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TITLE: THE EFFECT OF MARKET STRUCTURE ON INTERNATIONAL COAL TRADE

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THE EFFECT OF MARKET STRUCTURE ON INTERNATIONAL COAL TRADE

by

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ABSTRACT

This paper is concerned with the determinan international steam-coal trade. Most work in proj coal trade has been either qualitative (a consens experts) or, if quantitative, has been base competitive spatial-equilibrium models. Unfortun the competitive model of trade does not appear to a for observed and anticipated trade flows. Th consistent with findings in the commodity trade lite that, although markets may behave in a rational ec fashion, market concentration among producers, tr and consumers leads to trade patterns signifi different than those associated with competitive mark

The purpose of this paper is to explore significance and effect on patterns of steam-coal tr several deviations from the simple competitive mode addition to perfect competition, we examine mo (South Africa) and duopoly (South Africa, Australia a competitive fringe (US, Canada, Poland, Chin Columbia). Using a simple equilibrium model of trade, we examine these market structures and evalua extent to which they can explain existing and antic trade patterns.

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I. INTRODUCTION

One of the key economic questions in international commod explaining observed trade patterns. The principal motiva interest is in forecasting how trade may develop and how gover can influence that trade. Several decades of research, much c grain trade, have led to frustration with the simple compe trade where the least-cost supplier captures an importing c market. For many commodities, this behavioral model qualitative observations nor does it explain observed trade p research has concentrated on developing alternate theories of rational producer and consumer behavior. The purpose of this paper is to quantitatively explore the effect of market structure on trade, within the context of the international steam coal market.

II. BACKGROUND

A. The Steam Coal Market

With the rise in the real price of oil and natural gas over the past decade, interest has shifted to coal as a principal alternative source of energy. The use of coal has been encouraged in countries with plentiful domestic resources (such as the US) and in countries with negligible domestic resources (e.g., Japan). This has lead to modest international trade in steam coal and expectations of more significant trade over the coming decades.

Until very recently, metallurgical coal dominated international coal trade to the virtual exclusion of steam coal. This situation is changing due in large part to the oil price rises of recent years. Table I shows steam coal exports in 1979 and 1980 by country. Unfortunately, more historic or detailed data on steam coal trade patterns are not readily available. As can be seen, trade grew by a third from 1979 to 1980. The Australian government projects world demand for imported steam coal to grow to 100-170 million tonnes per year by 1985 and 191-291 million tonnes per year by 1990 (Australian Department of Trade and Resources, 1981). This is consistent with US government forecasts (Interagency Coal Export Task Force, 1981). One can conclude from these data that the international market is currently rather small but appears to be growing rapidly. Coal has the potential for being a very significant commodity in international trade, particularly if oil prices remain high.

TABLE I: STEAM COAL EXPORTS[a]
(10^6 tonnes)

Country	1979	1980
Australia	5.9	9.4
Canada	1.0	1.2
Republic of South Africa	15.9	21.4
United States to Canada	11.0	10.3
United States excluding Canada	2.4	15.2
Poland[b]	19.5	15.8
China	0.3	0.6
United Kingdom[c]	2.3	3.8
USSR	N/A	N/A
Other	N/A	N/A
Total	58.3	77.8

[a]Source: Abbey and Kolstad, 1982.
[b]Exports to West only.
[c]Total exports, principally steam coal.

There is much interest in the United States in the extent to which the US will be an exp er of coal. Table I indicates that the US share of the steam coal markets has een around 25%. The 1980 share is higher than the 1979 share, although this may be due at least in part to reduced exports from Poland. The US government anticipates the US share of the international market to rise to 38% by the year 2000 (Interagency Coal Export Task Force, 1981). However, current and anticipated significant US participation in steam coal trade would appear to be inconsistent with production cost information. As shown in Table II, North American coal is not particularly cost competitive with South African or Australian coal in either Europe or Japan. Indications are that this will persist even after significant depletion. Because Europe and Japan are by far the dominant importers of coal, Table II suggests that if the international coal market is competitive, Australia and South Africa should be the only exporters of coal.*

In fact, the common view is that the international coal market is competitive, a view based on the abundant endowment and wide distribution of resources. Consider, for instance, the suggestion of the International Energy Agency's coal research arm: "T ere is sufficient free competition in and between the four major coal exporting countries for the price of coal to tend towards long-run marginal cost " (National Coal Board, 1981). Yet the potential exists for a number of participants in the market to exert market power. In South Africa, virtually all output is from mines operated by members of the Transvaal Coal Owners Association (TCOA). The TCOA operates as a domestic cartel, assigning production quotas, and marketing member output.

*Other countries, such as Poland and Columbia, can compete in certain markets. However, their export potential over the next decade is expected to be modest.

TABLE II: COSTS OF DELIVERING COAL TO EUROPE AND JAPAN

Country of Origin	Mine-Mouth	Inland Transport	Ocean Transport	Delivered
A. TO EUROPE				
US East Coast	1.55	0.35	0.35	2.25
Australia	0.95	0.15	1.00	2.10
South Africa	0.95	0.30	0.60	1.85
B. TO JAPAN				
US West Coast	1.05	0.65	0.45	2.15
Australia	0.95	0.15	0.40	1.50
South Africa	0.95	0.30	0.60	1.85
Western Canada	1.30	0.45	0.40	2.15

[a]Units: 1980\$/10^9 Joules; Source: Interagency Coal Export Task Force, 1981.

The TCOA is also the principal owner of the export shipping terminal. To top this off, the South African government has a system of export licenses for coal (Abbey and Kolstad, 1982). Whether there is potential to exercise market power in Australia is less obvious, although there is concentration in the coal industry. Four firms control almost 40% of output from steam coal projects currently in production or planned for development in 1990. Labor unions or railroads could also extract rent, and the government has a system of export licenses (although they do not currently appear to be particularly constraining on exports). On the consuming side, a number of countries have a single or major national buyer of foreign coal (e.g., Japan, France and Spain). National utilities dominate buying in many other countries.

B. Applied Analyses of Coal Trade

In the last section we saw that although the international steam coal market might appear to be competitive, the perfect competition model of trade does not account for current or anticipated trade patterns. Most authors attribute this failing to institutional factors such as an inability to increase export port capacity or non-economic buying preferences. For instance, in projecting coal trade patterns, a typical approach is to assume that export capacity is constrained, particularly in Australia and South Africa. If demand is higher than constrained output levels, the higher cost suppliers will enter the market. This is the approach taken by the Department of Energy (1982) to project US coal exports: to ensure US participation in the market, output from all other exporters are constrained. Similarly, ICF (1981) constrains only South African and Australian exports to develop their forecasts. In an analysis of the effects of deregulating US railroads, the NERA Corporation (1981) takes a slightly different approach by assuming that certain exporters face sharply rising costs from rapid increases in exports. This effectively constrains exports, although not at a predetermined level. Constraints undoubtedly exist on short-run capacity, but it is difficult to determine and justify constraints on long-run capacity.

A somewhat plausible explanation for the participation of high cost suppliers in the market is the intent of consumers to diversify supply. ICF (1981) assumes consumers will obtain no more than a certain percentage of total imports from a single country. The Interagency Coal Export Task Force (1981) suggests that there is a finite elasticity of substitution for identical products from different suppliers. Reddy (1976) has estimated an elasticity of substitution between US and Australian coal in Japanese markets. Any of these assumptions can force the market participation of high-cost producers.

The various assumptions used in the above studies have the desirable characteristic of yielding a sizeable market share for the US. Unfortunately, the assumptions are rather ad hoc, and difficult to quantitatively justify. More importantly, the assumptions require data that are very difficult to obtain (e.g., a nation's coal production capacity at some future point in time).

C. Other Commodities

The search for a trade theory which can explain trade flows without resorting to questionable assumptions has some history, particularly in the grain trade literature (refer to Thompson, 1981; Sarris, 1981; Labys, 1978). The grain trade situation is strikingly similar to that of coal trade: trade flows do not seem to be explainable on the basis of perfect competition. McCalla's (1966) early attempt to explain observed wheat trade patterns suggested that Canada and the US act as a wheat cartel setting wheat prices which other producers follow. Alaouze et al (1978) extend this to a cooperative triopoly involving Australia. In both cases, cartel operating rules are hypothesized which result in a determinant set of prices and trade flows. Schmitz et al (1981) go a step further and examine how a formal grain cartel might operate. Carter and Schmitz (1979) counter that Japan and the European Economic Community act as non-cooperative duopsonists. They suggest that the Japanese import quota and the EEC variable import tariff result in the dominance of consumer power which can explain observed trade patterns.

The basic idea behind all of this work is that the structure of the market, in terms of the nature and extent of market power exerted by participants, is what determines trade. This is supported by the behavior of the soybean market which from a structural perspective appears to be competitive and for which the competitive model of trade explains observed trade reasonably well.* However, one problem with assuming that trade can be explained on the basis of market structure is that there are a variety of assumptions one can make about oligopolistic behavior and strategy (see Friedman, 1977; Bresnahan, 1981), each of which results in a different set of equilibrium prices and trades.

As with coal, the question of diversity of supply arises in discussions of commodity trade in general. Armington (1969) suggested that consumers may distinguish otherwise identical products on he basis of country of origin.

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*This observation was conveyed to the authors by Alex McCalla of the Stanford Food Research Institute and is supported by the work of Houck et al (1972) among others.

He developed a theory of demand involving a finite elasticity of substitution for a product from different countries. Grennes et al (1978) have applied this theory to grain trade, but resorted to an assumption about the elasticity of substitution rather than estimating it based on historic data.

III. A MODEL OF IMPERFECT MARKETS

It is an hypothesis of this paper that current and anticipated patterns of coal trade, including significant US exports, are consistent with rational economic behavior on the part of producers and consumers. We suggest that the use of market power by one or more participants in the market can lead to significant US participation in the international market. This suggestion can be supported by exploring the effect of market structure on coal trade. Our approach is to define a model of the steam coal market and test the effect of a variety of market structures on trade patterns. Our approach is a qualitative one in the sense that no attempt is made to rigorously test the hypothesis against observed and anticipated trade patterns. Nevertheless, such hypothesis testing is a desirable albeit ambitious long-term goal. In this work, a model of imperfect competition is developed. Using this model and nominal assumptions about demand and production costs, market operation can be simulated for a variety of market structures.

To overview the model, it is a spatial equilibrium model but not in the conventional sense. Nearly all spatial equilibrium models utilize mathematical programming to find an equilibrium set of prices and quantities (Takaykama and Judge, 1971; Thompson, 1981). This works well for finding a competitive partial equilibrium (by maximizing consumer and producer surplus) or even an equilibrium for the case of a single monopolist or monopsonist (by maximizing producer <u>or</u> consumer surplus). Unfortunately, most imperfect market situations involve a number of agents, simultaneously maximizing their objectives based on certain assumptions about their opponents' behavior In general such markets can be characterized as n-person non-zero-sum games. With the exception of a zero-sum, two-person game, such games cannot in general be couched as the maximization of a single function. Our approach to finding an equilibrium is to a) define for each agent the conditions under which he will maximize his objective; and b) solve for an equilibrium set of prices and quantities which simultaneously satisfies the maximization conditions for all agents.

In more technical terms, the Kuhn-Tucker conditions for each agent's maximization problem are collected. A solution to the entire set of conditions is determined using a linear complementarity algorithm applied to successive linearizations of the nonlinear Kuhn-Tucker conditions. Thus, in mathematical terms, the model consists of a set of equations of the form

$$f_i(\underline{z})\, z_i = 0 \quad , \forall i \tag{1a}$$

where f_i is a function of the vector of variables $\underline{z}$. We will seek a solution to Eqn. 1 such that $\underline{z}$ and $\underline{f}$ are non-negative:

$$f_i(\underline{z}) \geq 0, \; z_i \geq 0, \quad \forall i \tag{1b}$$

This is a standard way of formulating economic equilibrium problems (see Scarf and Hansen, 1973; Mathieson, 1982).

To simplify the presentation of the World Coal Trade Model, we have separated the coal production decision from the decision to exercise market power. This is achieved by assuming consumers and producers are price takers but that rents can be extracted by either agent through the imposition of an export or import tariff. Of course, this gives identical results to the case of a producer or consumer exercising market power directly. Thus, there are four basic sets of equations: producer profit maximizing conditions; consumer utility maximizing conditions; interregional price efficiency conditions; and tax-revenue maximizing conditions. Table III presents a synopsis of the endogenous and exogenous variables used in the model. The model is described below in terms of the four sets of equations.

A. Consumer Optimality Conditions

Each of the J consumers faces a local price for coal, $\tilde{p}_{jt}$. If the price is positive in the j^{th} region, demand as a function of price must be equal to the quantity consumed:

$$u_{jt} = \sum_k \sum_i a_{ik} q_{ijkt} - d_{jt}(\tilde{p}_{j\hat{t}}, t = 1, \ldots T) \geq 0, \; u_{jt} \tilde{p}_{jt} = 0 \qquad (2)$$

B. Producer Profit Maximization Conditions

The standard condition for profit maximizing behavior is that marginal cost equals marginal revenue. In the case of a competitive market, marginal revenue is price. Recall that we assume for conceptual purposes that market power is exercised by the taxing authority, not producers. First order conditions for producer profit maximization are

$$w_{ikt} = C_{ikt}(s_{ikt}) - \hat{p}_{ikt} \geq 0 \, , \; w_{ikt} s_{ikt} = 0 \qquad (3)$$

TABLE III: MODEL PARAMETERS AND VARIABLES

I. Indices

$j = 1, \ldots, J$	Demand regions
$i = 1, \ldots, I$	Supply regions
$k = 1, \ldots, K$	Coal types
$t = 1, \ldots, T$	Time periods

II. Endogenous variables

q_{ijkt}	:	quantity of k-coal shipped from i to j in time period t (10^6 tonnes/yr)
s_{ikt}	:	production of k-type coal in region i, time period t (10^6 tonnes/yr)
$\tilde{p}_{jt}$	:	price of coal to consumer j, time period t (\$/10^9 Joules)
$\hat{p}_{ikt}$	:	price of k-coal to producer i, time period t (\$/tonne)
π_{ijkt}	:	unit tax on k-coal from producer i to consumer j, time period t (\$/tonne)

III Exogenous variables

ρ	:	discount rate
τ_{ijt}	:	unit transport cost from region i to region j, time period t (\$/tonne)
d_{jt}	:	demand function for coal in region j, time period t (10^{15} Joules/yr)
C_{ikt}	:	marginal cost function for supplying k-coal in region i in time period t as a function of the production rate (\$/tonne)
α_{ik}	:	heating value of k-coal in region i ([illegible] Joules/tonne)

In other words, price equals marginal cost unless no production takes place. Note that because inter-period storage is not represented, the connection between changes in price over time and the interest rate is not embodied in the model.

It is also necessary to assume that quantities sold to consumers are consistent with production levels.

$$v_{ikt} = s_{ikt} - \sum_j q_{ijkt} \geq 0 \quad , \quad v_{ikt} \quad \hat{p}_{ikt} = 0 \tag{4}$$

This condition states that exports must be equal to production unless the price is zero in which case some production may be freely discarded.

C. Tax Revenue Maximization

In this conceptualization, market power is exercised through export (or import) taxes. For simplicity, we assume the taxing authority can price discriminate, setting a different tax rate for different destinations (or origins).

Arguments can be made on both sides as to whether price discrimination or a uniform tax is most appropriate. If market power is actually exercised through a tax, then the same tax rate for all coal might be most appropriate. If market power is exercised by producers, then price discrimination might be most appropriate since most sales are on the basis of long term contracts, with separate, private negotiations for each bilateral contract. It turns out that in the analysis presented in the next section, optimal tax rates do not vary widely.

We present the case of an export tax. The case of an import tax can be developed in a similar manner. Tax revenue is given by

$$\text{Revenue}_i = \sum_t (1 + r)^{-t} \sum_k \sum_j \tau_{ijkt} \; q_{ijkt} \tag{5}$$

In determining the tax rate that maximizes revenues, this equation will be differentiated with respect to the tax rate. Assume that changes in taxes to one country do not affect consumption from another country. The change in q with respect to π is just the slope of the residual demand curve in region j for region i's products:

$$\frac{dd_{jt}}{d\tilde{p}_{jt}} = \frac{\partial d_{jt}}{\partial \tilde{p}_{jt}} \div (1 + r_{ij}) \tag{6}$$

where r_{ij} is the conjectural variation; i.e., r_{ij} is the change in quantity supplied to j from all other producers with a change in quantity supplied to j by i (see Bresnahan, 1981 or Intrilligator, 1971). For perfect competition (or a Bertrand oligopoly), $r_{ij} = -1$; i.e., any reduction in output is assumed to be picked up by a competitor. The Cournot-Nash behavioral model assumes $r_{ij} = 0$. We can now write the first order condition for a maximum of Eqn. 5:

$$y_{ijk} = -\sum_{t} (1 + \rho)^{-t} \left\{ q_{ijkt} + \sum_{k} \pi_{ijkt} \frac{\partial q_{ijkt}}{\partial \pi_{ijkt}} \right\}$$

$$= -\sum_{t} (1 + \rho)^{-t} \left\{ q_{ijkt} + \frac{1}{(1 + r_{ij})} \sum_{k} \frac{\pi_{ijkt}}{\alpha_{ik}\alpha_{ik}} \frac{\partial d_{jt}}{\partial p_{jt}} \right\} \leq 0,$$

$$y_{ijkt} \pi_{ijkt} = 0 \tag{7}$$

Although equation 7 is somewhat complicated, it becomes simpler when one assumes Cournot-Nash behavior and no inter-temporal price effects vis-a-vis demand.

D. Price Efficiency Conditions

Because we deal with two sets of prices, one for consumers and one for producers, it is necessary to link these sets of prices to assure consistency:

$$z_{ijkt} = \tilde{p}_{ikt} + \tau_{ijt} + \pi_{ijkt} - \alpha_{ik} \bar{p}_{jt} \geq 0 , \quad z_{ijkt} q_{ijkt} = 0 \qquad (8)$$

The interpretation is that if any trade takes place between a producer and a consumer, the difference between producer and consumer prices must be precisely the sum of transport costs and taxes, and in any event cannot be greater than this sum.

IV. COURNOT-NASH PRODUCER MONOPOLY AND DUOPOLY

As was indicated earlier in this paper, the competitive model does not appear to explain current or anticipated steam coal trade flows. As was also indicated, studies of trade in other commodities suggest that alternate assumptions about market structure can explain trade patterns. In this section we take a first step in exploring this hypothesis by examining how trade flows differ from the perfect competition case under two alternate market structures.

On the producer side, it would appear that the Republic of South Africa (RSA) is in the best position to exercise monopoly power, not only because of its apparent cost advantage in delivering steam coal but also in terms of institutions which are already in place to exercise that power. Australia is a second producer which has the potential to exercise market power, principally because of its cost advantage. Institutional mechanisms for exercising power appear to be less developed in Australia than in the RSA. This suggests the two cases we will examine. One is the case of the RSA acting as a monopolist with all other producers acting competitively. The other case is that of a noncooperative duopoly involving the RSA and Australia with all other producers acting competitively. A fundamental assumption for both the monopoly and the duopoly case is that of Cournot-Nash behavior. In other words, in setting export taxes, production levels and shipment patterns from other producers are taken as given. No account is taken of the reaction of competitors to the strategies of either the RSA or Australia.

The assumption of Cournot-Nash behavior is very common in economic analysis of market behavior probably because it is the simplest of many models of oligopoly behavior. It has some intuitive appeal since in reality producers do see the production levels of competitors but may not be sure at all how competitors will react to changes in strategies on the part of the oligopolists. Unfortunately, there are also deficiencies with the Cournot-Nash model, the most glaring of which relates to deterring of entry of the competitive fringe (limit pricing). For instance, the strategy of setting price just below the price at which the fringe enters is not a Cournot-Nash strategy since the oligopolist is taking account of how the fringe will react to the oligopolist's price and quantity decisions. Nevertheless, the Cournot-Nash model is a good starting point for what we hope is a more extensive search for a market model with the best explanatory power.

The analysis involves exercising the World Coal Trade Model separately for each of these two different market structures plus the perfect competition structure. Description of the data assumptions and solution technique for the model is relegated to an appendix. Table IV presents the basic results of the analysis for the year 1990. In the table, export market shares are forecast from the three major producing areas to the two major consuming areas. The results do not reflect domestic coal use. As can be seen, results for the competitive case confirm our expectations in that Australia and the RSA capture 87% of the international market. North America (Canada and the US) plays no role. Such a result prompts analysts to either reject the competitive model or constrain output from Australia and RSA to force the entry of North America.

The second market structure examined is that of a RSA monopoly with all other producers on the fringe. In exercising its market power, the RSA increases prices by roughly $10-15 per tonne in Europe and less than $5 per tonne to east Asia. As a result, exports are cut by more than half relative to the competitive case with the difference attributable to reduced demand and increased production by Australia. However, since Australia is an inframarginal producer and is acting competitively, there is still no place in the market for North America.

The third case examined is that of a (noncooperative) duopoly involving the RSA and Australia with all other producers in the competitive fringe. Exports from the RSA and Australia are slightly over half those for the competitive case with the difference attributable to reduced demand and significant entry by the fringe, principally North America. Qualitatively, these results are particularly attractive because of the large market share for North America. Compare the 24% share of the 1990 market in Table IV with the 1979 share for North America of 25% (Table I).

TABLE IV: FORECAST 1990 INTERNATIONAL STEAM COAL MARKET SHARES FOR THREE DIFFERENT MARKET STRUCTURES[a]

From	To	Competitive	RSA Monopoly With Competitive Fringe	RSA/Australia Duopoly with Competitive Fringe
North America	Europe	--	--	0.03
RSA	Europe	0.43	0.27	0.28
Australia	Europe	--	0.09	0.05
North America	East Asia	--	--	0.21
RSA	East Asia	0.11	0.04	0.11
Australia	East Asia	0.33	0.44	0.13

[a]Totals do not add to unity because a number of minor producers (principally Poland, Colombia and China) and some consumers are not included in this table.

V. CONCLUSIONS

The basic problem addressed by this analysis is how to account for past and anticipated patterns of trade in steam coal. Our principal conclusion is that the exercising of market power has a significant effect on trade patterns. Exercising such power tends to increase the share of the market for the competitive fringe, rectifying the principal failing of the competitve model of trade.

Nevertheless, the research presented here only scratches the surface of this question. We have only examined two of many possible market structures. The case of bilateral monopoly involving Japan has to be considered a potential structure. More importantly, we have made no attempt to test the validity of a particular structure, comparing modeled trade flows with historic data. It is hoped that these questions can be explored in subsequent research.

APPENDIX: DETAILS OF THE WORLD COAL TRADE MODEL

In this appendix, we present a brief overview of the particulars of the World Coal Trade Model which was described in Section III. Most applied models are in a continual state of improvement, particularly with regard to model parameters and coefficients. Since the international steam coal market is so young, we expect sources of data used for this model to evolve rapidly. Nevertheless, it is useful to indicate the general sources of data used in the analysis presented in this paper. For more complete documentation, interested readers are referred to Abbey et al (1982).

The model consists of four discrete time periods, spanning the years 1985 through 2000. Four types of coal are considered: low-sulfur bituminous, subbituminous, lignite, and high-sulfur bituminous. Only the first two of these is considered to be tradeable internationally. These coals can be produced for export in ten coal supply regions. Coal supply in six of these regions (three US regions, western Canada, the Republic of South Africa and Australia) is represented by a linear marginal cost curve for each coal type giving marginal cost as a function of the rate of extraction of coal. These supply curves have been estimated (non-econometrically) by and for the Energy Information Administration (EIA) of the US Department of Energy. Estimates of mine to port transport costs were added to these supply curves. Modest inelastic supply was hypothesized for the other four supply regions (Poland, Colombia, China and Indonesia).

Demand for coal in each of 21 regions is represented by a single constant elasticity demand function. These demand functions were developed by assuming a price elasticity of demand for steam coal of -0.6. This is roughly consistent with EIA calculated elasticities. For most regions of the model, the EIA (in their annual report to the US Congress) forecasts consumption and prices for steam coal. These price-quantity pairs by region determine unique demand curves given the assumed price elasticity. Estimates of domestic coal supply were developed for countries expected to import steam coal (particularly in Europe). These supplies were assumed to be inelastic and were subtracted from overall steam coal demand to yield an import demand function.

A single ocean port was associated with each producer and each consumer. Assumptions were made about the capacity of each of these ports in terms of maximum vessel size. Thus, the maximum vessel size for a particular route would be based on the minimum capacity at the origin and destination. This in turn determines the cost of moving coal over that route.

The model is solved using a version of Lemke's algorithm for solving the linear complementarity problem (Tomlin, 1976). Since demand is nonlinear, the problem is successively linearized until convergence to a solution is realized. Such an approach has been used very successfully for general equilibrium problems by Mathieson (1982). Solution time varies with the assumed market structure and convergence criteria but takes on the order of 30-45 minutes of CPU time on a DEC-VAX computer. Such a problem would involve approximately 1000 constraints and variables.

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