Contract Duration and Relationship-Specific Investments: Empirical Evidence from Coal Markets

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This paper examines the importance of specific relationship investments in determining the duration of coal contracts negotiated between coal suppliers and electric utilities. Data for 277 coal contracts are used to perform the analysis. The results provide strong support for the view that buyers and sellers make longer commitments to the terms of future trade at the contract execution stage, and rely less on repeated bargaining, when relationship-specific investments are more important.

This paper seeks to test empirically the importance of relationship-specific investments in determining the duration of coal contracts negotiated between coal suppliers and electric utilities.[1] The analysis makes use of information for a large sample of coal contracts that were in force in 1979. It takes as a starting point Oliver Williamson's 1983 definitions and categorization of relationship-specific investments and applies them to the characteristics of coal market transactions. It also follows Williamson and Benjamin Klein, Robert Crawford, and Armen Alchian (1978) and assumes that risk aversion is not an important factor determining the structure of vertical relationships between coal suppliers and electric utilities.[2]

Coal market transactions are interesting to focus on because there is considerable variation in the duration and structure of vertical relationships between buyers and sellers. I observe spot market transactions, vertical integration, and a wide variety of longer-term contractual relationships with durations ranging from one year to fifty years.[3] My related work (1985) suggests that asset-specificity considerations may be an important factor affecting the structure of vertical relationships in coal markets. The empirical results reported below provide strong support for the hypothesis that buyers and sellers make longer *ex ante* commitments to the terms of future trade, and rely less on repeated negotiations over time, when relationship-specific investments are more important.

I. Contract Duration and Transaction-Specific Investments

The reliance on relationship-specific investments to support cost-minimizing ex-

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[1]Electric utilities account for over 80 percent of domestic coal consumption.

[2]Other empirical work in this tradition includes Kirk Monteverde and David Teece (1982) and Scott Masten (1984), which focus on vertical integration; Keith Crocker and Scott Masten (1986), J. Harold Mulhern (1986), and Victor Goldberg and John Erickson (1982) which focus on long-term contracts; my paper (1985) which examines both vertical integration and long-term contracts.

[3]About 15 percent of electric utility coal consumption is accounted for by transactions with integrated suppliers, 15 percent is accounted for by spot market purchases, and about 70 percent is accounted for by contracts with durations of one to fifty years. See my paper (1985, pp. 50–54).

change is frequently advanced as an important factor explaining why we observe the use of long-term contracts that establish the terms and conditions of repeated transactions between two parties *ex ante*.[4] According to transactions cost theory,[5] when exchange involves significant investments in relationship-specific capital, an exchange relationship that relies on repeated bargaining is unattractive. Once the investments are sunk in anticipation of performance, "hold-up" or "opportunism" incentives are created *ex post* which, if mechanisms cannot be designed to mitigate the parties' ability to act on these incentives, could make a socially cost-minimizing transaction privately unattractive at the contract execution stage.[6,7] A long-term contract that specifies the terms and conditions for some set of future transactions *ex ante*, provides a vehicle for guarding against *ex post* performance problems.[8]

A coal contract generally specifies in advance a method for determining the price that the buyer is obligated to pay for each delivery (generally a formula for determining prices for deliveries at each point in time),[9] quantities that the seller is obligated to deliver and the buyer is obligated to purchase at each point in time (usually monthly),[10] the quality of the coal (Btu, sulfur, ash, and chemical composition), the source of the coal, and the period of time over which the contractual provisions are to govern the terms and conditions of trade.[11] The primary readily quantifiable characteristics of coal contracts that appear to vary widely from contract to contract are the quantity and characteristics of the coal contracted for and the length of time that the parties agree *ex ante* to commit themselves to the terms and conditions specified in the contract. It is this length of time to which the parties agree *ex ante* to abide by the terms of a contract that I refer to as the "duration" of the contract.[12]

My hypothesis is that the more important are relationship-specific investments, the longer will be the period of time (or number of discrete transactions) over which the parties will establish the terms of trade *ex ante* by contract. I therefore expect to observe that the variation in the agreed upon duration of contractual commitments is directly related to variations in the importance of relationship-specific investments.[13]

[4]Williamson (1979, 1983), Klein et al., Oliver Hart and Bengt Holmstrom (1986, pp. 1–2; 86–101). Other reasons for the use of long-term contracts have also been suggested. These include information lags, income effects and risk aversion, and improved monitoring of performance.

[5]I use the term "transactions cost theory" to refer generally to the work of Williamson (1979, 1983, 1985) and Klein et al.

[6]As Klein et al. discuss, the sunk investments create a stream of quasi rents that gives one party or the other (or both) some *ex post* bargaining power.

[7]The presence of these contracting hazards and imperfections in the ability of the transacting parties to protect against them does not mean that a deal will not be made. It simply means that the costs of making the transactions—the cost of the coal in this paper—will be higher than it would be if these hazards could be fully mitigated. Both parties have an interest in trying to structure the relationship so that a cost-minimizing deal can be struck.

[8]As discussed in my earlier paper (1985), reputational considerations may provide a natural market constraint on "bad behavior" *ex post*. Reputational constraints reduce the need to write inflexible long-term contracts to support cost-minimizing exchange in the presence of asset specificity. Reputational constraints are likely to be imperfect in coal markets, however. At the other extreme, vertical integration may be chosen to deal with *ex post* performance problems if satisfactory contractual solutions cannot be found.

[9]See my earlier paper (1986).

[10]The typical contract specifies a monthly and annual delivery schedule subject to minimum and maximum production and take obligations. The allowed variations from the contracted quantities in actual contracts that I have reviewed is fairly small.

[11]There are many other provisions as well, including arbitration provisions, force majeur provisions, resale provisions, etc. These provisions are fairly standard in long-term coal contracts, however.

[12]The actual duration of a contract could be longer or shorter than this. Buyers and sellers frequently voluntarily negotiate an extension of an existing contract. Contracts may also be broken through breach or mutual agreement. As far as I can tell from the data that I have reviewed, however, coal contracts are rarely terminated prematurely See my paper (1986, p. 2).

[13]To the extent that there are tradeoffs between contract duration and the incidence and structure of other contractual "protective" provisions, such as the method for determining price adjustment and quantities, these other provisions should be included in the analysis as well. As indicated above, however, there

II. Asset Specificity and the Contractual Duration of Coal Supply Relationships

Williamson (1983, p. 526) identifies four distinct types of transaction-specific investments, three of which appear to be relevant to different types of coal supply relationships. The three types of relevance to coal market transactions are:[14]

(a) Site Specificity: The buyer and seller are in a "cheek-by-jowl" relationship with one another, reflecting *ex ante* decisions to minimize inventory and transportation expenses. Once sited the assets in question are highly immobile.

(b) Physical Asset Specificity: When one or both parties to the transaction make investments in equipment and machinery that involves design characteristics specific to the transaction and which have lower values in alternative uses.

(c) Dedicated Assets: General investment by a supplier that would not otherwise be made but for the prospect of selling a significant amount of product to a particular customer. If the contract is terminated prematurely, it would leave the supplier with significant excess capacity. Although Williamson does not discuss it, I think that there is probably a "buyer" side analogy to the dedicated asset story as well. A buyer that relies on a single supplier for a large volume of an input *may* find it difficult and costly to quickly replace these supplies if they are terminated suddenly and effectively withdrawn from the market and, as a result, a large unanticipated demand is suddenly thrown on the market.

As discussed in more detail in the Appendix, I have put together a data base that includes information for nearly 300 contracts between electric utilities and coal suppliers that were in force in 1979. The data base includes information of various kinds regarding the characteristics of the individual coal contracts, the suppliers, the buyers, and the quality and quantity of the coal contracted for. The strategy was to use the information about the individual contracts in the data base and to attempt to measure, at least ordinally, differences in the importance of transaction-specific investments of one or more of the types identified by Williamson for each contract.

Williamson's notion of "site specificity" is the easiest to capture explicitly for coal supply relationships. For most electric generating plants, coal is purchased in one of three major coal-producing regions and then transported by rail, barge, and/or truck (often at least two of these transport modes are involved) to the power plant where it is burned. However, there are a relatively small number of plants that have been sited next to specific mines in anticipation of taking all or most of their requirements from that mine. These "mine-mouth" plants are generally developed simultaneously with the mines themselves. This appears to be a classic case of the cheek-by-jowl relationship that Williamson has in mind when he discusses site specificity.[15] The potential for *ex post* opportunism problems arising if the parties were to rely on repeated bargaining appears to be especially great in this case.[16] I there-

appears to be relatively little variation in these provisions in my data base, especially relative to the very large variation in contract duration. I therefore feel that it is safe to assume for purposes of this analysis that we have a sample of contracts that essentially holds these other provisions constant. In any event, we can measure the utilization of these other provisions only for a small fraction of the contracts in the data base and therefore cannot examine such tradeoffs directly. Note that the coal market is not subject to the kinds of price regulation discussed in Masten-Crocker and Crocker-Masten regarding natural gas contracts.

[14] The fourth is what Williamson calls "human asset specificity" (1983, p. 526). Jean Tirole has suggested to me that Williamson's four types of relationship-(or transaction) specific investment are simply different instances of the same phenomenon. I believe that this is correct. However, I find the distinctions to be quite useful for empirical applications.

[15] This is discussed in much more detail in my 1985 paper.

[16] Williamson (1983) states that common ownership is the predominant response to site specificity. My work with coal supply arrangements indicates that common ownership (vertical integration) is much more likely to emerge for mine-mouth plants than other types of plants, but that contracts are also used to govern exchange for about half of the mine-mouth plants constructed since 1960. We would probably see more vertical integration

fore expect that contracts for supplies for mine-mouth plants will be much longer than the average contract involving supplies to other types of plants, other things equal.[17]

Let us turn next to physical asset specificity. When coal-burning plants are built, they are designed to burn a specific type of coal (see my 1985 paper; Richard Schmalensee and myself, 1986; my paper with Schmalensee, 1985). By "type" of coal, I mean coal with a specific Btu, sulfur, moisture, and chemical content. The type of coal that a generating unit is designed to burn affects its construction cost and its design thermal efficiency. Deviations from expected coal quality can lead to a deterioration in performance or require costly retrofit investments. Thus when a plant is designed, the operator becomes "locked in" to a particular type of coal.[18]

The fact that a plant is locked in to a particular type of coal does not necessarily imply that the buyer is locked in to a specific supplier, however. Whether or not the plant design/coal characteristic lock in also leads to a lock in with the current supplier depends on other characteristics of the transaction. In particular, it is likely that the relationship between this type of asset-specificity and *ex post* hold up or opportunism problems is related to inter- and intraregional variations in coal quality, least cost supply technology, and transportation alternatives.[19]

The characteristics of coal produced in the United States vary systematically among the three major coal-producing regions. The eastern coal-producing districts produce high Btu coal of reasonably uniform quality. The midwestern coal-producing districts produce lower Btu coal that generally has a very high sulfur content. Coal quality is also more variable than that in the East. Finally, the western coal-producing districts generally produce coal with a much lower Btu content and a very low sulfur content. The quality of the coal varies quite widely throughout the western region.[20]

In addition to variations in coal quality among the regions, there are also systematic variations in the least-cost technology for producing coal and in the transportation alternative available. In the East, relatively small underground mines are economical and the supply of eastern coal can be expanded fairly quickly. Relatively abundant transportation alternatives, combined with relatively short average transport distances, mean that transportation is not likely to be a significant barrier to a buyer's obtaining alternative supplies. In the West, large surface mines that can be most economically expanded in large "lumps," are the least-cost production technology. Transportation alternatives are poor, the average transport distance quite long, large unit train shipments are the most economical transport method,[21] and utilities often must rely on one or two railroads to move the coal. The situation in the Midwest lies somewhere between these two extremes.[22]

for mine-mouth plants if state and federal regulation of electric utilities did not discourage it. I have argued elsewhere (1985) that to the extent that electric utility regulation biases coal supply arrangements at all, it is probably to make short-term purchases more desirable than they might otherwise be. While utilities might also like to integrate backwards into coal production to shift profits from a regulated to an unregulated activity, the regulatory process has discouraged this.

[17] I have included two plants in this category that are not technically mine-mouth plants but have economic characteristics that are identical to those of mine-mouth plants. For example, if a mine and a plant are connected by a transportation facility (a slurry pipeline or a rail line) built and owned by the supplier or buyer specifically to transport coal from a specific mine to a specific plant, the associated coal contract was grouped with the mine-mouth plants.

[18] Exactly how locked in, is a variable of choice, however.

[19] Transportation costs are on average a large fraction of delivered costs and lining up efficient transportation arrangements for large quantities of coal can be a time-consuming process.

[20] The midwestern region is sometimes broken up into two subregions (eastern and western interior) in discussions of coal supply. The western region is sometimes broken up into three or more subregions. Texas, where lignite coal is produced, is often considered a separate producing region. My data base has no contracts for Texas coal and I do not discuss that area here.

[21] Unit train cars are often owned or leased by the utility rather than by the railroad.

[22] See Martin Zimmerman (1981, pp. 17–36).

There are also systematic differences in the relative and absolute importance of spot markets in the three supply regions.[23] On average, from 1974 through 1982 spot market transactions accounted for roughly 15 percent of total domestic coal purchases by electric utilities. In 1982, spot market sales accounted for about 10 percent of coal supplies or about 60 million tons. However, in the western region, less than 2 percent of the coal delivered to electric utilities was purchased on the spot market or less than 5 million tons.[24] The spot market is more active in the Midwest, accounting for about 8 percent of deliveries in 1982 or about 10 million tons per year. The spot market is most active in the East where about 18 percent of deliveries went through the spot market in 1982 or about 45 million tons.[25]

These considerations imply the following: Coal suppliers are likely to be less able to exploit the lock-in effect associated with boilers designed to burn coal with specific characteristics in the East than in the West.[26] Thus the protection of a long-term contract is likely to be more desirable from the buyers' (and the sellers'—see below) perspective, for transactions involving western coal relative to transactions involving eastern coal, with midwestern coal falling somewhere in between.

Finally, let us turn to "dedicated asset" considerations. The available information in the data base does not make it possible for us to know specifically whether the supplier made general investments that would not have been made but for the prospect of selling a *significant amount of product* to a particular customer and if the contract is terminated prematurely it would leave the supplier with excess capacity (see Williamson, 1983, p. 526).[27] Williamson's conceptualization of dedicated assets implies that the importance of this factor in structuring coal supply relationships should vary with the quantity of coal that is initially contracted for, other things equal. The larger the annual quantity of coal that is contracted for, the more difficult it is likely to be for the seller to quickly dispose of unanticipated supplies (if the buyer breaches) at a compensatory price, and the more difficult will it be for a buyer to replace supplies at a comparable price if the seller withdraws them from the market. Thus, I expect that the greater the annual quantity of coal contracted for the longer will be the specified duration of the contract.

Because of systematic variations in the optimal scale and capital intensity of coal production across regions, dedicated asset considerations are also likely to be more important for western coal than for eastern coal. The greater heterogeneity in coal supplies and the difficulties of obtaining suitable transportation for it in the West, suggest that dedicated asset problems are likely to be more severe in the western than the eastern region. The very thin spot market in the

[23] Spot market sales also vary from year to year. Spot market transactions tend to be higher when coal miner strikes are anticipated as utilities seek to build up stockpiles or after coal mining strikes are over and stockpiles are replenished. The volume of spot market transactions also varies in response to unanticipated changes in coal supply and demand.

[24] The aggregate volume of spot market transactions for western coal is quite small compared to the annual quantity of western coal contracted for in a typical contract. The contracts for western coal in my data base have a mean quantity of about 1.8 million tons per and a maximum quantity of over 8 million tons per year.

[25] I believe that the wide variation in the importance of the spot market in different regions is largely related to the same economic considerations that lead me to conclude that the importance of asset specificity also varies from region to region.

[26] Generating plants located along the eastern seaboard that use coal essentially always use eastern coal. These plants are also more likely to have units that have multifuel capabilities than plants located elsewhere and can switch back and forth between coal and oil or gas (often with some performance penalty). See my paper with Frederick Mishkin (1977). Purchasers of eastern coal with multifuel capabilities will be less susceptible to opportunism problems when coal and oil prices are close together.

[27] Indeed, as a practical matter, it is unclear to me how one could ever go about determining this directly given the data that are likely to be available for analysis. The coal contracts that I have reviewed do sometimes have language that appears to recognize the dedicated asset notion directly, but the absence of an explicit statement cannot be assumed to imply that dedicated asset considerations are not important.

western region should be especially problematical for both sellers and buyers when large contractual commitments are breached because of the heterogeneity of the coal, the characteristics of least-cost production and the limited transportation alternatives. This all implies again that contracts for western coal should have longer contractual durations than contracts for eastern coal.

To summarize, if variations in the importance of relationship-specific investments do in fact lead to variations in the extent to which the parties precommit to the terms of future trade *ex ante*, I expect to find that the duration of contractual relationships specified at the contract execution stage will vary systematically with three primary observable characteristics of coal supply transactions. First, whether the plant taking the coal is a mine-mouth plant or not. I expect to observe longer-term contracts negotiated for mine-mouth plants. Second, with the region of the country in which the coal is produced. I expect the western region to have the longest contracts and the eastern region the shortest with the midwestern region having contracts with prespecified durations that lie in between. Third, with the annual quantity of coal contracted for. I expect that coal supply arrangements involving large annual quantity commitments will be supported by longer contracts than supply arrangements involving smaller quantities of coal.

III. Model Specification and Estimation

I am primarily interested in estimating a set of simple relationships between the duration of contractual commitments (*DURATION*) specified by the parties at the contract execution stage and, (a) the *annual* quantity (*QUANTITY*)[28] of coal contracted for, (b) a dummy variable (*MINE-MOUTH*) that takes on a value of 1 for a mine-mouth plant and zero otherwise, and (c) dummy variables that indicate the coal supply region in which the supplier is located (*MIDWEST* and *WEST*, so that regional effects are measured relative to contracts for eastern coal). Additional variables are considered in the next section.

The data base that I use includes information for approximately 300 coal supply contracts between domestic coal suppliers and investor-owned electric utilities. The contracts included in the data base were negotiated in various years up through 1979 and were in force at least for part of 1979. The data are discussed in more detail in the Appendix. Information on all variables of primary interest for this study is available for 277 of the contracts in the data base. I present estimates using both the full 277 observation sample as well as a subsample consisting of 169 contracts that involve deliveries dedicated to a single power plant.[29] Table 1 provides the mean, standard deviation, minimum and maximum values, and a brief description for all of the variables used in this section and subsequent sections for both the primary sample and the single-plant subsample. Table 2 is a correlation matrix for all of the variables in the two samples with the correlations for the 277 observation sample below the diagonal and those for the 169 observation subsample above the diagonal.

I work first with three simple specifications of the contract duration equation:

$$(1)\quad DURATION_i = a_0 + b_1 QUANTITY_i + b_2 QUANTITY_i^2 + b_3 MINE\text{-}MOUTH_i + b_4 MIDWEST_i + b_5 WEST_i + u_i$$

[28] Quantities are expressed in terms of the thermal (Btu) content of the coal. The basic results are not affected when quantities are expressed in tons. For the extensions reported in the next section, normalizing quantities for Btu content makes it possible to more accurately examine the effects, if any, of contract quantities relative to total plant and utility utilization of coal.

[29] Several people suggested to me that relationship-specific investment effects are most likely to be revealed for contracts that dedicate all supplies to a single plant. I also focus on this subsample to obtain the data necessary to explore issues discussed in the next section.

TABLE 1—SAMPLE STATISTICS

Variable	Observations	Description	Mean	Minimum	Maximum	Standard Deviation
DURATION	277	Contract Duration	12.75	1.00	50	10.43
	169	(years)	14.18	1.00	43	10.77
QUANTITY	277	Annual Contract	20.45	0.3696	183.00	24.62
	169	Quantity (trillion Btu's)	22.83	0.3696	183.00	27.05
PLANT PROPORTION	169	Fraction of Total Plant Use from Contract	0.44	0.03	1.00	0.35
UTILITY PROPORTION	169	Fraction of Total Utility Coal Use from Contract	0.19	0.003	1.00	0.23
PLANT QUANTITY	169	Plant Utilization of Coal (trillion Btu's)	51.47	2.95	172.42	41.69
UTILITY QUANTITY	169	Utility Utilization of Coal (trillion Btu's)	221.54	2.95	919.80	270.56
PLANT/UTILITY	169	Plant Use as Fraction of Total Utility Use	0.455	0.007	1.00	0.323
MINE-MOUTH	277	Mine-Mouth Plant		($D=1$; 14 Observations)		
	169	Dummy Variable		($D=1$; 14 Observations)		
WEST	277	Western Region		($D=1$; 54 Observations)		
	169	Supply Dummy		($D=1$; 44 Observations)		
MIDWEST	277	Midwestern Region		($D=1$; 68 Observations)		
	169	Supply Dummy		($D=1$; 47 Observations)		
DATE-71	277	Contracts Signed		($D=1$; 43 Observations)		
	169	1971–73: Dummy		($D=1$; 29 Observations)		
DATE-74	277	Contracts Signed		($D=1$; 116 Observations)		
	169	1974–77: Dummy		($D=1$; 71 Observations		
DATE-78	277	Contracts Signed		($D=1$; 72 Observations)		
	169	1978–79: Dummy		($D=1$; 38 Observations)		
YEAR	277	Year Contract Executed	1974	1955	1979	4.49
	169		1974	1955	1979	4.64

[a] Data sources and variable definitions can be found in the Appendix.
[b] The 169 observation subsample includes contracts dedicated to a single plant.

TABLE 2—CORRELATION MATRIX

277 Observation Sample	169 Observation Sample											
	DURATION	*QUANTITY*	*LOG-QUANTITY*	*MINE-MOUTH*	*MIDWEST*	*WEST*	*YEAR*	*PLANT PROP.*	*UTILITY PROP.*	*PLANT/UTILITY*	*PLANT QUANTITY*	*UTILITY QUANTITY*
DURATION	–	0.60	0.68	0.64	0.004	0.51	−0.57	0.58	0.43	0.05	0.29	0.02
QUANTITY	0.60	–	0.78	0.42	−0.04	0.28	−0.35	0.48	0.43	0.05	0.41	0.11
LOG-QUANTITY	0.64	0.80	–	0.30	0.02	0.32	−0.44	0.57	0.42	0.02	0.45	0.17
MINE-MOUTH	0.54	0.38	0.27	–	−0.09	0.41	−0.37	0.46	0.41	0.05	0.10	−0.05
MIDWEST	0.14	0.08	0.11	−0.06	–	−0.37	−0.20	0.04	−0.04	−0.06	−0.03	−0.15
WEST	0.41	0.25	0.26	0.39	−0.28	–	−0.10	0.46	0.40	0.16	−0.06	0.16
YEAR	−0.63	−0.39	−0.44	−0.31	−0.27	−0.08	–	−0.28	−0.11	0.13	−0.16	−0.11
PLANT PROP.	–	–	–	–	–	–	–	–	0.61	−0.11	−0.24	−0.14
UTILITY PROP.	–	–	–	–	–	–	–	–	–	0.66	−0.08	−0.36
PLANT/UTILITY	–	–	–	–	–	–	–	–	–	–	0.15	−0.57
PLANT QUANTITY	–	–	–	–	–	–	–	–	–	–	–	0.34
UTILITY QUANTITY	–	–	–	–								–

Note: Figures below the diagonal are for the 277 observation sample, those above the diagonal are for the 169 observation subsample.

$$(2)\quad DURATION_i = a_0 + b_1 LOG\text{-}QUANTITY_i + b_3 MINE\text{-}MOUTH_i + b_4 MIDWEST_i + b_5 WEST_i + u_i$$

$$(3)\quad \log(DURATION_i) = a_0 + b_1 LOG\text{-}QUANTITY_i + b_3 MINE\text{-}MOUTH_i + b_4 MIDWEST_i + b_5 WEST_i + \log(u_i)$$

where i indexes contracts and u_i is an error term whose characteristics will be discussed further below.

I have allowed (*QUANTITY*) to enter these relationships nonlinearly by introducing a quadratic in quantity (*QUANTITY-SQUARED*) in (1) and using the natural logarithm of quantity (*LOG-QUANTITY*) in equations (2) and (3). Since powerplants have useful lives of roughly forty years and the costs of breach are likely to decline over time as plants and mines age, I expect that the impact of quantity on contractual duration will diminish as quantity increases. The following pattern of coefficient estimates for the three equations is implied by the hypothesized relationship between asset specificity and contract duration:

(*i*) All of the b_i's should be positive, except for b_2, which could be positive, negative, or zero (no nonlinearity), although I expect that it will be negative.

(*ii*) b_4 should be smaller than b_5.

Equations (1), (2), and (3) are estimated in three different ways. First, I present ordinary least squares (OLS) estimates of each equation for both samples. Next, I present OLS estimates that introduce dummy variables which indicate the date that the contracts were executed. Finally, I present maximum likelihood estimates based on the assumption that we have a truncated sample drawn from a population with either a normal or a log-normal density function. I discuss the rationale and results for each estimation approach and also present OLS results for contracts with suppliers in each of the three regions.

A. *OLS Estimates*

If we assume that the u_i in (1), (2), and (3) are independently distributed and drawn from a normal distribution with mean zero, then OLS will yield an unbiased estimator of the coefficients of interest. I proceed first with this assumption and provide estimates for alternative assumptions about the error structure below. The OLS results are presented in Table 3. The first three columns are estimates for the three equations using the 277 observation sample. Columns 4, 5, and 6 contain estimates for the 169 observation subsample.

The OLS estimates are, in all cases, consistent with the hypothesized relationship between asset specificity and contract duration. The effects of annual contract quantity, region, and mine-mouth plants have the predicted signs and are estimated quite precisely. A mine-mouth plant is predicted to have a contract that is about 16 years longer than those of other plants. Contracts with eastern producers are 3 to 5 years shorter than those for western and midwestern producers. Contracts with western producers are 2 to 3 years longer than those with midwestern producers. The difference in duration between the *WEST* and the *MIDWEST* is generally not significant at the 5 percent level for the 277 observation sample, but is significant for the single-plant subsample. An increase in annual contract quantity of 22 trillion Btu's (roughly 1 million tons) yields about a 13-year increase in contract duration. As a general matter, the estimates are more precise for the sample of contracts dedicated to a single plant.

B. *OLS Estimates with Contract Date Dummies*

The desirable properties of the OLS estimates depend on the strong assumptions made about the error structure. Since the contracts in the data base were signed at many different times, it is natural to consider the possibility that contracting practices

TABLE 3—CONTRACT DURATION[a]

Independent Variables	277 Sample DURATION (1)	277 Sample DURATION (2)	277 Sample LOG-DURATION (3)	169 Sample DURATION (4)	169 Sample DURATION (5)	169 Sample LOG-DURATION (6)	DURATION (7)	DURATION (8)	2SLS Estimate Duration (9)
QUANTITY	0.4289 (0.0373)	–	–	0.4091 (0.0040)	–	–	–	–	–
QUANTITY-SQUARED	−0.0024 (0.00030)	–	–	−0.0020 (0.00003)	–	–	–	–	–
LOG-QUANTITY	–	4.4206 (0.3742)	0.5057 (0.0425)	–	4.2080 (0.4069)	0.4942 (0.0453)	4.2022 (0.4617)	4.2057 (0.4084)	5.1066 (0.812)
MINE-MOUTH	16.3300 (2.0496)	16.4317 (2.0045)	0.5104 (0.2279)	15.9583 (1.9106)	16.2300 (1.8421)	0.4616 (0.2050)	16.3432 (1.9426)	16.2284 (1.8477)	15.4391 (1.968)
MIDWEST	3.4267 (0.9682)	3.8795 (0.9821)	0.5154 (0.1116)	2.7832 (1.0928)	2.7843 (1.1032)	0.5785 (0.1228)	2.7317 (1.1295)	2.7848 (1.1065)	2.4268 (1.153)
WEST	5.3550 (1.357)	5.2033 (1.1641)	0.6142 (0.1323)	5.9856 (1.2346)	5.6108 (1.2586)	0.6844 (0.1401)	5.6456 (1.3406)	5.6391 (1.2751)	4.8916 (1.394)
PLANT PROPORTION	–	–	–	–	–	–	0.9729 (1.9806)	–	–
UTILITY PROPORTION	–	–	–	–	–	–	−2.0570 (2.5832)	–	–
PLANT/ UTILITY	–	–	–	–	–	–	–	−0.2246 (1.4265)	–
Constant	3.6770 (0.6586)	−0.7902 (0.9579)	0.6014 (0.1089)	3.9334 (0.8109)	0.0155 (1.0917)	0.6242 (0.1215)	−0.0146 (1.0978)	0.1157 (1.2665)	−1.8922 (1.852)
Corrected R-squared	0.61	0.60	0.51	0.71	0.70	0.61	0.70	0.70	–
Observations	277	277	277	169	169	169	169	169	169

[a] OLS estimates. Standard errors of coefficient estimates are shown in parentheses.

changed over time. Not only might the duration of a typical contract have changed over time, but such changes may have been correlated with changes in contract quantities, supply location, and the development of mine-mouth plants over time. Failing to include variables indicated contract dates could then lead to a correlation between the independent variables and the error term. The OLS estimates would then be biased. To check to see if the estimates are sensitive to the presence of a left-out variable reflecting the contracting date, in Table 4, I report estimates of equations (1), (2), and (3) that have contract date dummies included. These contract date dummy variables are *DATE-71*, which is equal to one for all contracts signed between 1971 and 1973 inclusive, *DATE-74*, which equals one for contracts signed between 1974 and 1977, and *DATE-78* which equals one for contracts signed in 1978 and 1979. Since a separate variable for contracts signed prior to 1971 is not included, the coefficient estimates are all relative to pre-1971 contracts (i.e. the constant term). This aggregation of signing dates was made to reflect major shocks to coal supply and/or demand.[30]

[30] The 1971–73 period is just after the Clean Air Act Amendments of 1970 were passed, the 1974–77 period is the period after the Arab oil embargo and includes the subsequent increases in fossil fuel prices. The 1978–79 period coincides with the beginning of a slowdown in utility capacity additions. These periods are discussed in more detail in my paper (1986). The aggregation chosen is the same used to analyze pricing behavior in that paper. The results reported here are not sensitive to this aggregation, however. The same qualitative results are obtained if separate dummy variables are used for each year during the 1970's plus a separate dummy variable for pre-1965 and 1966–70 contracts.

TABLE 4—CONTRACT DURATION[a]

Independent Variables	*DURATION* (1)	*DURATION* (2)	*LOG-DURATION* (3)	*DURATION* (4)	*DURATION* (5)	*LOG-DURATION* (6)	*DURATION* (7)	*DURATION* (8)
QUANTITY	0.3120	–	–	0.3355	–	–	–	–
	(0.03547)			(0.0406)				
QUANTITY-SQUARED	−0.0018	–	–	−0.0018	–	–	–	–
	(0.00027)			(0.00029)				
LOG-QUANTITY	–	3.0482	0.3245	–	3.3485	0.3631	3.2847	3.3461
		(0.3655)	(0.0380)		(0.4330)	(0.0446)	(0.4923)	(0.4344)
MINE-MOUTH	13.9437	13.6701	0.3140	14.6494	14.6907	0.3792	14.5742	14.6800
	(1.8482)	(1.8260)	(0.1899)	(1.8495)	(1.8347)	(0.1891)	(1.9423)	(1.8403)
MIDWEST	1.6814	1.9761	0.3029	1.4906	1.6405	0.4083	1.5543	1.6323
	(0.8785)	(0.8952)	(0.0931)	(1.0544)	(1.0786)	(0.1112)	(1.1083)	(1.0821)
WEST	4.8429	4.8662	0.4831	5.1054	5.1731	0.5137	5.0697	5.1258
	(1.0301)	(1.0549)	(0.1097)	(1.2183)	(1.2524)	(0.1291)	(1.3338)	(1.2676)
PLANT PROPORTION	–	–	–	–	–	–	0.9930	–
							(1.8907)	
UTILITY PROPORTION	–	–	–	–	–	–	−0.9138	–
							(2.4975)	
PLANT/UTILITY	–	–	–	–	–	–	–	0.3785
								(1.3660)
CONSTANT	12.0145	9.4184	1.7205	9.2341	6.1982	1.4220	6.1583	6.0806
	(1.2526)	(1.5307)	(0.1592)	(1.5185)	(1.8612)	(0.1918)	(1.8853)	(1.9142)
DATE-71	−2.3734	−2.4564	−0.0988	−0.7282	−0.9103	−0.0311	−0.9389	−0.9455
	(1.2715)	(1.2876)	(0.1339)	(1.4890)	(1.5057)	(0.1552)	(1.5290)	(1.5154)
DATE-74	−6.6815	−7.3044	−0.5098	−3.9714	−4.3786	−0.3149	−4.3848	−4.4134
	(1.2647)	(1.1446)	(0.1190)	(1.3483)	(1.3685)	(0.1410)	(1.3789)	(1.3781)
DATE-78	−10.5052	−10.6151	−1.3926	−7.0789	−6.5193	−1.0317	−6.4995	−6.5749
	(1.2647)	(1.2976)	(0.1349)	(1.5540)	(1.6324)	(0.1682)	(1.6702)	(1.6493)
Corrected R-squared	0.70	0.69	0.67	0.74	0.73	0.69	0.73	0.73
Observations	277	277	277	169	169	169	169	169

[a] OLS/Contract date dummies. Standard errors of coefficient estimates are shown in parentheses.

While the introduction of these contract date dummy variables may help to control for contract date related correlations between the error term and the independent variables, the estimated coefficients of these variables themselves have no obvious economic meaning. This is because of the nature of the sample. Recall that I observe contracts *in force* in 1979. If we think of the population as consisting of contracts written for particular plants (i) in a particular year (t), we can observe a contract only if

$$(4)\quad DURATION_{it} \geq (1979 - \text{Contract } YEAR)$$

This means that of those contracts signed in 1970, I can observe, in 1979, only those that had durations of at least 9 years, while I will observe shorter contracts that were signed in later years. Even if there were no changes in contracting behavior over time, we would inevitably find that the coefficients of the contract date dummies indicate that the average length of a contract in the sample is negatively correlated with the date of the contract.[31] The coefficients of the contract date variables can therefore tell us nothing directly about the changes in contracting behavior over time.

With these considerations in mind, we can turn to the results reported in Table 4, columns 1 through 6. The results obtained are again consistent with the hypothesized relationship between asset specificity and contract duration. The coefficients of the quantity, mine-mouth, and regional variables

[31] In the sample, the simple correlation between contract date (*YEAR*) and *DURATION* is about −0.60. See Table 2.

continue to be of the predicted signs and relative magnitudes. The only interesting difference between these results and those reported in Table 3 is that the difference between the durations of contracts signed with western and midwestern producers is now generally statistically significant at the 5 percent level for both samples.

C. *Maximum Likelihood Estimates*

A third alternative for estimating these equations is to follow Keith Crocker and Scott Masten (1986), who work with a sample of natural gas contracts with similar sampling properties, and assume that the sampling procedure which chooses contracts in force in a single year (1981 in their paper) represents a classical sample truncation problem as discussed by G. S. Maddala (1983, pp. 165–170). The population of contracts then implicitly consists of all contracts written since the earliest contract in the data base. We obtain a truncated sample because we observe contracts only if the duration of the contract is greater than or equal to L_i, where L_i is equal to 1979 minus the contract date. In this case, OLS estimates of (1), (2), and (3) would be biased, because the sampling process is likely to induce a correlation between the independent variables and the error term.

We can obtain estimates with desirable asymptotic properties by specifying the likelihood function of the sample, given the nature of the sampling truncation, and then solve for the maximum likelihood estimates (MLE) of the coefficients of interest. Following Maddala (p. 166), I assume that the population relationship between contract duration and the independent variables has a normally distributed error and that each observation is truncated at L_i. This leads to a standard maximum likelihood estimator.

The maximum likelihood estimates are reported in Table 5, columns 1 through 6.[32] The results are again quite consistent with the hypothesized relationship between asset specificity and contract duration. The signs and magnitudes of the coefficients of *QUANTITY*, *MINE-MOUTH*, *WEST*, and *MIDWEST* are again as predicted. With the exception of the mine-mouth dummy in equation (3), the coefficients are estimated quite precisely. The magnitudes of the estimated coefficients in this table are difficult to compare directly with those in Tables 3 and 4 because of the need to incorporate the truncation effects into estimates of contract duration.[33] Correcting for the sample truncation, the estimates reported in Table 5, column 5, for example, yield the following expected durations: The expected duration evaluated at the means of the independent variables is 10.5 years (compared to a mean of 14.2 years for the truncated 169 observation sample). Mine-mouth plants have contracts with an expected duration that is about 12 years longer than the average non-mine-mouth plant. Midwestern contracts are about 3.5 years longer than eastern contracts. Western contracts are about 11 years longer than eastern contracts and 6 years longer than midwestern contracts. The difference between western and midwestern contracts is generally significant at the 5 percent level.[34]

D. *Estimates for Individual Coal Supply Regions*

Finally, in Table 6, I report estimates of the relationship between *DURATION*, *LOG-QUANTITY*, and *MINE-MOUTH* for

[32] The estimates were obtained using the MLE routine in the *Statistical Software Tools* package (Version 1.0 as of October 1986) developed by Jeffrey Dubin and R. Douglas Rivers running on an IBM XT. The estimates in cols. 3 and 6 assume that the density function is log-normal. Contracts executed in 1979 have been dropped since the likelihood function includes terms that require taking the logarithm of $L_i = (1979 - YEAR)$ which is zero for contracts written in 1979. Since the shortest contract in the data base has a duration of one year, we can impose a lower bound between zero and 1 on L_i to include all observations. Estimates obtained using different lower bounds does not change the results, so I simply report results for the sample excluding the small number of contracts in the data base executed in 1979.

[33] See Maddala (p. 167).

[34] I have also produced maximum likelihood estimates of equation (2) for subsamples consisting of pre-1974 contracts and those signed between 1974 and 1979. The hypothesized relationship between contract duration and the variables representing variations in asset specificity persists for both subsamples.

TABLE 5—CONTRACT DURATION[a]

Independent Variables	*DURATION* (1)	*DURATION* (2)	*LOG-DURATION* (3)	*DURATION* (4)	*DURATION* (5)	*LOG-DURATION* (6)	*DURATION* (7)	*DURATION* (8)	*2SLS ESTIMATE DURATION* (9)
QUANTITY	0.7948	–	–	0.5807	–	–	–	–	–
	(0.1046)			(0.0717)					
QUANTITY-SQUARED	−0.0043	–	–	−0.0030	–	–	–	–	–
	(0.00061)			(0.0004)					
LOG-QUANTITY	–	11.8527	0.6733	–	8.4367	0.6340	8.2709	8.4505	8.5737
		(1.5663)	(0.0897)		(1.0816)	(0.0816)	(1.0854)	(1.0815)	(3.5777)
MINE-MOUTH	16.5557	13.8763	0.2407	15.5484	14.4004	0.2736	14.1237	14.3841	15.4508
	(4.2407)	(3.8955)	(0.5714)	(2.9435)	(2.7764)	(0.4614)	(3.0120)	(2.7650)	(2.1083)
MIDWEST	8.3650	8.1377	0.4493	5.0050	4.7042	0.5376	4.4397	4.7468	2.4404
	(2.8188)	(2.5461)	(0.2281)	(2.5018)	(2.4511)	(0.2763)	(2.5221)	(2.4820)	(2.1797)
WEST	15.4864	13.8045	1.0500	11.7771	10.5506	1.0522	10.1238	10.4730	6.9477
	(4.1940)	(3.4244)	(0.0500)	(3.0124)	(2.4220)	(0.2416)	(2.6136)	(2.4095)	(1.8329)
PLANT PROPORTION	–	–	–	–	–	–	2.4401	–	–
							(3.7927)		
UTILITY PROPORTION	–	–	–	–	–	–	−2.0043	–	–
							(3.1937)		
PLANT/UTILITY	–	–	–	–	–	–	–	1.4626	–
								(2.1945)	
Constant	−18.4532	−35.6427	−0.4699	−6.9510	−19.0118	−0.2789	−19.0377	−19.7755	−36.1521
	(5.7203)	(7.2690)	(0.26709)	(3.4094)	(4.6758)	(0.2448)	(4.8545)	(4.8645)	(6.9717)
Log-Likelihood	−781.08	−769.29	−174.29	−475.17	−466.99	−101.60	−466.68	−466.83	−451.38
Observations	277	277	255	169	169	160	169	169	169

[a]Maximum likelihood estimates. Standard errors of coefficient estimates are shown in parentheses.

TABLE 6—CONTRACT DURATION[a]

Independent Variables	Dependent Variable: *DURATION*							
	WEST (1)	*MIDWEST* (2)	*EAST* (3)	*EAST* (4)	*WEST* (5)	*MIDWEST* (6)	*EAST* (7)	*EAST* (8)
LOG-QUANTITY	3.4825	5.1249	4.2362	4.2968	3.5878	4.0269	4.408	4.4992
	(1.0714)	(0.7646)	(0.4668)	(0.4661)	(1.0992)	(0.6538)	(0.5798)	(0.5786)
MINE-MOUTH	18.4179	11.8107	–	17.6804	17.616	12.8372	–	17.0887
	(2.5064)	(5.1695)		(3.7348)	(2.3183)	(3.6363)		(3.8111)
Constant	6.819	1.365	−0.3975	−0.5265	7.2101	3.4075	0.4106	−0.6028
	(3.1610)	(5.1695)	(1.1159)	(1.1151)	(3.3441)	(1.8264)	(1.4256)	(1.4246)
Corrected R-squared	0.68	0.42	0.35	0.43	0.73	0.52	0.42	0.54
Observations	54	68	155	158	44	47	78	81

[a]OLS by region. Standard errors of coefficient estimates are shown in parentheses.

each coal supply region.[35] The samples do not include any mine-mouth plants using eastern coal, so columns 3 and 7 simply report the estimated relationship between *DURATION* and *LOG-QUANTITY*. There are in fact a few mine-mouth plants in the East and I have some information for three of them. These were not included in the sample because the data base did not have information on annual contract quantities for them. However, I was able to obtain information for delivered quantities for three eastern mine-mouth plants and have aug-

[35]I report only this variant of equation (2) to conserve space. It should be clear by now that the alternative specifications of (1), (2), and (3) do not yield any important differences in results.

mented the sample to include these plants, using delivered quantities rather than contract quantities as the values for the *QUANTITY* variable. These results are reported in columns 4 and 8 of Table 6.[36]

The effects of contract quantity and the mine-mouth dummy on contract duration are clearly not simply associated with the contracting behavior for coal from a particular region. The expected effects are found in each of the three regions. The coefficients of *QUANTITY* and *MINE-MOUTH* are of the expected signs and are estimated precisely in all cases. While there are differences in the magnitudes of the coefficients of these variables between the three regions, they are not very large numerically and equality of the coefficients of *QUANTITY* and *MINE-MOUTH* across regions cannot be rejected at standard significance levels. Contracts basically simply get longer as we move from East to West, other things equal.

IV. Alternative Measure of Asset Specificity

Clearly, the hypothesized relationship between contract duration and the variables that I have chosen to capture variations in asset specificity is quite robust to alternative specifications, samples, and estimating technique. Nevertheless, it is natural to ask whether there are alternative or additional factors that might explain the observed variations in contract duration. One argument that has been suggested to me is that it is not only the size of the contractual commitment that is likely to be important, but also the fraction of a plant's, and perhaps the utility's, requirements obtained from a specific contract. The argument is that as a larger fraction of a plant's requirements is associated with a specific supplier, "physical asset specificity" attributes are likely to be more important and lead to longer contracts. It has also been suggested to me that opportunism problems are likely to be less severe if the utility as a whole is not heavily dependent on supplies provided pursuant to a specific contract. These arguments imply that variables measuring plant and/or utility "dependence" on a specific contract should be introduced into the contract duration relationship.

To examine this possibility, I have included variables in (2)[37] that measure the fraction of a plant's requirements (*PLANT PROPORTION*) and the fraction of the total coal requirements of the utility (*UTILITY PROPORTION*) that operates the plant which are accounted for by a particular contract. As an alternative, I also estimate (2) introducing a variable that is equal to total plant utilization of coal divided by total utility utilization of coal (*PLANT/UTILITY*). I can estimate these relationships only for the contracts that are for delivery to a single plant because it is only for these contracts that I can construct a meaningful measure of plant specific dependence (i.e., the 169 observation subsample must be used).

The results are reported in columns 7 and 8 of Tables 3, 4, and 5. The coefficient estimates for *PLANT PROPORTION* and *UTILITY PROPORTION* are very imprecise. They are of opposite signs and are neither individually nor jointly significant at conventional significance levels. The coefficient of *PLANT/UTILITY* is also very imprecise and varies in sign depending on estimating technique. Introducing these variables has no effect on the estimates for the primary variables of interest. These results imply that a plant or utility that relies on a single supplier for a large fraction of its requirements, or that depends heavily on a specific plant, does not encounter significant hold-up problems per se. The lock-in effect associated with designing plants to burn a particular type of coal becomes a potential contractual problem only to the extent that the other asset specificity characteristics are active.

[36] The inclusion of these three additional observations does not change the aggregate results.

[37] Including these variables in (1) and (3) does not change the results and I report the results for (2) in order to conserve space.

V. Contract Quantity

Before concluding, it is useful to explore the role of asset specificity in determining annual contract quantities since this variable plays such an important role in the contract duration equation. A relationship between contract quantity and asset specificity potentially emerges because of the presence of all three types of asset specificity. First, other things equal, physical asset specificity considerations suggest that a plant operator would like to rely on a specific supplier producing a particular type of coal at a particular location to the greatest extent possible.[38] This implies that contract quantity should vary directly with the coal requirements of the individual plant (*PLANT QUANTITY*).[39] On the other hand, the more a utility comes to rely on a single supplier the more costly a breach of contract may be. This suggests that a utility may be willing to rely more on a single supplier for an individual plant the larger is total utility utilization of coal (*UTILITY QUANTITY*) given the utilization of a specific plant.

Second, in the case of mine-mouth plants, the nature of the *ex ante* location/investment decision involves the mutual expectation that all or most of a plant's requirements will be taken from the proximate supplier. This implies that the quantity per contract will be larger for mine-mouth plants, other things equal.

Finally, as discussed above, when utilities design plants to closely match specific coal quality attributes they will have an interest in relying more heavily on a specific supplier who contracts to supply coal from a seam with these characteristics. This is likely to be an especially important consideration for coal supplies from the western region.

I estimate the following relationship using the single-plant (169 observation) subsample to determine empirically whether and how these considerations affect annual contract quantities.

$$(5)\quad QUANTITY_i = c_0 + d_1 PLANT\text{-}QUANTITY_i + d_2 PLANT\text{-}QUANTITY_i^2 + d_3 UTILITY\text{-}QUANTITY_i + d_4 UTILITY\text{-}QUANTITY_i^2 + d_5 MINE\text{-}MOUTH_i + d_6 MIDWEST_i + d_7 WEST_i + v_i.$$

I expect d_1, d_3, d_5, d_6, and d_7 to be greater than zero, and d_7 should be larger than d_6.

Equation (5) is estimated in two different ways. First, OLS estimates are presented. Second, OLS estimates with a correction to reflect the possibility that I have a censored sample are also presented. The OLS estimates of the coefficients of (5) may be biased as a result of the sampling procedure discussed earlier. We observe contract quantity only if contract duration is greater than or equal to (1979 − contract *YEAR*), so we have a censored sample. This implies that the random error (v) in the contract quantity equation (5) may be correlated with the random error (u) in the contract duration equation. If this is the case, the random error (v) in the contract quantity equation will be a function of the independent variables in the contract duration equation. The OLS estimates of the coefficients of the independent variables in the quantity equation (5) would then be biased if they are correlated with the independent variables in the duration equation. In particular, independent variables that appear in the contract duration equation may appear to be significant when introduced as independent variables in equation (8) when in fact they are not.[40] Since three

[38] One might also argue that, other things equal, a buyer would rather rely on a single supplier to conserve on more traditional types of transactions cost associated with negotiating, monitoring, and enforcing contracts with multiple supplies.

[39] Ideally, we would like to look at specific generating *units* rather than specific generating *plants* where plants have multiple units with different design characteristics. Unfortunately, coal supply information is not available at the generating unit level.

[40] See George Judge et al. (1985, pp. 610–13) and James Heckman (1976, 1979).

TABLE 7—CONTRACT QUANTITY[a]

	Dependent Variable: *QUANTITY*			
	OLS		OLS/*H*	
Independent Variables	(1)	(2)	(3)	(4)
PLANT QUANTITY	0.2501 (0.0441)	0.3133 (0.1573)	0.2128 0.0489	0.2827 (0.1578)
PLANT QUANTITY-SQUARED	–	−0.00066 (0.0010)	–	−0.00067 (0.00099)
UTILLITY QUANTITY	0.00349 (0.00689)	0.0672 (0.0311)	0.00393 (0.00685)	0.06376 (0.03104)
UTILITY QUANTITY-SQUARED	–	−0.00007 (0.00003)	–	−0.000063 (0.000032)
MINE-MOUTH	29.7932 (6.8591)	27.1594 (6.8997)	30.3261 (6.8251)	27.775 (6.879)
WEST	13.5416 (4.6437)	13.5865 (4.6259)	8.4955 (5.4680)	8.9738 (5.4597)
MIDWEST	5.2469 (4.1841)	4.856 (4.1708)	2.5832 (4.4371)	2.4749 (4.4193)
H	–	–	−66.7618 (38.7474)	−60.6647 (38.5749)
Constant	1.7329 (3.5879)	−4.2283 (5.0515)	10.6708 (6.2951)	4.0997 (7.3027)
Corrected *R*-Squared	0.33	0.34	0.34	0.35
Observations	169	169	169	169

[a]Standard errors of coefficient estimates are shown in parentheses.

variables that appear in the quantity equation (5) also appear in the duration equation, this is a potential problem here.

We can obtain consistent estimates of the coefficients of (5) by obtaining maximum likelihood estimates of a reduced-form contract duration equation[41] to generate a sample selection correction H for each observation, adding the estimated values of H to (5) and then estimating the augmented equation (5) using OLS. The coefficient of H is then a consistent estimate of the covariance of u and v.

The results are reported in Table 7.[42] The OLS results appear in columns 1 and 2 and the OLS results with H introduced appear in columns 3 and 4. In both cases, estimates with and without quadratic terms in plant and utility quantities are reported. The results are generally consistent with my expectations. Larger plants tend to place larger orders and utilities with larger aggregate requirements do so as well, although the utility effect is generally small. The quadratic in plant quantity is not significantly different from zero. The coefficients of the mine-mouth dummy has the predicted sign and is estimated fairly precisely. Mine-mouth plants have contracts that are nearly 1.5 million tons larger (30 trillion Btu's) than other plants *ceteris paribus*. Regional differences in supply characteristics lead to larger contracts with western suppliers than with suppliers elsewhere. The coefficient of the correction variable H is negative, although not quite significant at the 5 percent level (two-tailed test), implying that the errors in the duration and quantity equation are negatively correlated. Including this correction does not have dramatic effects on the results for the coefficients of interest, however. The primary effect is to reduce the magnitude and significance of the coefficient of *WEST*.

[41]*QUANTITY* and *LOG-QUANTITY* are treated as being endogenous.

[42]The mean value for H is 0.076.

Finally, for the record, I report two-stage least square (*2SLS*) estimates of equation (2) in Table 3, column 9, and the equivalent of two-stage least squares for the maximum likelihood estimates of equation (2) in Table 5, column 9.[43] The estimates do not change in any important way from those obtained using the other estimating techniques in either case.

VI. Conclusions

The purpose of this paper has been to examine empirically hypotheses about the relationship between the duration of coal contracts and the presence of the three types of relationship specific investments discussed by Williamson (1983).[44] I argue that as relationship-specific investments become more important, the parties will find it advantageous to rely on longer-term contracts that specify the terms and conditions of repeated transactions *ex ante*, rather than relying on repeated bargaining. I make use of a large sample of coal contracts to examine this hypothesis. The empirical results obtained provide fairly strong support for this hypothesis. They are quite robust to alternative model specifications, samples, and estimating techniques. The results therefore provide additional empirical support for the view that the structure of vertical relationships between buyers and sellers is strongly affected by variations in the importance of relationship-specific investments.

[43] I assumed that *LOG-QUANTITY* is endogenous, and use the right-hand side variables in (5) as instruments for the *2SLS* results reported in Table 3, col. 9. Obtaining the equivalent of *2SLS* estimates for the case in which I treat the sample as being truncated and use maximum likelihood techniques, is more complicated. Following Maddala (pp. 234–40) and L. S. Lee et al. (1979), I proceeded in the following way. First, I estimate a reduced-form duration equation using maximum likelihood techniques. This allows me to obtain consistent estimates of H_i which can in turn be used to obtain consistent estimates of a contract quantity equation as discussed above. I use these estimates of the quantity equation to obtain predicted values of *QUANTITY* or *LOG-QUANTITY* which are then used in place of *QUANTITY* and *LOG-QUANTITY* to estimate equations (1) and (2) using maximum likelihood techniques. The results reported in Table 5, col. 9, assume that log(*PLANT QUANTITY*), log(*UTILITY QUANTITY*), *MIDWEST*, *WEST*, and *MINE-MOUTH* are exogenous variables. These variables are used to estimate a reduced-form duration equation using the maximum likelihood technique described earlier. An equation for log(*QUANTITY*) is then estimated using log(*PLANT QUANTITY*), log(*UTILITY QUANTITY*), *MIDWEST*, *WEST*, *MINE-MOUTH*, and *H* (generated from the reduced-form duration estimates) using OLS. The predicted values from this equation are then used instead of *LOG-QUANTITY* in (2) to obtain the maximum likelihood estimates reported. Specification (1) has also been estimated using this approach. The results appear to be robust.

[44] As well as similar considerations of transaction-specific investments identified by Klein et al.

APPENDIX

Here I discuss the sources of the data and the construction of the variables. The data base that I rely on was constructed from a variety of sources for use in a research project focusing on vertical relationships between electric utilities and coal suppliers. This is one of three papers that has been produced so far from this project.

The construction of the data base began with the choice of contracts to use in the analysis. Contracts were chosen if they appeared in *both* the 1981 and 1983 editions of *The Guide to Coal Contracts* (Pasha Publications) and for which information necessary for the project was reported. Contracts had to appear in both publications because some information that was desired appeared in one or the other publication, but not both. This also made it possible to check for errors and inconsistencies in the contract characteristics reported. To appear in both publications, contracts had to be in force in 1979. In five cases, actual contracts were used to supplement the data available from the primary sources.

This collection procedure resulted in a sample of 296 contracts (of which 277 had enough information to be used here) which generally had the following information, some of which is used in this paper and some of which I am using in related work:

1. Information required to calculate the agreed upon duration of the contract (see discussion below).
2. Contract quantities for 1979, 1980, and/or 1981 in tons.
3. The contract specifications for the Btu content and the sulfur content of the coal.
4. The identity of the seller and the location of the mine.
5. The identity of the buyer and the destination of the coal.
6. The base price for the coal at the time the contract was signed.
7. The actual price for the coal in 1979, 1980, and/or 1981.
8. Delivered quantities in 1979, 1980, and/or 1981.
9. Actual Btu and sulfur content of the coal.

Once the contract sample was selected, individual contracts were matched with specific utilities and power plants (where possible). Two publications were utilized to obtain coal quantity and quality (Btu content) information by plant and utility: *Cost and Quality of Fuels for the Electric Utility Industry* (U.S. Department of Energy, various years) and *Steam Electric Plant Factors* (National Coal Association, various years). For public utility holding companies, coal utilization for subsidiaries was aggregated. Jointly owned plants were assigned to the operating company.

The three coal supply regions represent aggregations of smaller U.S. Bureau of Mines (BOM) districts. The West was defined as including BOM districts 16 through 23. The Midwest included BOM districts 5, 9, 10, 11, 12, 14, and 15. BOM district 15 includes Texas, but we have no contracts for coal produced in Texas. The East includes coal from the remaining BOM districts, primarily in Appalachia. The differences between regions is discussed in more detail in my 1985 paper. The *Keystone Coal Industry Manual* (Mining Information Services) and an atlas were used to help locate mines in specific BOM districts.

The variable definitions and construction are as follows:

DURATION: Contract Duration: The contract data base generally provides information for the date the contract was executed, the termination date and (less frequently) the date of first delivery of coal. A specific month and year is often provided, but sometimes the source specifies only years. Because the contract execution date was available more often than the date of first delivery and because the two are generally quite close together, contract duration was measured as contract termination year minus execution year. Initial experimentation with duration measured using the date of first delivery or using month and year indicated that the results were unaffected, so the definition that preserved the largest number of contracts was used.

QUANTITY: Annual contract quantity in trillion Btu's. The contracted tonnage reported for 1980 (if that was not available, or obviously not representative, 1979 or, alternatively, 1981 were used instead) was multiplied by the contracted Btu content of the coal to arrive at the contract quantity variable.

MINE-MOUTH: Mine-mouth dummy variable that is equal to one if the plant is a mine-mouth plant and zero otherwise. The information in my 1985 paper combined with the coal destination information in the *Guide To Coal Contracts* was used to construct this variable. The Navajo and Mohave plants were included in this category as well since they have economic characteristics very much like a mine-mouth plant.

MIDWEST: A regional dummy variable that equals one if the coal is from a midwestern mine (as defined above) and zero otherwise. The contract data base provides information on mine location.

WEST: A regional dummy variable that equals one if coal is from a western mine (as defined above) and zero otherwise.

PLANT QUANTITY: Annual plant utilization of coal. Coal utilization by a plant to which a specific contract is dedicated (at least 90 percent of the coal delivered to a single plant) for 1980 (1979 or 1981 if necessary to match *QUANTITY*) in trillion Btu's. Obtained from the Department of Energy and National Coal Association publications identified above.

UTILITY QUANTITY: Annual utility utilization of coal. Coal utilization in 1980 (or 1979 or 1981 if necessary to match other data) by the utility operating a plant to which a contract is dedicated. Obtained from the Department of Energy and National Coal Association publications identified above.

PLANT PROPORTION: Delivered contract quantity in Btu's divided by plant utilization in Btu's. Delivered contract quantity in tons was pulled from the contract information for 1980 (or 1979 if 1980 was not available), and multiplied by the delivered Btu content of the coal to obtain quantities delivered to a specific plant under a contract dedicated to that plant. This figure was then divided by *PLANT QUANTITY*.

UTILITY PROPORTION: Delivered contract quantity in Btu's (as defined above in definition of *PLANT PROPORTION*) divided by utility utilization of coal in Btu's for 1980 (1979 or 1981 otherwise).

PLANT/UTILITY: *PLANT QUANTITY* divided by *UTILITY QUANTITY*.

YEAR: The year specified as the execution date of the contract.

DATE-71: A dummy variable that equals one for contracts signed in 1971, 1972, and 1973.

DATE-74: A dummy variable that equals one for contracts signed in 1974, 1975, 1976, and 1977.

DATE-78: A dummy variable that equals one for contracts signed in 1978 and 1979.

The mean, standard deviation, minimum, and maximum values of these variables for the 277 observation sample and the 169 observation (single delivery point) subsample are contained in Tables 1 and 2. The data for the variables used in this paper are available upon request.

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