Resources and Energy 10 (1988) 293–314. North-Holland

MEASURING RELATIVE MARKET POWER IN THE WESTERN U.S. COAL MARKET USING SHAPLEY VALUES

Frank A. WOLAK

Stanford University, Stanford, CA 94305, USA

Charles D. KOLSTAD

University of Illinois, Urbana, IL 61801, USA

Received July 1988

There has been a great deal of policy discussion about the extent to which prices of low-sulfur western coal have been inflated over costs. Railroads serving the Powder River basin and the states of Wyoming and Montana, through their severance taxes, have been accused of extracting monopoly rent from the market for cheap low-sulfur western coal. The question posed in this paper is who has market power? And if more than one party possesses power (as is likely) what is the relative power of participants in the market? To measure power in this market, we propose a new metric. We set up the market as a four-person game involving the states of Wyoming and Montana and the two railroads serving the Powder River Basin – the Burlington Northern and the Chicago and Northwestern. We then compute the Shapley values for this game and normalize them by potential industry revenue. We call this measure the Lerner–Shapley index and demonstrate that it has several desirable characteristics as a conduct-endogenous measure of market power. One conclusion of the paper is that the railroad serving Wyoming has more power than the other actors in the market.

1. Introduction

With the passage of the 1970 Clean Air Act, a significant shift in coal demand occurred in the U.S., away from high-sulfur coal, found mostly in the east and midwest, and to low-sulfur coal. Although low-sulfur coal exists in many parts of the country, particularly rich deposits (in the sense of low production costs) are found in the northwestern Great Plains, in the Powder River basin of Montana and Wyoming. Production in the area has grown from close to nothing in 1970 to over a sixth of U.S. production in 1987.

Although there are many coal producers in this region of the country, states and railroads seem to have considerable market power, at least on the basis of concentration or ability to coordinate producers. The two states (Montana and Wyoming) have significant severance taxes on coal (16–30%

of value). Two railroads (until recently, only one) serve the coal deposits in question. It is frequently charged that rail tariffs out of the Powder River basin are in excess of competitive levels, although this is difficult to prove.

The purpose of this paper is to measure both the absolute and relative market power of the participants in this coal market. Certainly market structure suggests that power exists. But questions remain concerning the magnitude of the power and how it is distributed among the four participants in the market (two states and two transport links). Other papers [Alt et al. (1983), Kolstad and Wolak (1983, 1985)] have explored the issue of the taxation power of the states. In this paper we extend the question to include railroads and focus less on aggregate market power of the group and focus on the division of power among the four participants in this market.

As a measure of market power, we propose Shapley values normalized by potential industry revenues. If the market is represented as a non-cooperative game with or without collusion, the Shapley value for a player in the game indicates the incremental contribution the player makes to all coalitions it could join. Hence, the higher the Shapley value for an agent, the larger its absolute and relative potential for exercising market power. Besides providing a rigorous measure of relative market power, an advantage of this measure over others that have been suggested is that the computation of Shapley values requires no information on market conduct or performance. In that sense, this methodology provides a more robust measure of market power in comparison to other indices.

The remainder of the paper proceeds as follows. In the next section we discuss background information on the western coal market, giving a policy context for the remainder of our paper. In section 3 we discuss the use of Shapley values to measure market power. In section 4 we present a game-theoretic model of imperfect competition in the western coal market. In section 5 we present our empirical results. The paper closes with policy implications.

2. The Western coal market

In recent years there has been tremendous growth in coal production in the Western U.S., particularly in the states of Montana and Wyoming. Large oil and gas price increases and the stagnation of the nuclear power industry have increased the overall demand for coal in the U.S. This trend has been moderated recently by the drop in oil prices and the glut in the gas market. Increased environmental consciousness (for example, over acid rain) has forced coal users away from high-sulfur midwestern coal to low-sulfur western coal.

Both Montana and Wyoming possess vast reserves of by far the cheapest domestically productive coal. Consequently, high levels of production from both states can be sustained for long periods of time without appreciable depletion effects. Currently there are two railroads serving the Montana and Wyoming coal basins, the Chicago and Northwestern and the Burlington Northern. The combination of rapidly increasing demand for very low-cost, low-sulfur coal in the midwest has apparently endowed these two states and railroads with considerable market power. Other western states possess low-sulfur coal but market conditions are such that they tend to serve local, or at best, regional, markets.

Because Montana and Wyoming export almost all of their coal out of the west, primarily to the midwest, severance taxes[1] are an excellent way for these states to collect rents from coal production with little burden on residents of the state. However, because the major demand centers for this type of coal are so distant, transport costs account for a significant portion of the delivered price of coal. With rail the only viable mode of transport for coal from these states, railroads could enter the rent capturing game through manipulation of rates. The passage of the Staggers Act of 1980, which exempts from regulation all rail transport rates below a critical percentage of unit variable costs while subjecting rates above the critical ratio to a test of reasonableness, has released much of the regulatory constraints on the railroads in their attempt to exercise market power [Levin (1981)]. Consequently, the railroads seem to have the legal freedom to set rates in competition with states to capture the rent from goods they transport.

Most previous studies of this market have focused almost exclusively on the rent capturing ability of either the producing regions or the modes of transport. Recent work by Mutti and Morgan (1983) gives an analysis of the competition for rents between Wyoming and the railroad serving its producers. However, this study ignores the high degree of substitutability, in the long run, between Montana and Wyoming coal and thus assumes the actions of Montana and its railroad have no effect on Wyoming's level of coal production. Other studies acknowledge that both the states and railroads possess market power but have chosen to focus on one of the two groups in the analysis. Zimmerman's (1979) analysis of the rent capturing ability of the railroads serving the Western U.S. coal market indicates that railroads have had some success in exercising their market power through higher transport tariffs and should have greater success in the future.

In a recent article, Atkinson and Kerkvliet (1986) look at the power of the railroads, producers and states in the Wyoming coal market. They attempt to measure the fraction of the rents (Ricardian or monopoly) accruing to the Wyoming producers, Wyoming state, Wyoming railroad and consumers of Wyoming coal. They find that consumers capture half the available rent with

[1] Montana's tax rate (including county taxes) on surface mined coal is 33 percent of value at the mine; Wyoming's tax rate is 17 percent [Blackstone (1983)]. Recently, in response to a soft coal market, Montana reduced its rates by a third for new contract sales.

the bulk of the remaining rent split between the producers and the railroad. Their analysis sheds light on a number of important issues including the effect of rail deregulation. The disadvantage of their model relative to the one presented here is that it defines the difference between observed price and estimated cost as rent, without letting rents be derived from an underlying model of producer and consumer behavior.

Two studies have dealt with the market power of the states in the Western U.S. coal market [Alt et al. (1983), Kolstad and Wolak (1985)]. Both studies addressed the issue of the gains to the western states from the formation of a western coal cartel. The second study also examined the effect on the market equilibrium of different types of competition between states in severance tax setting.

3. Measuring market power

The basic problem an analyst faces in understanding the western coal market is that there are several dominant actors in the market, each with potential market power. Is market power being exercised? Not surprisingly, the participants say no. It is true that there is no obvious collusion or other restraint of trade. But are there other, less obvious means these participants are using to exercise market power?

One approach to answering this question is to measure the power of the participants in the market, separating each participant's endowment of power (bestowed by the basic conditions of the market) from their exercise of that power because possessing power is necessary but not sufficient to exercise power. Also, knowledge that a participant possesses a large amount of potential market power will provide the impetus to look closely for more subtle ways that it can exercise market power.

The approach of this paper is to measure the endowment of power among the participants in the market as opposed to realized market power using a game-theoretic, market conduct independent, measure of the relative power of participants in a game: the Shapley value.

In order to understand this use of the Shapley value, in the next section we briefly discuss the general literature on indices of market power, particularly the Lerner index. We then briefly develop the Shapley–Lerner index.

3.1. Lerner and concentration indices

Conceptually, it is difficult to fault the Lerner index as an ex post measure of market power. The firm-level Lerner index is simply the proportion of firm receipts that are monopoly rents or, as defined by Lerner (1934), the relative extent that prices exceed marginal cost:

$$\lambda_i = \frac{(p - mc_i)q_i}{pq_i}, \tag{1a}$$

$$= \frac{p - mc_i}{p}, \tag{1b}$$

where q_i is output of firm i, p is product price and mc_i is marginal cost of firm i. In a static model, a positive firm-level Lerner index is de facto evidence of the exercise of monopoly power.

Regardless of concentration or other indicators of monopoly, if in the long run a firm sells at prices above competitive levels, then market power is being exercised.

As attractive as the Lerner index is, concentration ratios are more frequently used as indices of market power.[2] The Lerner index is information-intensive, requiring information on firm-level marginal costs, actual output, price and market share; i.e., information of basic market conditions, market structure and market performance. Frequently, such data are not completely available, particularly basic market conditions and performance. The virtue of concentration ratios is that they are relatively easy to measure using census or tax data. The problem with concentration measures is that they are at best only approximate indicators of market power; a high concentration index is neither necessary nor sufficient for the exercise of monopoly power and a low index does not necessarily indicate an absence of monopoly rents.[3]

Structure (concentration) indices are useful only to the extent that they imply power (Lerner) indices; i.e., they are a means to an end. A number of recent papers have attempted to bridge the gap between structure indices and power indices by focusing on how structure determines power, showing under what conditions the two indices are in 1–1 correspondence.[4]

[2] The n-firm (frequently four-firm) concentration ratio indicates the proportion of the market captured by the n largest firms. The Herfindahl index is the sum of squared market shares for all firms in an industry, with larger firms contributing relatively more to the index, a desirable characteristic for a concentration index [see Encaoua and Jacquemin (1980) and Hause (1977) for discussions of desirable characteristics for a concentration index].

[3] For instance, as pointed out by Lerner and others, a single firm with 100% of the market has no market power if demand is perfectly elastic. Similarly, an industry with a low concentration index can capture rents if formal or informal cooperation or coordination exists, either through agreement or coordinating agents such as government or trade associations. Knowledge of market structure alone is not sufficient to predict market performance qualitatively or quantitatively.

[4] In essence, most of this work has assumed a model of market conduct. For example, in a seminal paper, Saving (1970) derived a relationship between concentration ratios and the Lerner index within the context of the price leadership or monopoly with a competitive fringe model. In these models, conduct and structure information are sufficient to predict performance and thus power. In contrast, we propose an alternate index to predict power, involving a minimum of knowledge of either structure or conduct.

This line of work suggests that there is a clear need for a measure of market power which requires little or no information on market conduct and performance. Recent applications of game theory to power measures moved in this direction but still made significant assumptions about market conduct: non-cooperative Cournot–Nash behavior [Encaoua and Jacquemin (1980)], non-cooperative reaction function behavior [Cowling (1976), Donsimoni et al. (1984)] or critical concentration ratio models [d'Aspremont and Jacquemin (1985)].

3.2. Shapley–Lerner indices

In this section we develop an alternate measure of market power, a measure focusing on assessing the endowment of power in a market. Clearly, this definition of market power is different in spirit than that discussed by Lerner. However, for many markets this definition of market power is more relevant because of the many different ways the power possessed by a participant can manifest itself. If we view the market as an n-person game then game-theoretic measures of relative power in an n-person game can be translated into a measure of market power. The notion of power in an n-person game that we adopt is that of a Shapley value.

Measuring power in a game distinct from the outcome of the game is a difficult task. The actual outcome of a non-cooperative game is a priori indeterminant, in most cases, because the core of the game may contain more than a single point and the observed outcome may be solely a function of an aggressive first move on the part of one player. Consequently, assessing market power based on this single outcome as is done by conventional indices may lead to serious biases in assessing the endowment of market power of each participant. The Shapley value addresses this issue by asking if participants in a game were to collude, how much of a contribution, on the average, would each player make to each colluding coalition it joins? The average contribution a player makes to all the coalitions it could join is a reasonable proxy for its power in the game *independent of whether collusion actually takes place*. In addition, using this average contribution as a measure of market power should ameliorate the possibility of serious mismeasurement of the endowment of power, as can occur when the power measure is based on a single outcome from a non-cooperative game, as is the case for the Lerner index.

The notion of a Shapley value as a measure of relative power is even more appropriate in a market context. Even though open collusion may not take place, a myriad of other means can be used to coordinate players. Consequently, a reasonable assumption for our development is that if a firm has market power, it will exercise it if it is not legally constrained. In other words, if open collusion is precluded, that does not negate the power but only causes it to manifest in different ways. Therefore, even without any sort of explicit collusion, the Shapley value still makes sense as a measure of relative market power.

This measure of market power provides useful information in cases where the Lerner index is not computable. Because virtually no information is required about market conduct in order to construct our measure of market power, it can be used to assess the potential market power of participants in regulated markets or markets that do not yet exist. For instance, in a regulated market, given individual firm costs and market demand, the index we propose could be calculated.

The information embodied in the index would be very useful to regulators in deciding whether or not to deregulate the market and if so in what kind of fashion. This measure could also be used to predict the market conduct of firms in the market for a new product. Within the political context, Shapley and Shubik (1954) discuss the use of Shapley values as a way to assess the re-distribution of political power resulting from re-designing the size or type of a legislative body in a government. Because the Lerner index requires knowledge of actual market conduct, it is not available for use in these instances. In instances when both are available, it provides a measure of endowed market power to be contrasted with the market-conduct-specific Lerner index of actual market power.

The only information necessary to compute Shapley values is basic market conditions: costs and demands. While these may not always be easily obtained, they can often be estimated econometrically or from engineering data and in any event are much easier to measure than market conduct. In this sense we can say that the Shapley value index is a market-conduct-robust measure of market power. A discussion of the computation of the Shapley values is contained in the appendix.

To bridge the gap between Shapley values and Lerner indices, we normalize Shapley values by potential market revenues to produce the Shapley–Lerner index. Because of the averaging process used to compute each participant's Shapley value, the sum of the individual Shapley values is equal to the total profits from a cartel composed of all players. Because of this property, the natural definition of potential industry receipts for our purposes are those associated with a cartel composed of all participants.

Define the Shapley–Lerner index for firm i as the ratio of the assumed monopoly rent (Shapley value) for firm i to the firm's share of potential industry receipts:

$$\mu_i = \frac{\phi_i}{T/n}, \qquad (2)$$

where T is industry revenue associated with a cartel of all participants (potential industry receipts) and n is the number of firms in the industry. In a conventional Lerner index, the denominator of eq. (2) would be firm sales. However, with a perfect cartel, firm-level sales are not meaningful; some firms may produce nothing but just by withholding output contribute significantly to cartel profits. The industry-level Shapley–Lerner index can be any aggregating function of the individual Shapley–Lerner indices. A natural candidate is the mean value of the firm-level indices taken over all firms:

$$M = \frac{\sum_i \phi_i}{T}. \tag{3}$$

The above index is the ratio of potential industry monopoly rents to potential industry sales.

What is the significance of the firm-level and industry-level Shapley–Lerner indices? In most actual markets, we may not know the actual conduct of firms. For the purposes of anti-trust or other regulatory scrutiny, it is extremely valuable to know the relative market power of firms in a market. If firms have potential power, it is highly likely they will be ingenious in devising a way to exercise that power. Thus even if power does not appear to be exercised, there may be a variety of tacit or formal arrangements which result in the extraction of monopoly rents. Conversely, if there is not potential for power, then it certainly will not exist in actuality. In this way the Shapley–Lerner indices provide a useful measure for gauging the power possessed by individual firms in a market, which may or may not be distinct from actual amount of power exercised in the market.

4. An oligopoly model of the coal market

The purpose of this part of the paper is to introduce our model of price setting in the Montana–Wyoming coal market. A model of price formation is necessary to obtain the profit functions used to compute the Shapley–Lerner measures of market power discussed in the previous section.

To this end we first develop a general model of price setting in a spatial coal market. Our goal is to determine price levels and output as a function of conduct and basic market conditions. We then apply this model to the western coal market, using data on supply, demand and transport costs in that market.

4.1. The model

The general setting we will consider is that of several states selling a homogeneous good to a single demand center. Each state is connected to the demand center by a single transport link. Thus our model is a stylized version of the Western U.S. coal market. Because there are many individual producers within a state, producer output will be priced at marginal cost; thus all the producers within a state can be aggregated into a single supply schedule. There are also many transport links serving the many regions of the country purchasing western coal. On the supply side, the Burlington Northern railroad serves both Montana and Wyoming and the Chicago and Northwestern railroad serves Wyoming only. However, we believe that by abstracting to the case of a single demand center and separate transport links for each state we keep our problem computationally tractable yet still preserve the salient features of the competition between states and railroads in the Western U.S. coal market. Each state and transporter has as an objective to maximize tax revenue and profits, respectively.

The standard approach to competition among a small number of agents is to utilize a Cournot–Nash quantity based equilibrium concept. This approach has been used to analyze oligopoly behavior in the world oil market [e.g., Salant (1976)]. We propose to use a modification of this approach for our analysis. Instead of using quantity as the player's decision variable, we propose more relevant decision variables for each participant.

For states, we have chosen markup over marginal cost as the appropriate decision variable. Although there is extensive empirical evidence [see Scherer (1980)] that many firms price in this manner, the basic reason is that a severance tax on coal is basically a markup on the price of coal net of tax. Further support for this decision variable may be found in Kolstad and Wolak (1983)

For transporters, we have chosen the unit transport price ($ per unit shipped) as the appropriate decision variable. This seems to be a more intuitively appealing decision variable than quantity shipped since transporters generally offer a price and then ship whatever shippers desire, at that price.

Bearing in mind this general setting, we now introduce the model in mathematical notation. We represent the marginal cost function for state i as $S_i(q_i)$, where q_i is that state's output. The inverse demand function for output at the demand center is $P(\sum_j q_j)$. The markup and transport price per unit transported from state i are t_i and τ_i, respectively. The average cost of transport from state i to the demand center is $C_i(q_i)$.[5]

The equilibrium condition is that the price at which states and transporters offer coal equals the price consumers are willing to pay:

[5]Transport costs are assumed to be a function of quantity shipped in order to reflect source competition. In a more complex spatial market, if increased prices reduce the quantity shipped, then distant markets will be lost first, lowering the average shipment costs. This phenomenon can be embodied in our simple model by making average transport costs a function of quantity shipped.

$$(1+t_i)S_i(q_i)+\tau_i=P\left(\sum_j q_j\right) \quad \forall i. \tag{4}$$

Here the marginal cost of the coal from state i, increased by the tax rate and transport price must equal the demand price. The two equilibrium conditions (4) can be solved for q_i as a function of taxes and transport costs to yield

$$q_i(t_{\mathrm{m}}, t_{\mathrm{w}}, \tau_{\mathrm{m}}, \tau_{\mathrm{w}}) \qquad i=\mathrm{m}, \mathrm{w}. \tag{5}$$

If tax rates or tariffs change, the total derivative of this equation defines the corresponding shift in the market equilibrium:

$$\mathrm{d}q_i=\frac{\partial q_i}{\partial t_{\mathrm{m}}}\mathrm{d}t_{\mathrm{m}}+\frac{\partial q_i}{\partial t_{\mathrm{w}}}\mathrm{d}t_{\mathrm{w}}+\frac{\partial q_i}{\partial \tau_{\mathrm{m}}}\mathrm{d}\tau_{\mathrm{m}}+\frac{\partial q_i}{\partial \tau_{\mathrm{w}}}\mathrm{d}\tau_{\mathrm{w}}, \quad \forall i \tag{6}$$

1. Payoff functions. Because we will deal with numerous market structures in the calculation of the Shapley value, we will first specify the payoff for each individual player in the rent capturing game. For any coalition the payoff to the coalition is just the sum of the individual payoffs for each member.

For each state, we assume their payoff is tax revenue:

$$T_i=t_iS_i(q_i)q_i \quad \forall_i \tag{7a}$$

For the transport links we assume their payoff is profit,

$$\pi_i=\tau_iq_i-C_i(q_i)q_i \quad \forall i. \tag{7b}$$

2. Pure non-cooperative equilibrium. We outline the general methodology for the computation of a non-cooperative equilibrium for the case of no coalition formation among players and with all players attempting to exercise market power – the Nash solution to this non-cooperative game.

In this case, each state sets its markup to maximmize profits. This results in the following first-order condition for all producers (assuming an interior solution):

$$\frac{\mathrm{d}T_i}{\mathrm{d}t_i}=S_i(q_i)q_i+t_i[S_i'(q_i)q_i+S_i(q_i)]\frac{\mathrm{d}q_i}{\mathrm{d}t_i}=0 \quad \forall i. \tag{8a}$$

Each transporter sets its transport price to maximize profits. This yields the following first-order condition:

$$\frac{d\pi_i}{d\tau_i}=q_i+\tau_i\frac{dq_i}{d\tau_i}-[C_i'(q_i)q_i+C_i(q_i)]\frac{dq_i}{d\tau_i}=0 \quad \forall i. \tag{8b}$$

Assuming there are two states and two transport links, the four equations (8) can be solved to yield the market equilibrium tax rates and transport prices. In solving these equations, one makes use of the equilibrium condition (4). To compute dq_i/dt_i and $dq_i/d\tau_i$, eq. (6) and the standard Nash conditions that $dt_i/dt_j=d\tau_i/d\tau_j=0$, $\forall i, j$, $i\neq j$ and $dt_i/d\tau_j=d\tau_i/dt_j$, $\forall i, j$.

The first-order conditions [eq. (8)], once they are reduced to functions of the tax rates and transport prices, constitute a set of reaction functions for the players, written in implicit form. If each of these first-order conditions is solved for that player's decision variable, then the reaction function gives that player's optimal response to the level of its opponent's decision variables. By definition, a Nash equilibrium is obtained by the simultaneous solution of these reaction functions for the equilibrium tax rates and transport prices.

3. Coalition formation. For the computation of market equilibria with coalition formation (necessary to construct the Shapley value) we use this same procedure. A coalition is treated as a single player with its payoff the sum of its individual members' payoffs. This 'single player' also has as many decision variables as it has members. The expressions for dq_i/dt_j and $dq_i/d\tau_j$ ($\forall i,j$) calculated from eq. (6) are used in an analogous fashion to compute market equilibria with coalitions.[6]

4.2. Application to the coal market

We assume that the marginal cost, average transport cost and demand functions described in the previous section are linear. This is done principally for reasons of tractability but also for want of a better functional form to fit the data. The computation of the various market equilibria requires tedious numerical methods even for these functional forms. The specific functional forms are

$$P_i=(1+t_i)(\alpha_i+\beta_i q_i)+\varepsilon_i, \qquad i=\mathrm{m,w}, \tag{9a}$$

$$P_\mathrm{d}=a_\mathrm{d}+b_\mathrm{d}(q_\mathrm{m}+q_\mathrm{w})+\varepsilon_\mathrm{d}, \tag{9b}$$

[6] Other market equilibria, not necessary for the computation of the Shapley value, are calculated. These can be classified into two groups: those with average cost pricing by the transporters and those with zero markup for producers. The procedure to compare equilibria for the first group, is simply to substitute $C_i(q_i)$ for τ_i in (4), and continuing in the same fashion as discussed earlier. For the second group, substituting $t_i=0$, $\forall i$, in (4) is appropriate.

Table 1

Regression results western coal market model.[a]

	Eq.	α, c	β, d	R^2	Standard error of regression
Montana supply	(9a)	5.57 (136)	0.00134 (4.5)	0.99	0.11
Wyoming supply	(9a)	4.69 (13.4)	0.00665 (5.7)	0.89	0.43
Demand	(9b)	21.29 (86)	−0.00835 (−15.9)	0.97	0.18
Montana transport	(9c)	7.61 (36.7)	0.0101 (8.0)	0.87	0.34
Wyoming transport	(9c)	5.98 (51.7)	0.00505 (14.3)	0.96	0.09

[a] t – statistics (coefficient/standard error) are in parentheses. Units are \$/ton (p) and millions of tons per year (q). Estimation via two-stage least squares with eleven observations.

$$\tau_i = c_i + d_i q_i + \eta_i, \qquad i = \text{m, w}, \tag{9c}$$

$$P_d = P_i + \tau_i, \qquad i = \text{m, w}, \tag{9d}$$

where disturbance terms (ε_i, η_i) of zero mean have been introduced. This model is identical to that found in Kolstad and Wolak (1983) with the exception of eq. (9c). The model is estimated using output from a large scale activity analysis model of the U.S. coal market for the year 1990.[7] Other details on the model and a justification for this approach may be found in Kolstad and Wolak (1983). Since the transport links were priced at average cost in the activity analysis model, for the purposes of estimation of $C_i(q_i)$ railroads are average-cost pricing.[8] Table 1 presents the results of a two-stage least squares[9] estimation of the coefficients of (9) based on the activity analysis generated data.

[7]The year 1990 was chosen for several reasons, including data availability and model validity [see Wolak et al. (1981)]. An examination of years much earlier than 1990 would undoubtedly encounter market rigidities which would bias this type of analysis. We selected an analysis year far enough into the future for market rigidities to be of a minor concern, but also close enough to the present to have relevance to current market conditions. Thus, although the choice of 1990 is somewhat arbitrary, it is expected that analysis of other years would give qualitatively similar results.

[8]Unit transport costs for each link, defined as the difference between the average delivered price in dollars per ton less the minemouth price for its respective state (including tax), were regressed on quantity shipped, to obtain the average transport cost eq. (9c). Since states serve different markets and we deal with only one average delivered price for coal, some of the dependence of the transport cost on the quantity transported from that state is due to the spatial heterogeneity of coal markets.

[9]Two-stage least squares is thought to be more robust than full-information techniques when samples are small and there is the potential for misspecification, since any error is restricted to a single equation and is not allowed to propagate throughout the entire system [Johnston (1984)]. Because of the nature of the data generation process, a larger sample was unnecessary to adequately estimate the parameters of the model.

5. Empirical results

We now merge the development of the oligopoly model of the western coal market with our Shapley–Lerner indices of power.

5.1. Possible market equilibria

The various market equilibria are presented in table 2. For each market structure, the table shows the equilibrium levels of the tax rates and transport prices, the payoff to each player, equilibrium output levels, minemouth price excluding tax, transport cost, and delivered coal price. The table spans all possible cases where participants price at average cost or set a zero tax, act as non-cooperative oligopolists or act as members of some coalition, although not all possible coalition structures are shown. For all of these market equilibria the railroads were required to price at least to cover costs and the states were not allowed to have negative tax rates. This was done to insure realism in the analysis, but it also guarantees a unique market equilibrium for all of market structures considered.

Perhaps the most striking characteristic of this table is the very small variation in the delivered price of coal throughout the several market structures.[10] Confirming intuition, the most non-cooperative solution yields the lowest delivered price of coal. The market structure where the state of Montana and Wyoming's transport link collude against the coalition of Wyoming and Montana's transport link has the highest delivered price. This market structure results in one of the smallest amounts of total rent extracted. This seems to make sense because one would expect this type of market structure to be extremely counterproductive from the rent capturing standpoint.

Another interesting feature of these results is the small variation in the total rent extracted across all of the market structures. The smallest total amount of rent extracted is 70 percent of the total rent extracted under the fully cooperative solution. The most non-cooperative solution, no coalitions, results in total rent extracted that is 83 percent of the fully cooperative solution. The least amount of rent is extracted under the market structure where Montana and its transport link compete against Wyoming and its transport link. Ironically, this type of collusion is probably the most plausible from an informational standpoint, since one would expect some communication between a state and the transport link serving it.

Nevertheless, these results show quite a large variability in the production levels of the individual states. However, the total delivered production to the

[10]The fact that average delivered prices are somewhat independent of market structure is largely due to the spatial nature of the market whereby distant consumers are lost as the mill price increases. Delivered prices to a *specific* consumer (if that were treated explicitly) would not be independent of market structure.

Table 2

Western coal market equilibrium values.[a]

Market structure	t_m	t_w	τ_m	τ_w	T_m	T_w	π_m	π_w	Total rent
Cartel all players	1.03	0.00	8.17	13.96	331.60	0.00	0.00	1,564.90	1,896.60
Cartel states vs. cost pricing rails	0.71	0.87	8.74	7.07	468.80	1,084.60	0.00	0.00	1,553.40
Cartel rails vs. no tax states	0.00	0.00	12.80	12.39	0.00	0.00	485.50	1,155.50	1,640.90
Cartel states vs. cartel rails	0.36	0.51	11.58	10.81	196.40	400.50	287.90	576.70	1,461 50
Cartel states vs. individual rails	0.43	0.59	10.71	9.69	300.20	550.00	228.20	468.10	1,546.50
Cartel rails vs. individual states	0.11	0.23	12.51	11.61	73.00	241.40	439.30	844.70	1,598.50
Pure non-cooperative	0.14	0.28	11.58	10.32	130.60	368.20	378.10	669.70	1,576.60
WYR vs. Rest	0.72	0.84	9.12	8.93	620.30	554.50	0.00	282.00	1,456.80
MTR vs. Rest	1.21	0.00	7.71	14.40	67.80	0.00	0.00	1,798.30	1,866.10
MTS vs. Rest	0.07	0.00	12.66	12.51	33.80	0.00	370.30	1 225.90	1,630.00
WYS vs. Rest	1.17	0.11	7.88	14.51	490.20	100.90	0.00	1,229.80	1,820.80
MTS & MTR vs. WYS & WYR	0.56	1.20	9.57	6.53	630.30	712.10	0.00	0.00	1,342.40
MTS & WYR vs. WYS & MTR	0.36	0.53	11.63	10.76	188.80	408.10	285.80	562.70	1,445.50

Market structure	P_m	P_w	C_m	C_w	P_d	q_m	q_w	Total output
Cartel all players	5.64	6.21	8.17	7.14	18.90	56.90	229.50	296.40
Cartel states vs. cost pricing rails	5.72	6.06	8.74	7.07	18.60	115.40	205.90	321.30
Cartel rails vs. no tax states	5.73	6.13	8.85	7.08	18.44	122.80	217.50	330.30
Cartel states vs. cartel rails	5.70	5.62	8.57	6.69	19.32	95.80	139.80	235.60
Cartel states vs. individual rails	5.73	5.76	8.84	6.80	18.92	121.80	161.80	283.60
Cartel rails vs. individual states	5.73	5.87	8.80	6.88	18.80	118.50	178.70	297.20
Pure non-cooperative	5.78	6.12	9.24	7.07	18.14	161.30	215.00	376.30
WYR vs. Rest	5.77	5.49	9.12	6.59	19.03	149.70	120.60	270.30
MTR vs. Rest	5.58	6.36	7.71	7.25	19.10	10.00	251.30	261.30
MTS vs. Rest	5.69	6.20	8.51	7.13	18.64	89.30	228.10	317.40
WYS vs. Rest	5.67	5.74	7.88	6.78	19.34	73.70	159.20	232.90
MTS & MTR vs. WYS & WYR	5.83	5.41	9.57	6.53	18.75	193.90	109.50	303.40
MTS & WYR vs. WYS & MTR	5.69	5.60	8.54	6.68	19.37	92.40	137.70	230.10

[a]Definition of notation: MTS: Montana State; WYS: Wyoming State; MTR: Montana Rail; WYR: Wyoming Rail. t_i: tax rate in state i (fraction); τ_i: transport price for rail serving state i ($/ton); T_i: tax revenue for state i ($$10^6$/year); π_i: profit for rail serving state i ($$10^6$ year); P_i: minemouth price of coal in region i excluding tax ($/ton); P_d: delivered price of western coal ($ ton); C_i: average transport cost to demand center from region i ($/ton); q_i: coal production from region i (10^6 tons/year). All dollar values are in 1975 dollars.

demand center remains relatively constant. This is indicative of the large degree of substitutability, in the long run, between Montana and Wyoming coal. Minemouth prices, excluding tax, in both states have little variability. This is indicative of the very small, if any, depletion effects from higher levels of production and should provide greater validity to our static analysis.

Finally, a glance at tax rates and transport prices show that they vary greatly from one market structure to the next. The tax rates vary from 11 percent to 120 percent. The transport prices range from \$6.53 per ton to \$14.51 per ton. Focusing only on the levels of these variables, one would conclude that the western coal market is highly volatile. However, as discussed above, the delivered price and total quantity produced, the two variables determining consumer welfare, are quite stable over all of the market structures considered. The issue of losses in consumer welfare for the various market structures will be addressed in detail later in the paper.

An interesting question to ask while discussing table 2 is what coalitions are likely to form if we take as a starting point the fully non-cooperative solution. Assuming no side payments are possible (in this market overt transfers are illegal) implies that only coalitions leading to higher payoffs for each member relative to the non-cooperative solution are likely to form. Based on this criterion, only two coalitions are likely to form: They are a cartel of the states and a cartel of the railroads. Regardless of whether or not the two railroads decide to collude, there is an incentive for the two states to cooperate in setting taxes so that individually both can earn more tax revenue than in the non-cooperative solution. For the railroads there are gains to coalition formation only if the states are competing against each other. However, conditional on the states formed as a cartel, each rail link earns a higher profit by colluding with the other link as opposed to competing against it.

Whether or not these collusions may in fact form is a question of degree. The formation of any two participants as single optimizing agent seems highly unlikely. However, some degree of communication between the players is very likely so that some degree of coordination in decision-making is very possible, and more so as time passes and more communication among the players takes place. The question of the possibility of making side payments among participants is logically similar. Clearly, overt side payments are illegal, but because much of this coal is delivered on a contract basis, the design of more elaborate agreements among consumers, producers and transporters may allow greater room for implicit side payments among players.

Certainly the recent drop in Montana's severance tax on new contracts was in response to a desire of both Montana and its transport link to earn more revenue in the recent soft coal market. Clearly, for this to happen some degree of cooperation exists between these two players because Montana

Table 3

Western coal market rent capturing game.[a]

A. Payoffs coalitions can guarantee

$v(\phi) = 0$	$v(2,3) = 694.0$
$v(1) = 33.8$	$v(2,4) = 712.1$
$v(2) = 100.9$	$v(3,4) = 864.6$
$v(3) = 0.0$	$v(1,2,3) = 1{,}174.8$
$v(4) = 282.0$	$v(1,2,4) = 1{,}866.1$
$v(1,2) = 596.9$	$v(1,3,4) = 1{,}719.9$
$v(1,3) = 630.3$	$v(2,3,4) = 1{,}596.2$
$v(1,4) = 751.5$	$v(1,2,3,4) = 1{,}896.6$

B. Shapley values and Shapley–Lerner indices

	Value	Shapley–Lerner index[b]
Montana State	424.1	0.30
Wyoming State	409.2	0.29
Montana rail	357.8	0.26
Wyoming rail	705.5	0.50
Total	1,896.6	0.34

[a]All payoffs are in millions of 1975 dollars per year. Definitions: 1 = Montana State; 2 = Wyoming State; 3 = Montana rail link; 4 = Wyoming rail link.

[b]See eq. (2) and eq. (3).

knows that the drop in the severance tax will not be met with an equivalent increase in the transport fees.

5.2. *Measures of market power*

Table 3 gives the western coal market rent capturing game in characteristic form; i.e., all the guaranteed payoffs for the various coalitions are shown. Note that the Montana rail link cannot guarantee itself any rent since it captures no rent when it faces a coalition of the other three players (see table 2). In fact there is a sizable difference between guaranteed payoffs (assuming individual rationality) and those resulting from non-cooperative Nash behavior.

Also shown in the table are Shapley values and Shapley–Lerner indices for the four players. Note first that the potential or endowed rents reflected in the Shapley values differ significantly from what the actors reap in a non-cooperative Nash equilibrium. The interpretation of the industry Shapley–

Lerner indices is that 34% of consumer expenditures could potentially go to the four cartel players in the form of profits. From these figures it is clear that the Wyoming railroad possesses much more market power than the other participants in the market, by nearly a factor of two. While it is not surprising that the cost structures for the two states differ enough to yield different levels of market power, it is surprising that the Wyoming railroad possesses so much more market power than the state of Wyoming.

A natural response in interpreting these Shapley values is that since the railroads and states aren't actually colluding, of what use are these measures of market power? First of all, we do not know whether or not there is collusion. Collusion can be very subtle or tacit, including price leadership behavior. Furthermore, most coal contracts involve negotiated prices. The relative market power of the negotiating parties bears directly on the outcome of the negotation. Finally, an indication of where the power rests points to the agents which should perhaps be scrutinized more closely by regulatory bodies. For these reasons, these generalized Lerner indices are very useful.

5.3. *Efficiency losses and sensitivity analysis*

In this section we discuss the losses in consumer surplus due to the various cooperative market equilibria and the sensitivity of our market power results to our modeling framework.

Table 4 presents various measures of consumer welfare loss, where welfare is defined as consumer surplus. All welfare losses are relative to the non-cooperative Nash equilibrium. The first column of the table gives the fall in consumer surplus as a percentage of the fall in total revenue going from the non-cooperative equilibrium to each of the other equilibria in table 2. The second column gives the change in welfare as a percentage of the change in total rent extracted for each equilibrium relative to the base equilibrium. The third column is the consumer surplus associated with each equilibrium as a percentage of the base equilibrium level of consumer surplus.

This table addresses the question of the size of the welfare losses associated with the various equilibria. Viewed relative to the change in total revenue these welfare losses are very small. Viewed relative to the change in the total rent extracted the welfare losses seem quite large. This column also illustrates the inefficiency, from a rent capturing standpoint, of several of the coalition equilibria relative to the non-cooperative equilibrium. With the exception of the fully cooperative cartel and the last three of the three-player cartels, the remainder of the coalition equilibria yield reductions in aggregate rent collected and welfare losses relative to the non-cooperative solution. Finally, the third column provides an intermediate view of welfare losses. Consumer

Table 4

Consumer welfare measures.[a]

Market structure	$\frac{\Delta W}{\Delta TR}$	$\frac{\Delta W}{\Delta RENT}$	$\frac{W_i}{W_B}$
Cartel all players	2.48	−9.48	59.76
Cartel state vs. cost pricing rails	1.49	53.53	72.91
Cartel rails vs. no tax states	1.25	−14.31	79.42
Cartel states vs. cartel rails	3.65	61.12	38.90
Cartel states vs. individual rails	2.48	153.98	56.70
Cartel rail vs. individual states	2.11	−180.59	62.43
WYR vs. Rest	2.80	44.24	51.53
MTR vs. Rest	3.00	−19.86	48.28
MTS vs. Rest	1.62	−55.15	70.96
WYS vs, Rest	3.71	−29.36	38.31
MTS & MTR vs. WYS & WYR	1.96	15.56	65.01
MTS & WYR vs. WYS & MTR	3.80	55.76	37.27

Definition of notation: W_i: consumer surplus for equilibrium i; W_B: consumer surplus for non-cooperative (base) equilibrium; $\Delta W = W_i - W_B$; ΔTR = change in total revenue relative to base equilibrium; $\Delta RENT$ = change in total rent relative to base equilibrium. All magnitudes are in percentage terms.

surplus runs from 37 percent to 79 percent of that for the non-cooperative solution. By this measure, three of the coalition equilibria yield sizable welfare losses, while the remainder of the equilibria yield only moderate losses.

We now discuss the issue of a sensitivity analysis. Due to the lack of closed form solution for even the non-cooperative equilibrium, a sensitivity analysis relating changes in model output to a change in each of the parameters of the model is impossible. However, given that all of the equilibrium are so close together on the demand curve and the very small slope associated with each supply function once the non-cooperative market equilibrium is established, the rest of the analysis is essentially done local to this point. For example, all of the equilibria in table 2 are contained in an interval comprising less than 6 percent of the range of the demand curve in quantity space. The intrinsically very flat nature of the supply functions for each state leaves most of the potential sensitivity in the model to the transport sector. However, the very large fixed portion of the average transport cost functions (see table 1) should mitigate some of this sensitivity of the model to variability in the parameters of the transport cost functions. So, although we cannot perform a detailed sensitivity analysis, comparison of the economic model assumed for the market to the actual market does yield some insight into the sensitivity of the model results to parameter changes. This potential sensitivity in the transport cost sector can explain some portion of the result that Wyoming's rail link possesses a very large degree of relative market power.

6. Policy implications

On the basis of the Shapley value calculation for the western coal rent capturing game we can see the importance of recognizing the market power of the transport links in an oligopoly environment and modeling this market power. This exercise has also shown the robustness of the western coal market equilibrium. Despite a wide range of market structures, the delivered price and quantity of western coal changed very little. The level of total rent extracted also showed very little variation over all of these market structures. This result also reinforces the earlier conclusion of Kolstad and Wolak (1983) that significant rents from natural resource extraction can be captured even without a cartel.

The wide variation in the severance tax levels and transport prices, and the relative stability of the delivered quantity and price of coal over the many market structures evaluated, is both distressing and comforting to a western coal market observer. It is comforting (although somewhat deceptively, as we noted earlier) in the sense that almost regardless of the behavior of the producers and transporters the average delivered price of western coal will remain unchanged in the long run. It is distressing because it indicates the difficulty regulators will encounter in their attempts to limit the market power of the participants in the Western U.S. coal market, because so many market structures yield significant rents to the participants.

Perhaps the best policy to be pursued by regulators in this market is to encourage competition among the players. Although the Nash equilibrium did not lead to the lowest amount of aggregate rent being captured it did lead to a very even distribution of the rent and, as discussed earlier, is a coalitionally stable solution to the game. Also, by encouraging entry in the market for transporting western coal much of the market power of the transport firms should be eroded. This analysis appears to be an excellent argument in favor of coal slurry pipelines and offers very strong reasons why the railroads have been fighting so vigorously to prevent their introduction into the coal transport market.

One recommendation from the Shapley value calculation and the various market solutions is that regulation of either the railroads or the states but not both groups would be largely in vain. If one group is allowed to run free while the other must cost price, significant rents are captured by the non-regulated agents. Hence the proper strategy in this market would be regulation of all agents or regulation of none of the agents. Given the proximity of the Nash solution to the present levels of the tax rates and rail tariffs, if one is satisfied with the present market outcome then the optimal policy is simply to encourage as much competition as possible in the market for western coal.

Appendix: Shapley values

Let there be n firms with profit functions $\Pi_i(\boldsymbol{q})$ where the $\boldsymbol{q}$ is the vector of n decision variables for the firms. For any coalition or cartel of firms, $S \subseteq N = \{1,2,\ldots,n\}$, define $v(S)$ as the highest joint profit these firms can guarantee themselves, assuming firms outside the cartel follow individual rationality given the Nash equilibrium behavioral assumption (i.e., attempt to maximize their profits given the actions of those outside their coalition). The mapping $v(S)$ is a set function associating with any subset of N a real number. Now consider the power an individual firm contributes to a coalition. A firm joining a coalition may give the coalition more market power. Define the marginal value of a coalition S as the value of the coalition, $v(S)$, less the marginal value of all *proper* subcoalitions of S:

$$mv(S) = v(S) - \sum_{K \subset S} mv(K), \tag{A.1}$$

with the marginal value of the empty set defined as zero [see Friedman (1977, pp. 250–251)]. However, when a firm joins a coalition it would be inappropriate to ascribe all of the marginal value of the new coalition to that firm. Dividing the marginal value equally among all firms in the coalition leads to the definition of the Shapley value of a firm as the sum of the marginal contributions of the firm to all coalitions it joins:

$$\phi_i = \sum_{\substack{K \\ K \subseteq N,\, i \in K}} mv(K)/k \tag{A.2}$$

where k is the number of members of K. This is equivalent to the possibly more intuitive definition of the Shapley value for firm i:

$$\phi_i = \sum_{K \subseteq N} \frac{[v(K) - v(K - \{i\})](k-1)!(n-k)!}{n!}. \tag{A.3}$$

Letting $w_K = \{(k-1)!(n-k)!/n!\}$ and using the notation of table 2, the Shapley value for the state of Montana is the following sum of eight terms:

$$\phi_1 = w_1(v(1) - v(\phi)) + w_2(v(1,2) - v(2)) + w_2(v(1,3) - v(3))$$

$$+w_2(v(1,4)-v(4))+w_3(v(1,2,3)-v(2,3)))$$

$$+w_3(v(1,2,4)-v(2,4))+w_3(v(1,3,4)-v(3,4))$$

$$+w_4(v(1,2,3,4)-v(2,3,4)). \tag{A.4}$$

The Shapley values for the other players are calculated in a similar fashion.

The Shapley value satisfies several properties which are reasonable to impose on a value function for a game in characteristic function form. In addition, it is the only value function for a game which satisfies all of these properties. These properties are detailed in Friedman (1977, pp. 248–249).

References

d'Aspremont, Claude and Alexis Jacquemin, 1985, Measuring the power to monopolize, European Economic Review 27, 57–75.

Alt, C.B., M.G. Baumann and M.B. Zimmerman, 1983, The economics of western coal severance taxes, Journal of Business, Oct., 519–536.

Atkinson, S.E. and J. Kerkvliet, 1986, Measuring the multilateral allocation of rents: Wyoming low-sulfur coal, Rand Journal of Economics 17, 416–430.

Blackstone, S.L., 1983, Mineral severance taxes in the western states: An update (Colorado Energy Research Institute, Golden, CO) Dec.

Cowling, K., 1976, On the theoretical specification of structure-performance relations, European Economic Review 8, 1–14.

Cowling, K. and M. Waterson, 1976, Price-cost margins and market structure, Economica 43, 267–274.

Donsimoni, Marie-Paule, Paul Geroski and Alexis Jacquemin, 1984, Concentration indices and market power: Two views, Journal of Industrial Economics 32, no. 4, 419–434.

Encaoua, David and Alexis Jacquemin, 1980, Degree of monopoly, indices of concentration and threat of entry, International Economic Review 21, no. 1, 87–105.

Friedman, J.W., 1977, Oligopoly and the theory of games (North-Holland, Amsterdam).

Friedman, J.W., 1988, Game theory with applications to economics (Oxford University Press, New York).

Hause, J.C., 1977, The measurement of concentrated industrial structure and the size distribution and firms, Annals of Economic and Social Measurement 6, no. 1, 77–107.

Johnston, J., 1984, Econometric methods, 3rd ed. (McGraw-Hill, New York).

Kolstad, C.D. and F.A. Wolak, Jr., 1983, Competition in interregional taxation: The case of western coal, Journal of Political Economy 91, no. 3, 443–460.

Kolstad, C.D. and F.A. Wolak, Jr., 1985, Strategy and market structure in western coal taxation, Review of Economics and Statistics LXVII, no. 2, May.

Lerner, A., 1934, The concept of monopoly and the measurement of monopoly power, Review of Economic Studies 1, 157–75.

Levin, R.C., 1981, Railroad rates, profitability, and welfare under deregulation, Bell Journal of Economics 12, no. 1, 1–26, Spring.

Mutti, J.H. and W.E. Morgan, 1983, Changing energy prices and economic rents: The case of western coal, Land Economics 59, no. 2, 163–179.

Salant, S.W., 1976, Exhaustible resources and industrial structure: A Nash–Cournot approach to the world oil market, Journal of Political Economy 84, 1079–1093, Oct.

Saving, Thomas R., 1970, Concentration ratios and the degree of monopoly, International Economic Review 11, no. 1, 139–146.

Scherer, F.M., 1980, Industrial market structure and economic performance (2nd ed.) (Rand McNally, Chicago, IL).

Shapley, L.S. and M. Shubik, 1954, A method for evaluation of the distribution of power in a committee system, American Political Science Review 48, 787–792.

Wolak, F.A., R.L. Bivins, C.D. Kolstad and M.L. Stein, 1981, Documentation of the Los Alamos coal and utility modeling system, version 3.0, Los Alamos National Laboratory Report LA-8863-MS (LANL, Los Alamos, NM), May.

Zimmerman, M.B., 1979, Rent and regulation in unit-train rate determination, Bell Journal of Economics 10, no. 1, pp. 271–281, Spring.