulfur coal has commanded a higher price from Illinois generating plants throughout the 1970’s and 1980’s. As Figure 5 indicates, the average price of coal purchased in Illinois meeting the standard of 0.6 lb/MMBtu of sulfur has been at least $0.40 more costly
Figure 4.
Table 1. Illustration of Database Capabilities

Question #1: What states purchased Illinois coal in 1986?
ORACLE Query: SELECT PLSTATE FROM YR86 WHERE COALORIGIN = IL
Response: AL FL GA IA IL IN KS KY MN MS TN
Wait Time: 31 sec.

Question #2: What was the average price paid for high sulfur coal (> 2.5%) and low sulfur coal (<1%) in 1982?
ORACLE Query: SELECT AVG(COST) FROM YR82 WHERE SULFUR > 2.5
SELECT AVG(COST) FROM YR82 WHERE SULFUR < 1
Response: 1.44 $/MMBtu, 2.66 $/MMBtu
Wait Time: 1 minute, 56 sec.

Question #3: What were the average sulfur and ash levels of coal purchased by Illinois plants on the spot market in October 1983?
ORACLE Query:
SELECT CORDANT.PLANTNAME, SOURCENAME MINENAME,
   COST/100., SULFUR*100./BTU, ASH*100./BTU
FROM YR83,SOURCE,CORDANT
WHERE YR83.CONTYPE=7
AND YR83.PLANTNO = CORDANT.PLANTNO
AND YR83.SOURCE = SOURCE.CODE
AND YR83.PLSTATE = IL
AND YR83.MONTH = '10'
Response:

<table>
<thead>
<tr>
<th>PLANTNAME</th>
<th>SUPPLIER</th>
<th>COST</th>
<th>SULFUR</th>
<th>ASH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>cents/</td>
<td>pounds</td>
<td>pounds/</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MMBtu</td>
<td>MMBtu</td>
<td>MMBtu</td>
</tr>
<tr>
<td>Grand Tower</td>
<td>AMAX COAL CO</td>
<td>109.2</td>
<td>2.39</td>
<td>8.88</td>
</tr>
<tr>
<td>Havana</td>
<td>ENERGY FUEL CORP</td>
<td>271.4</td>
<td>.49</td>
<td>8.67</td>
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<tr>
<td>Havana</td>
<td>ENERGY FUEL CORP</td>
<td>273.3</td>
<td>.49</td>
<td>8.67</td>
</tr>
<tr>
<td>Grand Tower</td>
<td>KENELLIIS ENERGIES</td>
<td>111.7</td>
<td>2.72</td>
<td>16.04</td>
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<tr>
<td>Marion</td>
<td>WESTERN FUEL COAL</td>
<td>84.7</td>
<td>2.66</td>
<td>14.30</td>
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<tr>
<td>Marion</td>
<td>PEABODY COAL CO</td>
<td>48.4</td>
<td>3.42</td>
<td>31.39</td>
</tr>
<tr>
<td>Hennepin</td>
<td>OMNI #4</td>
<td>118.26</td>
<td>2.33</td>
<td>13.30</td>
</tr>
<tr>
<td>Vermilion</td>
<td>GREAT LAKES</td>
<td>109.73</td>
<td>2.54</td>
<td>11.78</td>
</tr>
<tr>
<td>Joppa</td>
<td>SOLAR SOURCES INC</td>
<td>145.2</td>
<td>1.51</td>
<td>7.75</td>
</tr>
<tr>
<td>Hutsonville</td>
<td>SOUTHARD</td>
<td>125.9</td>
<td>2.10</td>
<td>8.51</td>
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<tr>
<td>Hennepin</td>
<td>KOCH CARBON</td>
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<td>3.33</td>
<td>.33</td>
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<tr>
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<td>BITTLE CARBON</td>
<td>54.3</td>
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<td>Grand Tower</td>
<td>FREEMAN UNITED COAL</td>
<td>126.3</td>
<td>2.76</td>
<td>9.44</td>
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<tr>
<td>Joppa</td>
<td>PEABODY COAL CO</td>
<td>146.2</td>
<td>1.19</td>
<td>6.72</td>
</tr>
<tr>
<td>Location</td>
<td>Company</td>
<td>Value 1</td>
<td>Value 2</td>
<td>Value 3</td>
</tr>
<tr>
<td>----------</td>
<td>--------------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Marion</td>
<td>AMERICA #7</td>
<td>51.6</td>
<td>2.06</td>
<td>30.79</td>
</tr>
<tr>
<td>Marion</td>
<td>PEACOCK CARBON</td>
<td>43.6</td>
<td>2.82</td>
<td>37.39</td>
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<tr>
<td>Marion</td>
<td>E &amp; B CARBON</td>
<td>63.8</td>
<td>3.40</td>
<td>21.14</td>
</tr>
<tr>
<td>Marion</td>
<td>TEK BAR</td>
<td>71.6</td>
<td>2.73</td>
<td>11.31</td>
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<tr>
<td>Vermilion</td>
<td>LEE</td>
<td>112.26</td>
<td>1.57</td>
<td>8.66</td>
</tr>
<tr>
<td>Vermilion</td>
<td>J H &amp; L COAL CO</td>
<td>119.95</td>
<td>2.43</td>
<td>11.07</td>
</tr>
<tr>
<td>Vermilion</td>
<td>FOSSIL FUELS</td>
<td>116.37</td>
<td>1.62</td>
<td>9.79</td>
</tr>
</tbody>
</table>

21 records selected.
Price Premium Paid by Illinois Plants for Low Sulfur Coal
(in constant 1982 dollars)

Average Price ($/10^6 Btu)

- low sulfur coal (under 0.6 lb/MMBtu)
- high sulfur coal (over 2.5%)

Year

Figure 5.
per million Btu than high sulfur coal since 1972. The premium has exceeded $0.75 since 1979, reaching a peak of $1.40 in 1982. Desulfurization processes that meet this cost target could offer Illinois coal producers an expanded market for their product.

Further research challenges include fully characterizing the demand for low sulfur coal. This may be achieved by utilizing generating plant characteristics supplied by the EIA Form 767 such as air emission standards, desulfurization equipment and boiler/generator design to measure demand for low sulfur coal. The effect of the various demand characteristics on the premium for low sulfur coal may then be determined by using the implicit valuations on sulfur and ash estimated from the hedonic price equation to estimate a demand function.

3. **Price Formation for Low Sulfur Coal.** Econometric analysis of the price formation model is in progress at the time of this report. Work is underway on the specification of strategies for the entry deterrence game.

C. **The International Market for Utility Coal**

As of August 22, 1988, 256 responses had been received from electric utilities in 67 different countries. This is a 38 percent response rate in terms of the number of surveys mailed. While the statistics for the initial database are being collected and organized, as of yet only half of the data has been entered into the database.

In its initial form the international electric utility database is useful for generating reports and queries of electric power generators overseas. For instance, a very useful report which can be constructed from the database is a list of all generating companies grouped by countries. This type of report provides contract names, addresses, and a summary of generation statistics. An example of the type of information supported by the database for such a report is presented in Table 2. Other useful reports which can be constructed from the initial database include a breakdown of electric power generating companies by size, fuel type, and plants which use coal among others. The database will also be instrumental for designing the survey instrument which will be used to obtain the unit-level data and verifying the data in the initial database. In conclusion, once the international electric utility database is in its final form it will provide the groundwork for future research on current and future clean coal needs in potential international markets for Illinois coals.

In its current form, the international database is useful for providing general statistical information about electric power generation overseas. However, once in final form, the database will be extremely useful for determining fuel requirements, generation capacity, operating characteristics of foreign coal-fired plants and units, demand and supply relationships, and applicable environmental regulations.
Table 2. Example of Information in the International Electric Utilities Data System

Denmark

<table>
<thead>
<tr>
<th>Company:</th>
<th>Randers Kommune</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact:</td>
<td>K.E. Hansen</td>
</tr>
<tr>
<td>Mailing address:</td>
<td>Agerskellet 7, 8900 Randers, Denmark</td>
</tr>
<tr>
<td>Total generation:</td>
<td>217,000,000 kWh</td>
</tr>
<tr>
<td>Total capacity:</td>
<td>48 MW</td>
</tr>
<tr>
<td>Number of plants:</td>
<td>2</td>
</tr>
</tbody>
</table>
The procedures necessary for completing Phase II are outlined above. In the meantime, the database needs to be reconciled before a survey instrument can be developed and power generation companies can be resurveyed.

CONCLUSIONS AND RECOMMENDATIONS

Survey data gathered from electric utilities in the market area for Illinois coal reveal that a 1% reduction in the sulfur content of Illinois coal could prompt up to a 3% growth in demand. The premium for sulfur reduction is in the neighborhood of $1/ton for a 10% reduction in sulfur content below the sample mean of 0.79 lb/MMBtu. However, this premium will be offset by changes that diminish the burning and handling characteristics of coal. A key characteristic is volatility. The survey responses imply a probability of 0.02 that a generating unit already in compliance with sulfur regulations would accept a desulfurized product with low volatility. The sample probability of acceptance for a conventional level of volatility is 0.44. The data imply that a 10% reduction in volatile matter below the already low level of 17.8 lbs/MMBtu will result in a price penalty of about $1/ton. It must be stressed that the statistical support for the survey results is weak due to the sample's small size.

Data on actual purchases of sulfur by electric utilities suggest somewhat different conclusions for the desulfurization premium. Comparing prices paid in Illinois per million Btu of low and high sulfur coals suggests a premium of $.75-$1.00. This translates to $18-$24 per ton of Illinois coal. These estimates are much above the survey-based estimates. One reason is the disparate treatment of volatile matter content. The survey results are based on a mean volatile matter content of about 25% while the actual transactions involve coals with volatile contents for the most part exceeding 35%. Since utilities will pay much less for low volatility fuels, the premium for sulfur reductions in such coals should be correspondingly low. A second explanation is that the survey results are based on small changes in the sulfur content of coal already in compliance with federal standards while the transaction comparisons are made between compliance and non-compliance coals with much greater differences in sulfur content. A third explanation is that the transactions data account for Illinois alone while utilities in other states were represented in the survey sample. The average price premium for low sulfur coal appears to be higher in Illinois than in nearby states and this could inflate the differential in the actual transactions.

The results for sulfur premia must be considered in the context of the overall market for low sulfur coal. Mining costs in western low sulfur coal basins are significantly lower than in midwestern and eastern fields. Transportation costs to midwestern markets are higher, but preliminary analyses suggest that the current freight rates yield above competitive profits to the haulers. The observed price differentials for low sulfur coal are composed in part of rents resulting from a
lack of competition in the transportation sector and the demand created by environmental regulations. Competition from desulfurized midwestern coal could be countered in part by lowering western coal freight rates. The price premia observed in market or survey data for low sulfur content may overstate the premia that would be sustainable if those freight rates were reduced.

The issue of the domestic market value of desulfurized coal raises complex questions of price formation in coal markets. In addition to estimates of the premium under historical conditions, this project has provided initial insight into the price formation process and compiled extremely useful data on which further analyses could be based.

In addition to the domestic market, foreign markets may open increasingly to Illinois coal. This project began an extensive process of gathering data about the fuel needs of electric utilities in other countries. Nearly 700 foreign utilities were identified and asked to supply information about their fuels, generating capacity, and other pertinent information. Over 250 responses were received. Salient data have been inventoried in a database management system. With further development and oversight, this database could be extremely useful in supporting efforts to expand international markets for Illinois coal.

Flowing from our research are the following recommendations:

1. Additional work is needed to model, quantify, and analyze market forces that shape prices for Illinois coal and values for its sulfur content and other attributes.

2. Coal transactions data gathered in this research represent an extremely valuable resource for analyzing economic questions confronting Illinois coal. Maintaining the useability of these data should be a high priority.

3. Data gathered in this project on foreign demand for coal could be extremely useful in assessing foreign markets for Illinois coal. Further development and maintenance of this database will be required if it is to fulfill its potential.
REFERENCES


REPORTS AND MANUSCRIPTS ISSUED IN YEAR TWO


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3Does not include technical reports to the Center for Research on Sulfur in Coal.