Marketable Permits, Low-Sulfur Coal, and the Behavior of Railroads*

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ABSTRACT

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This paper presents evidence that railroads hauling low-sulfur coal from Wyoming's Powder River Basin exercise significant monopoly power in the determination of freight charges to electric utilities. This result is obtained using a Lerner index derived from a model of the behavior of mines, railroads, and utilities and estimated with data on railroad freight revenues and costs. An important policy implication of railroad monopoly power is that the introduction of marketable emission permits by the Clean Air Act Amendments of 1990 had no effect on the utilization of low-sulfur coal to generate electric power. Instead, declining costs both in mining and in rail transportation of coal appear to be responsible for this outcome.

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1. Introduction

The Clean Air Act Amendments of 1990 represented a landmark change in U.S. environmental policy favoring the use of market mechanisms over command and control to lower emissions of sulfur dioxide (SO_2). The cap-and-trade program authorized by Title IV of these amendments provided electric utilities with unprecedented flexibility to meet emission reduction targets.[1] Indeed, over the past 25 years, SO_2 emissions have been reduced by 50% at as little as 10% of the originally estimated cost (Kerr 1998) and, just as the Congress anticipated (Department of Energy 2000), the years following passage of Clean Air Act Amendments saw electric utilities significantly expand their use of low-sulfur coal from the Powder River Basin (PRB) of Wyoming and Montana. Between 1990-2002, annual production of PRB coal increased from 190 million to 420 million tons, the number of utilities burning this fuel increased threefold, and Wyoming emerged as the leading coal-producing state in the U.S.

This paper investigates the extent to which the Clean Air Act Amendments of 1990 induced electric utilities to switch to low-sulfur PRB coal, thereby reducing SO_2 emissions. This issue is important both because of the apparent success of this legislation and because of the related surge of recent proposals to apply cap-and-trade programs to other environmental problems in the U.S. and abroad. This issue also has attracted attention from a number of prominent scholars. Carlson *et al.* (2000) measure the gains from emissions trading in the first two years of the program by looking at the behavior of utilities. Montero (1999)

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[1] A detailed discussion of these amendments and the political economy of allocating tradeable emission permits may be found in Joskow and Schmalensee (1998).

examines the role of unanticipated availability of PRB coal for performance of the voluntary opt-in feature of Phase I of the emissions trading program, again from the standpoint of utilities. Schmallensee *et al.* (1998), Ellerman and Montero (1998), Ellerman *et al.* (2001), and Ellerman (2003) study the market for emission permits and analyze the possible role played by another federal policy, railroad deregulation, in expanding the geographic market for PRB coal. They argue that the Staggers Rail Act in 1980 led both to reductions in railroad costs and to increased competition in coal transportation, forces which worked in combination to produce a pattern of declining freight rates over time.

To evaluate the performance of federal SO_2 control policy, this paper asks a different question than those addressed in prior work: Do railroads have any incentive to haul additional low-sulfur PRB coal in response to the change in the regulatory landscape brought about by the Clean Air Act Amendments of 1990? The behavior of railroads is a crucial aspect of evaluating this policy because PRB coal is typically transported long distances by rail (1000 miles or more) and freight charges can run in excess of 80% of the delivered price. If the railroad sector is competitive, as implicitly assumed in previous studies, then the input market response to public policy can be inferred entirely through an analysis of downstream electricity markets (Just and Hueth 1979). If the railroad sector is noncompetitive, however, then it is necessary to formally disengage the vertical markets to properly identify the role of public policy. In the case of the SO_2 cap-and-trade program, doing so involves explicitly modeling the spatial market structure of railroads that haul PRB coal.

The analysis is framed by a three-sector model of PRB coal production, transportation, and consumption that focuses on railroads as spatial market intermediaries. The model predicts that if railroads exercise monopoly power in selecting freight rates for

PRB coal, then the introduction of a cap-and-trade program to control SO_2 emissions has no effect whatsoever on the utilization of low-sulfur coal. The effect of the cap-and-trade policy is to raise the cost of burning high-sulfur fuels, bid up delivered PRB coal prices, and stimulate shipments of low-sulfur coal to distant utilities, as intended; however, under monopoly, these increased shipments are exactly offset by reduced shipments to existing buyers.

Because the identification of railroad monopoly power amounts to a test of whether the cap-and-trade program had any effect the utilization of low-sulfur coal as an input for electricity generation, this paper also estimates Lerner indices for each of 353 PRB coal shipment routes out of Wyoming over the period 1988-1999. The evidence indicates a substantial degree of railroad market power that actually increased over time despite the intended effects of deregulation. Thus, consistent with the findings of Greenstone (2004), the results point to the general ineffectiveness of environmental policy in increasing the utilization of low-sulfur PRB coal. Instead, as described more fully below, the dramatic expansion of production and utilization of PRB coal is more likely to have been driven by declining costs in both the railroad and mining sectors.

2. Background

The model developed in the following section has three types of agents (mines, railroads, and electric utilities) and two types of markets (a market between mines and railroads and a series of spatially distributed markets between railroads and utilities). There are three key aspects of the model: (1) mines are perfect competitors, (2) railroads potentially exercise market power in setting freight rates, and (3) utilities have no bargaining power over mines. These aspects differ in several respects from the way industry structure has been conceptualized in earlier studies, and this section reconciles these views.

In the 1980s, leading studies of the PRB coal market suggested at least four potentially important sources of noncompetitive behavior among mines, railroads, and utilities. First, Atkinson and Kerkvliet (1986) argued that mines may have market power due to entry barriers that arise from restrictions on federal coal leasing, from the long lead times required to construct mines and to obtain operating permits, and from the large capital investments required to minimize average extraction cost. In the period 1980-82 that framed their study, only a few mines had achieved significant economies of scale. Second, mines in the PRB, both then and today, produce heterogeneous coal with important differences in BTU and water content and with various levels of impurities such as sulfur, sodium, and ash. Power engineers in the early 1980s widely believed that, because particular generating units only could accommodate coal with narrowly defined characteristics, the heterogeneity of PRB coal deposits limited substitution possibilities between suppliers. The (perceived) limited ability of utilities to substitute between PRB coals provided both mines and utilities with incentives to enter into long-term contracts to protect relationship-specific investments (see Joskow (1987)). To the extent that contract and spot prices diverge, as can occur when contracts have price escalation and take-or-pay provisions, long-term marketing agreements provide another potential source of disequilibrium rents. Third, railroads may have market power. Mines and utilities are served by a small number of railroads, and alternative modes of coal transportation out of the PRB either are not cost-effective (i.e., trucking) or else do not exist (i.e., barges and coal slurry pipelines). Finally, state governments may also exert market power. As Kolstad and Wolak (1983) observe, even if mines, railroads, and utilities behave as perfect competitors, government authorities may compete strategically to acquire resource rents through the use of production (severance) taxes.

Since these early studies were completed, new information has come to light to suggest that much has changed in the coal market. Following the pro-coal decision of the U.S. Supreme Court in *Sierra Club v. Kleppe* in 1976, barriers to entry in the mining sector eased substantially. In that year, PRB coal production began to increase at a rate of 8.4% per year, and this expansion was further promoted by the end of the moratorium on federal coal leasing in the 1980s. Between 1984 and 2002, the number of operating mines remained constant (20 mines), while the average annual production per mine grew from 6.1 million tons to 18.75 million tons, suggesting that mines today exploit economies of scale to a greater extent than they did in earlier years (Lyman and Hallberg 1999). Average production costs for PRB coal declined sharply over this period through scale economies achieved by substituting capital equipment such as conveyors, larger earth-moving vehicles, and draglines for labor. A production-weighted average of engineering estimates of mine-specific real variable costs per ton declined by 57% between 1985 and 2000 ($4.68/ton vs. $2.01/ton in 2000 dollars). Even in nominal terms, the average extraction costs for PRB coal declined by nearly 40% over this period from $3.32/ton to $2.01/ton (BXG, Inc. 1985, Hill and Associates, Inc. 2000).

The period 1984-2000 was also marked by industry consolidation in the mining sector. The number of mine owners declined from 14 to 10, as major energy corporations including Amax, Exxon, Arco, Kerr-McGee, and Shell sold properties (now operated by RAG International, Peabody, Arch, Kennecott, and Vulcan), and the production-based four-firm concentration ratio rose from 0.625 to 0.737 in the industry. However, two factors suggest that the increased market concentration did not limit competition among producers. First, there has been a virtually complete turnover in mine ownership over the past 20 years, a feature that suggests narrow profit margins. Second, relationship-specific investments associated with the production of heterogeneous coal have greatly diminished in importance. Coals obtained from different mines are now commonly mixed in an increasingly diversified fuel portfolio. In 1999, for example, 73% of plants that bought PRB coal did so from more than one mine and the PRB coal purchased by each plant was sourced (on average) from 2.75 mines. Partly as a result of fuel-mixing, long-term contracts diminished in importance throughout the 1990s. Today, spot market purchases combined with a portion of sales under shorter-term contracts of four years or less represent the industry norm. Moreover, current PRB coal contracts almost uniformly contain market based re-opener provisions in place of price escalation or take-or-pay requirements, and this increases the exposure of both mines and utilities to market forces. As demonstrated in the empirical estimates in Section 4, spot coal prices and contract coal prices are now virtually identical.

Evidence from the last twenty years also suggests a limited scope for strategic behavior by state governments in the PRB. Over the period 1980-2000, Wyoming coal production more than tripled from 94 million tons to 340 million tons, while Montana coal production increased only slightly from 30 million tons to 38 million tons (U.S. Department of Energy, Energy Information Administration 2003). At least three factors appear to explain the differing fortunes of the coal industry in the two states. First, largely because of lower in-situ ratios (bank cubic yards of overburden moved per ton of recoverable coal), coal production costs have remained substantially lower in Wyoming than in Montana. In 2000, a production-weighted average of engineering estimates of mine-specific variable costs per ton was 67% higher in Montana than in Wyoming, a percentage cost difference approximately identical to that which prevailed in 1985 (BXG, Inc.1985, Hill and Associates 2000). Second, Wyoming coal is generally of higher quality and contains fewer impurities than Montana coals. For example, among the so-called "super-compliance" coals (those with very low SO_2 per million BTU), the high sodium content of Montana deposits limits their marketability. As a result, the preponderance of super-compliance coal today is sourced from Wyoming mines. Third, the transportation infrastructure out of Wyoming is better developed than its counterpart out of Montana, a feature undoubtedly related to the differences noted above in the cost and quality of deposits. In any case, because virtually all of the growth of PRB coal production since 1980 occurred in Wyoming, strategic behavior among state governments is suppressed and the remainder of the paper focuses on Wyoming PRB coal production.

Anecdotal evidence suggests that railroads may exert market power. In the railroad sector, only two lines --Burlington Northern Santa Fe (BNSF) and Union Pacific (UP)-- currently transport PRB coal out of Wyoming.[2] These railroads generally employ trains of 100 cars or more to haul coal from Wyoming mines to either individual electric power plants or terminals, and the rail cars, which do not simultaneously carry other commodities, subsequently return empty to the mines. Data from the Carload Waybill Sample (Surface Transportation Board, U.S. Department of Transportation 2000), described more fully in Section 4, indicate that the service territories for the two railroads geographically overlap, with the BNSF and UP serving utilities in many of the same states. This suggests a duopolistic market structure in coal transportation. Along 29 of the 353 observed

[2] Entry in the early 1980s by the Chicago and Northwestern Railroad initially was thought to promote greater competition in coal transportation (*Coal Week* August 1, 1983, April 15, 1985); however, this railroad no longer operates out of the PRB.

transportation routes, the railroad hauling coal switched from BNSF to UP or vice-versa at least once over the period 1988-1999.[3] In 1999, the market share of the BNSF was 55.3%, while the UP shipped the remaining 44.7% of Wyoming coal.

3. The Model

The model centers on the behavior of duopolistic railroad intermediaries. Each railroad purchases PRB coal from a perfectly competitive mining industry and hauls it along a rail line to a series of identical, spatially distributed utilities. The railroads, which deliver only a single product --coal-- and hold no inventories, either compete in prices in a non-cooperative duopoly market or else cooperate to maximize joint industry rents.[4]

The model extends the framework of Greenhut and Ohta (1972) to consider spatial price discrimination by transportation firms with endogenous service regions. Specifically, each railroad jointly selects a freight schedule over distance and a terminal point in space that defines the maximal shipping distance, so that a change in economic conditions alters both the freight rates and the equilibrium number of utilities served. As in Greenhut and Ohta (1972), attention is limited to cases in which economies of scope do not exist in the transportation cost function. This assumption is consistent with the data described in Section 4. In the data, each delivery of PRB coal involves a separate trip between the mine and the utility, which implies that the cost of hauling coal to a given utility is independent of the transportation cost incurred to haul coal to all other utilities.

The spatial dimension of the market is described by railroad shipments between mine-utility pairs, where a mine-utility pair is measured as the distance between a utility and its

[3] A transportation route is defined as a railhead to a particular power plant.
[4] As will become clear in a moment, the spatial distribution of markets rules out the possibility of a Nash-Cournot outcome. This is because aggregate output does not clear at unique prices across the spatial markets, whereas, at the individual level, utilities make discrete choices between railroads for delivery services.

nearest available source of PRB coal. To simplify the analysis, the source mines for PRB coal are collapsed in the model to a single location in space, a point taken as the origin, and all PRB coal sold at this point is exchanged in a single, competitive upstream market. In the downstream utility markets, each utility defines a separate market, and the location of utilities is characterized by an ordered set, ascending by distance, according to the length of each respective mine-utility pair. This amounts to treating the downstream markets as if all utilities were located along a single rail line from an originating mine. Along the rail line, the downstream utility markets are measured continuously over the support $[0, \bar{N}]$, where $\bar{N}$ is the length of the rail line.[5] The utilities are assumed to be uniformly distributed with unit density over this support, which allows the maximum distance shipped by a railroad, $N^* \leq \bar{N}$, to be interpreted, equivalently, as the equilibrium number of utilities served in the market.

In the upstream market, the spot price per unit of coal at the mine mouth is *w*. In the transportation sector, the marginal cost of hauling an additional unit of coal an additional unit of distance is given by the constant, *t*.[6] Accordingly, the total cost of delivering the quantity, *q(x)*, to a utility at distance *x*, is $txq(x)$. The total cost of procuring and delivering the aggregate quantity, $Q = \int_0^N q(x)dx$, of PRB coal is $c(Q) = \int_0^N (w+tx)q(x)dx$, where $N \leq \bar{N}$ is the (endogenous) number of utilities served. Fixed costs, which are necessary to justify the existence of railroad market power, play no role in the analysis and are consequently omitted.

In the downstream markets, electric utilities select fuels from a portfolio that includes low-sulfur coal, high-sulfur coal, natural gas, and oil. For simplicity, all fuels are conceived

[5] Greenhut and Ohta (1972) consider a discrete (and exogenous) number of consumers that are evenly distributed along a line. The specification here of a continuous distribution of utilities simplifies the calculation of the endogenous service region, but does not qualitatively affect the outcome.
[6] This assumption of constant marginal shipping cost per ton-mile, which has important implications for the spatial identification of market power, is corroborated by careful empirical analysis in Section 4.

to be perfect substitutes in the portfolio and fuels other than low-sulfur coal are assumed to be ubiquitously available. Units of fuels other than low-sulfur coal are selected so that the market price per unit of each fuel is measured by a common price, which is denoted by p_s.[7]

In the railroad sector, transportation is considered to be a homogeneous good. Implicitly, this assumes that each railroad has the ability to serve all mine-utility pairs along the overlapping routes and that the expected reliability of service is equivalent. With homogeneous transportation services available from either railroad, it follows that utilities procure the transportation of PRB coal at the minimum freight rate available in the market, and it is assumed that utilities have full information on rates.

The rail line is served by two, potentially noncompetitive railroads. The market structure of the railroad sector is characterized by either non-cooperative or cooperative duopoly. The equilibrium outcome is considered for each case in turn.

Consider, first, the outcome under non-cooperative duopoly. In a non-cooperative duopoly setting, the railroads compete to acquire individual shipping routes along the rail line through the selection of freight rates. Because economies of scope do not exist when PRB coal is transported to multiple locations, it follows that the freight rate selected by a railroad for each utility is independent of the freight rate offered to all other utilities. This, in turn, implies that the spatial duopoly model degenerates to a sequence of homogeneous product equilibria, with spatially-independent freight rates determined for each route. Accordingly, the non-cooperative duopoly equilibrium freight rate charged to a utility at distance x is the competitive rate, $f^c(x) = tx$. Under non-cooperative duopoly, the freight schedule increases

[7] This specification of a composite alternative fuel suppresses spatial considerations from the delivered price of alternative fuels. If alternative fuels in the portfolio were priced spatially, then the demand for PRB coal would be heterogeneous across utilities according to a vector of distances between each utility and its potential fuel sources.

linearly over distance at rate t until the delivered price equates with p_s. Because the freight rate to all utilities equals the marginal cost of service, this case is referred to subsequently as the competitive outcome.

Now consider the cooperative case. Under cooperative duopoly, the railroads seek to maximize their joint rents; hence this case is referred to as the monopoly outcome. Freight rates depend, in this case, on utility demand for PRB coal at each point in space. With perfectly substitutable fuels, residual (inverse) demand for coal at each utility is given by $p(q(x))$ for $p(q(x)) \leq p_s$, and zero otherwise. Demand is assumed to be downward sloping, differentiable and to satisfy the condition

$$p'(q(x)) + q(x)p''(q(x)) < 0 . \quad (1)$$

Condition (1), which always holds for concave demand, is a standard existence condition under oligopoly (see, e.g., Novshek (1985)). Here, condition (1) ensures that marginal revenue declines faster than price as the delivered quantity increases.

An essential feature of the monopoly model is that the demand for delivered coal becomes more elastic as more distant utilities are served. There are two reasons for this. First, the marginal cost of shipping a unit of coal, tx, rises with distance, while marginal revenue at each utility does not change. This implies that a monopoly railroad sells on successively more elastic portions of the demand curve over distance. Second, as the marginal cost of delivery increases over distance, the delivered price of PRB coal rises, and this facilitates greater substitution possibilities between PRB coal and alternative fuels in the portfolio.[8]

[8] The model creates a clear separation between these forces by conceiving the alternative fuel to be a perfect substitute for PRB coal in the fuel portfolio. This has the analytically convenient property that the alternative fuel has a discrete affect on the elasticity of PRB demand. For delivered PRB coal prices below p_s, the alternative fuel has no bearing on the elasticity of demand for PRB coal, but the demand for PRB coal becomes

Figure 1 depicts the outcome in the monopoly case. The horizontal axes, respectively, measure the utility demand at distance zero, $q(0)$, and utility demand at distance, $q(x)$. The vertical axes measure the average and marginal revenue values for a monopoly railroad in terms of the freight rate. Average revenue at each location has a kink at p_s - w, where the delivered coal price equates with the alternative fuel price, and marginal revenue has a discontinuity at this point. In Figure 1(a), marginal transportation cost is zero, and the freight rate is selected to maximize total revenue. This occurs at a delivered quantity of $q^*(0)$. In Figure 1(b), marginal transportation cost to a utility at distance x is tx, and the optimal delivered quantity of PRB coal is $q^*(x)$, which clearly satisfies $q^*(x) < q^*(0)$ for $x > 0$. As a monopoly railroad industry serves utilities at successively greater distances, the quantity delivered decreases and the freight rate per unit commensurately increases.

In the cooperative case, the railroad's problem is to select the number of utilities to serve, N^*, and a delivered quantity $q(x)$ for each utility in the service region $x \in [0, N^*]$. The freight charge per unit of coal delivered to a utility at distance x is defined as the difference between the delivered price and the mine price, $f^*(x) = p(q^*(x)) - w$. The optimal freight schedule potentially has two distinct spatial regions, which are referred to throughout as region I and region II. In region I, utilities are located sufficiently close to the mine that the availability of the alternative fuel does not constrain the railroads from setting monopoly prices, $p(q^*(x)) < p_s$. In region II, utilities are sufficiently distant that the unconstrained monopoly price would exceed the price of the substitute fuel. The railroads may continue to serve utilities in this region; however, this only can be done under the binding constraint

infinitely elastic at p_s. If the alternative fuel is taken to be differentiated from PRB coal, then the substitution between PRB coal and the alternative fuel would induce smooth changes in the demand elasticity over distance.

that $p(q^*(x)) = p_s$. Given the homogeneity of utilities, this constraint implicitly defines a unique quantity delivered to each region II utility, and this is denoted hereafter by q_s.

Let n denote the number of region I utilities served, and $m = N - n$ denote the number of region II utilities served. The total quantity of coal shipped can be expressed as

$$Q(x) = \int_0^n q(x)dx + mq_s, \tag{2}$$

where $q(x) = q_s$ for all $x \geq n$ by the region II pricing constraint. The railroad's profit is

$$\pi\left(Q, w, t, p_s, F\right) = \int_0^n \left(p(q(x)) - tx - w\right)q(x)dx - \int_n^N \left(p_s - tx - w\right)q_s dx. \tag{3}$$

The first term in the profit expression represents the return from delivering coal to region I utilities, and the second term represents the return from delivering coal to region II utilities.

The first-order necessary conditions for a profit maximum are characterized by the Euler equation,

$$p(q(x)) + q(x)p'(q(x)) = tx + w, \qquad \text{for } x \in [0, n], \tag{4}$$

the region I boundary condition

$$p(q(n)) = p_s, \tag{5}$$

and the transversality condition

$$\left(p_s - tN - w\right)q_s = 0. \tag{6}$$

The Legendre condition associated with the maximization of (3) is $2p'(q(x)) + q(x)p''(q(x)) \leq 0$, which holds strictly in this case by condition (1).

Equations (4)-(6) have a straightforward interpretation. Equation (4) is the optimality condition for unconstrained spatial pricing in region I. Because both revenue and variable cost for a utility at distance x are unrelated to the quantity delivered to other utilities, the railroads jointly select a delivery quantity to each utility to equate marginal revenue with the sum of the mine price and marginal transportation cost. This is the outcome depicted in Figure 1. Equation (5) is the boundary condition that defines the extent of unconstrained monopoly pricing in region I. At a distance of n, the cooperative duopoly delivered price rises to $p(q(n)) = p_s$ and the demand facing the railroads thereafter becomes perfectly elastic. The railroads may continue to serve more distant region II utilities, but the marginal revenue from doing so is now constant. Equation (6) defines the extent of the railroad's total service region. At a distance of N, the region II freight rate, $p_s - w$, equates with marginal transportation cost, tN, and shipments to utilities beyond this point are no longer profitable.

Unlike the outcome in the non-cooperative case, railroads always serve utilities in region II under cooperative oligopoly. To see this, evaluate (4) at $x = n$. Next, substitute the region I boundary condition (5) into this equation, whereupon it follows immediately by inspection of (6) that $m^* > 0$.[9]

Let $q^*(x,t,w)$, $n^*(t,w,p_s)$, and $N^*(t,w,p_s)$ denote the solution to (4)-(6). The cooperative outcome for the spatial pricing of PRB coal is then given by the freight schedule,

$$f^*(x,t,w,p_s) = \begin{cases} p(q^*(x,t,w)) - w & \text{for } x \le n^*(t,w,p_s) \\ p_s - w & \text{for } x > n^*(t,w,p_s) \end{cases}. \tag{7}$$

Notice that the cooperative freight schedule rises gradually over distance in region I until the delivered price equates with the price of the alternative fuel. Freight charges remain constant thereafter in region II until the freight rate equates with marginal transportation cost, $f^*(N^*(t,w,p_s),t,w,p_s) = tN^*(t,w,p_s)$. At this point, deliveries cease. Under cooperative duopoly, the freight schedule is a piecewise concave function of distance.

[9] This can also be inferred from Figure 1. At $x = n$, the unconstrained monopoly delivered price to a region I utility equates with p_s, and marginal revenue becomes discontinuous. Nonetheless, p_s exceeds marginal revenue at distance n so that deliveries must continue at a maximum.

Comparative static results for the region I delivery schedule in the cooperative case follow directly from (4). Consider, first, the delivered quantity schedule over distance. Dropping arguments for notational convenience, use of the implicit function theorem on (4) yields

$$\frac{\partial q^*}{\partial x} = \frac{t}{2p' + q^* p''} < 0 \tag{8}$$

where the sign holds by (1). As the marginal cost of delivering a unit of coal increases over distance, the delivered quantity falls at a rate determined by the slope and curvature of demand. Differentiating the region I freight schedule (7) with respect to distance and making use of (8) gives

$$\frac{\partial f^*}{\partial x} = \frac{tp'}{2p' + q^* p''} > 0. \tag{9}$$

The cooperative freight rate remains constant thereafter in region II.

Figure 2 compares the freight schedule under cooperative and noncooperative duopoly. In the noncooperative case, the freight schedule, $f^c(x) = tx$, rises from zero at a rate of t over distance until the alternative fuel price is met, at which point all further deliveries cease. In the cooperative case, the freight schedule per ton of coal is piecewise concave. Relative to the non-cooperative outcome, the freight rate begins higher at $x = 0$, but rises more slowly (at a rate of $t/2$ in the case of linear demand). The terminal distance, N^*, coincides in each case by (6).

In the empirical analysis to follow, it is helpful to express these results in terms of freight rate per ton-mile, f/x, and in terms of market power. Under non-cooperative duopoly, the freight rate per ton-mile is constant and equal to unit transportation cost t. Under cooperative duopoly, the freight rate per ton-mile is a decreasing and convex function of distance.

Market power is measured in the conventional manner by the Lerner index, which, in this context, is defined by the schedule,

$$L^*(x,t,w,p_s) = \frac{f^*(x,t,w,p_s) - tx}{f^*(x,t,w,p_s)}. \tag{10}$$

The measure in (10) defines the mark-up of the freight rate over marginal transportation cost for the utility at distance *x* as a percentage of the freight rate. Under non-cooperative duopoly, railroad market power does not exist, and the index in (10) reduces to zero for each mine-utility pair. Under cooperative duopoly, market power is positive for each mine-utility pair, and evolves over distance according to

$$\frac{\partial L^*}{\partial x} = \frac{-t}{f^{*2}}\left(f^* - x\left(\frac{\partial f^*}{\partial x}\right)\right).$$

Making use of (4) and (9), this reduces to

$$\frac{\partial L_I^*}{\partial x} = \frac{-t}{f^{*2}}\left(tx\left(\frac{p' + q^* p''}{2p' + q^* p''}\right) - q^* p' \right) < 0,$$

$$\frac{\partial L_{II}^*}{\partial x} = \frac{-t}{p_s - w} < 0,$$

in region I and region II, respectively, where the first inequality holds by (1). Notice that railroad market power declines monotonically with distance in both regions.

Effects of Cap-and-Trade

The introduction of a cap-and-trade program to control SO_2 emissions has two main effects. First, a binding emissions cap creates a positive shadow price for SO_2 emissions, and this, in turn, leads to decreased demand for high-sulfur coal and increased demand for cleaner fuels in the utilities fuel portfolio. Second, to the extent that utilities have heterogeneous technology, the program induces emission trading. Emission trading is clearly an important aspect of the cap-and-trade program; however, because the goal of this paper is to focus on the effect of changes in the coal market that occur in response to a change in the shadow price of SO_2, this aspect of permit trading is suppressed. Considering heterogeneous utilities would make emission trading explicit in the model, but doing so would needlessly complicate the model without qualitatively influencing the results.

The primary effect of the cap-and-trade program is to increase the effective price of high sulfur coal. When all fuels are perfect substitutes, the effect of the regulation, after accounting for the value of permits surrendered when high sulfur fuels are burned, is to induce an equilibrium increase in the alternative fuel price p_s.[10] Under cooperative duopoly, an important implication of this is that the regulation does not create any incentive to discriminate against particular generating units (in this case, the 261 dirtiest units targeted for cleanup by Phase I of the cap-and-trade program). Instead, the policy provides the railroad with the opportunity to raise freight rates to all utilities in proportion to the increase in p_s, regardless of the regulatory designation of individual plants.

Under non-cooperative oligopoly, the effect of the cap-and-trade program is straightforward. A marginal increase in p_s causes the railroad sector to expand the service region. The quantity of PRB coal shipped to incumbent utilities remains constant and the entry of utilities into the expanded service region increases aggregate output of PRB coal.

[10] An implication here is that high sulfur fuel producers shoulder the burden of the more stringent environmental policy by receiving lower prices for their output. Because producers of other fuels may receive higher prices for their output, the main effect of introducing marketable permits is to shift resource rents among producers of different types of fuels, leaving the incentive to reduce emissions to operate only through the increase in p_s.

Now consider the case under cooperative oligopoly. Making use of the implicit function theorem on (4), it follows that $\partial q^*/\partial p_s = 0$. As in the non-cooperative case, the increase in p_s has no effect on the freight rates charged to incumbent utilities in region I. Prior to the implementation of the cap-and-trade program, the railroads were unconstrained in setting monopoly prices to these utilities, and this remains so after the increase in p_s. Next substitute $q^*(x,t,w)$ and $n^*(t,w,p_s)$ into (5) to get

$$p\left(q^*(n^*(t,w,p_s),t,w)\right) - p_s = 0. \qquad (11)$$

Implicitly differentiating (11) and making use of (8) gives

$$\frac{\partial n^*}{\partial p_s} = \frac{2p' + q^* p''}{tp'} > 0, \qquad (12)$$

where the inequality holds by (1). The effect of the cap-and-trade program is to increase the number of region I utilities. This is because an increase in the price of the alternative fuel relaxes the pricing constraint and allows the railroads to set interior monopoly prices for a greater number of utilities.

For the effect on the railroad's service region, substitute $N^*(t,w,p_s)$ into (6) to get

$$p_s - tN^*(t,w,p_s) - w = 0. \qquad (13)$$

By the implicit function theorem,

$$\frac{\partial N^*}{\partial p_s} = \frac{1}{t}. \qquad (14)$$

The cap-and-trade program increases the distance that the railroads ship coal by exactly the same amount as the service region would expand under non-competitive duopoly. The expansion also alters the extent of region II service. Making use of (12) and (14),

$$\frac{\partial m^*}{\partial p_s} \equiv \frac{\partial N^*}{\partial p_s} - \frac{\partial n^*}{\partial p_s} = \frac{-(p' + q^* p'')}{tp'} < 0 \,,$$

where the inequality holds by (1). An increase in the price of substitute fuel price decreases the extent of region II service.

The cap-and-trade program has offsetting effects on total output. For incumbent region I utilities, the delivered quantity remains unchanged after the regulation. For newly-designated region I plants and for region II utilities, the delivered quantity decreases as the freight rates increase. At the same time, however, new utilities enter the service region. The effect of an increase in p_s on the total quantity of coal can be derived from (2) as

$$\frac{\partial Q^*}{\partial p_s} = \int_0^{n^*} \frac{\partial q^*}{\partial p_s}(x)dx + q^*(n)\frac{\partial n^*}{\partial p_s} + q_s \frac{\partial m^*}{\partial p_s} + m^* \frac{\partial q_s}{\partial p_s} \;. \tag{15}$$

Notice that, because $\partial q^*/\partial p_s = 0$, the first term on the right-hand side of (15) is zero. There is no quantity effect for incumbent region I utilities. The remaining three terms represent, respectively, the increased quantity provided, on the margin, to the newly-designated region I utilities, the reduction in quantity from the contraction of region II service, and the decline in quantity shipped to each region II plant under the higher pricing constraint. These terms can be combined as follows. By definition, $q_s = q^*(n)$, and, making this substitution in (5), use of the implicit function theorem gives $\partial q_s/\partial p_s = 1/p'$. For region II utilities bound by the pricing constraint, the change in delivered quantity following an increase in p_s is the reciprocal of the slope of residual demand. Substituting this value and $q_s = q^*(n)$ into (15), and making use of (14) yields

$$\frac{\partial Q^*}{\partial p_s} = \frac{q^*(n)}{t} + \frac{m^*}{p'} \,.$$

The interpretation of this equation is that the cap-and-trade program, on the margin, has an expansion effect, $q^*(n)/t = q^*\left(\partial N^*/\partial p_s\right)$, which is the effect of the increased price of alternative fuel on the total service area of PRB coal, and a contraction effect, $m^*/p' = m^*\left(\partial q^*(n)/\partial p_s\right)$, which is the effect of the price increase price on sales per utility in region II. From (6), $m^*t = p_s - w - n^*t$, so that

$$\frac{\partial Q^*}{\partial p_s} = \frac{q^*(n)p' + p_s - w - n^*t}{tp'}.$$

By definition, $p_s = p(q^*(n))$, and it follows immediately from (4) that $\partial Q^*/\partial p_s = 0$. The cap-and-trade program, which increases the price of the alternative fuel, has no effect on the total quantity of PRB coal delivered under railroad collusion.

The intuition for this result is as follows. Because total delivery cost increases linearly with distance, m^* is proportional to the wedge between the delivered price and marginal cost at the terminal point of region I, $p_s - w - n^*t$. The factor of proportion, $1/t$, maps the change in marginal cost into distance as marginal cost rises smoothly up the demand curve to p_s in region II. Under competitive freight pricing, this wedge is zero, so that $m^* = 0$, whereas, under monopoly pricing, the magnitude of this wedge is p/ε_d, where ε_d is the elasticity of demand (in absolute terms). A marginal increase in the alternative fuel price of dp_s reduces the quantity purchased by a utility in region II by $dq_s = -q_s\varepsilon_d/p_s$. The effect of the substitute price increase on the quantity of PRB coal purchased by region II utilities, on the margin, $m^*\left(\partial q^*(n)/\partial p_s\right)$, is therefore $-q^*/t$. This is the contraction effect. A marginal increase in the alternative fuel price of dp_s also increases the railroad service region by $1/t$. The maximal service length is governed by the zero profit condition, so that the effect of a change in p_s maps into the same effect on service distance under both competition and monopoly. The expansion effect, therefore, is $q^*\left(\partial N^* / \partial p_s\right) = q^* / t$, which exactly offsets the contraction effect under railroad industry collusion.

Under non-cooperative duopoly, the freight rates for PRB coal are set at the competitive level, so that the cap-and-trade program induces only an expansionary effect. The net result is an aggregate increase in shipments of PRB coal. Under cooperative duopoly, utilities enter the railroad service region, which increases output through the expansion effect, but the additional quantity delivered to these utilities is exactly offset by the lower quantity delivered to region II utilities through the contraction effect. Somewhat ironically, the cap-and-trade program has adverse implications for transportation costs in the rail sector under cooperative pricing. In response to the policy, the railroads ship an identical amount of coal, but now ship it farther (on average).

Finally, consider the implications of the cap-and-trade program for railroad market power (see equation (10)). It is clear by inspection of (7) that SO_2 regulation has no effect on the freight rate or market power in region I. In region II, the freight rate rises by the same magnitude as the increase in the alternative fuel price, $\partial f^*=\partial p_s$, so that market power rises proportionally. In sum, the cap-and-trade program has no effect on the output of PRB coal, and leads to an overall increase in railroad market power.

4. Empirical Analysis

This section analyzes data on railroad costs and railroad freight rates for hauling Wyoming PRB coal. The main purpose of the analysis is to test for railroad monopoly power This section is organized into three subsections that: (1) describe the data, (2) compute Lerner indices of market power by coal shipment route and over time, and (3) econometrically model the behavior of freight rates and costs to develop additional tests for railroad market power and to assess the accuracy of other predictions from the Section 3.

a. Data.

Data on railroad costs and freight rates are taken from the 1988-1999 Carload Waybill Samples of the Surface Transportation Board (STB), U.S. Department of Transportation. These data are not generally available, but can be provided for a state when officially requested for research purposes by that state's government. Data consist of a sample of railroad shipments either originating, terminating, or passing through Wyoming. For each year, the data were filtered to eliminate all non-coal shipments, and coal shipments of fewer than 50 cars. The latter filter was applied to eliminate intermittent coal shipments (i.e., for test burns). Each year, the filtered data represent between 35-45 percent of total Wyoming coal shipments.

The filtered data on individual coal shipments were aggregated to yield 1229 observations on annual coal shipments by route (i.e., from a particular railhead to a particular power plant) for the period 1988-1999. The data form an unbalanced panel, because, with increasing coal shipments over the sample period, deliveries were made to an increasing number of power plants over time. For example, available information pertains to 55 routes in 1988 and to 150 routes in 1999. The main data elements for each route in each year consist of total variable costs, total freight revenue, total tonnage of sampled shipments, and route length (in miles). As described below, additional information about the sampled coal shipments is available in the STB data as well as from other sources.

While STB data on variable costs of coal shipments are quite detailed, they are subject to two limitations. First, STB estimates costs, rather than measuring them directly, using national relationships (for 40 Class I railroads) between expenses in 15 accounting categories (i.e., wages, repairs, fuel, track maintenance) and measures of railroad activity, such as ton-miles. Second, several expense categories include an unknown amount of administrative overhead. To the extent that these expense categories include components of fixed cost, this implies an upward bias in the reported estimates of variable costs. These data show that mean average real variable cost for all routes declined from 11.467 mills per ton-mile in 1988 to 7.460 mills in 1999, a decline of 32% over this period. This finding of declining railroad costs over time is consistent with results presented previous studies (MacDonald and Cavalluzzo (1996), Wilson (1997), Ellerman *et al.* (2001, p.83)).

The freight rate data are subject to limitations as well. Exact freight revenue data are confidential and known only by the STB and the reporting railroad. Approximate or "masked" values of freight revenue are reported for some shipments for non-STB use. As noted by the Association of American Railroads (2000), freight revenues may be overstated due to this confidentiality mechanism. This point is considered in the analysis below. Examination of the freight revenue data shows that annual average real freight rates per ton-mile (in 2000 dollars) declined by 36% from 19.65 mills in 1988 to 12.59 mills in 1999.

Ellerman and Montero (1998) and Ellerman *et al.* (2001) use more aggregated data than those used here to find that real freight rates for hauling PRB coal declined by 44% over the 1987-1993 period. This estimate and the one just presented, however, do not control for route-specific effects and in particular for the increasingly long distances that coal was shipped over this period. In the STB data, control for route-specific effects can be achieved by measuring freight rates per ton-mile from route-specific time means. This control reduces the estimate of freight rate decline over 1988-1999 from 36% to 22% and, at the very least, hints at the existence of railroad monopoly power. As demonstrated in Section 3, if railroads exercise monopoly power and marginal transportation cost is independent of distance (see below), then the freight rate per ton-mile is a convex function of distance. Thus, a portion of the decline in average freight rates observed in the earlier studies, ironically attributed to deregulation, may be due an expanding geographic market served by a monopoly railroad.

b. Lerner Indices.

Evidence of railroad market power in transportation of Wyoming PRB coal can be obtained using the cost and freight rate data to compute Lerner indices by route and over time. As shown in equation (10), the Lerner index (L^*) expresses the monopoly wedge between the freight rate and marginal cost as a percentage of the freight rate. Competitive pricing behavior implies that $L^*=0$ and market power over price implies that $0<L^*\leq 1$. Lerner indices are computed using data on real freight rates per ton-mile along each of the 353 rail routes over the period 1988-1999 together with corresponding estimates of real marginal transportation cost per ton-mile.

Estimates of marginal cost are obtained using the familiar relationship that the elasticity of total variable cost with respect to output is equal to the ratio of marginal cost to average variable cost. Applying this relationship to the setting at hand, railroad output could be measured as ton-miles of coal hauled. Moreover, if the elasticity of total railroad variable cost with respect to ton-miles equals unity, then marginal cost per ton-mile equals (average) variable cost per ton-mile, implying that marginal cost of transporting a unit of coal is independent of both distance and tonnage, as specified in the model presented in Section 3.

The elasticity of total railroad variable cost with respect to ton-miles is estimated from the double-log, two-way fixed effects unbalanced panel regression shown in equation

(16). In this regression, the unit of observation is a route from a railhead to a utility in a particular year (n=1229) and route and time subscripts have been suppressed.

$$Log(total\ real\ variable\ cost)=constants+\underset{(0.003)}{0.98}Log(ton\text{-}miles)+e \qquad R^2=0.997 \qquad (16)$$

The estimated elasticity is 0.98 with a standard error of 0.003. Although a 1% confidence interval about this estimate does not bracket unity, the estimate itself is sufficiently close to unity that real variable cost per ton-mile is used as the estimate of real marginal cost per ton-mile in computing the Lerner indices.

For all routes in all years, estimated values of L^* always were positive and averaged 0.37 with standard error of 0.004. Thus, the null hypothesis that $L^*=0$ is rejected at the 1% level in favor of the alternative hypothesis that railroads exercise monopoly power over freight rates. Additionally, after differencing the Lerner indices to control for route-specific effects, annual average values of L^* were 15% larger in 1999 than in 1988. This difference is significantly different from zero at the 1% level. Thus, in spite of the intended effects of the deregulation process to make rail transportation more competitive, the monopoly power of railroads hauling Wyoming coal actually grew during the 1990s. Based on the model presented in Section 3, this evidence of railroad market power suggests that the cap-and-trade program had no effect on the production of PRB low-sulfur coal.

These values of L^*, however, either may be underestimates of railroad monopoly power because the average variable cost data contain components of fixed cost or overestimates of such power because of the previously noted upward bias in reporting freight revenue. The problem of including fixed cost items in the variable cost data does not appear to be serious: Equation (16) suggests that variable cost per ton-mile is constant with respect to distance and tonnage, rather than a decreasing function of ton-miles as would be expected if this variable included large fixed cost components. On the other hand, possible upward bias in reporting freight revenue (mentioned above) is a worrisome source of error when estimating the extent of monopoly power. Thus, it is useful to have an independent estimate of freight rates from another source. Lacey (2002) estimated freight rates for each PRB coal shipment in the 1988-1999 STB sample by taking the difference between the delivered the coal price per ton reported by utilities (U.S. Department of Energy, Federal Energy Regulatory Commission, various years) and mine-specific, mine-mouth coal prices reported by Hill and Associates (2000). In making these calculations, difficulties emerged in matching mines to railheads (in some cases a railhead is used by more than one mine) and because Hill and Associates reports average mine-mouth prices by year, rather than prices by shipment. Nevertheless, aggregating these data into the same 1229 route-years considered above and using the STB data on variable cost per ton-mile yields an estimate of the average value of L^* of 0.28 with standard error of 0.01. This estimate implies that while the STB data may over-estimate freight revenue, an alternative approach to estimating the Lerner index still suggests that railroads possess a substantial degree of market power in setting freight rates for PRB coal.

The model predicts that the Lerner index for a monopoly railroad declines over distance. Evidence to support this prediction using the STB freight revenue data is presented in Table 1. This table reports averages of time-means of Lerner indices for routes in each of three shipment distance categories. Distance categories were chosen so as to divide the 353 routes into roughly equal sized groups. For the first group of utilities, located within 948 rail miles of the PRB mines, values of L^* average 0.41. For the second group, located between 948 and 1190 rail miles from the mines, values of L^* average 0.36. For the third group, located more than 1190 rail miles from the mines, values of L^* average 0.33. Assuming independent samples, t-tests reject the null hypothesis of equal mean values of L^* in each of the three possible comparisons at the less than the 1% level. This result, which could be anticipated from previous results presented earlier in this section (i.e., the freight rate per ton-mile decreases with distance while the marginal cost of shipping coal by rail is independent of distance), implies that the Lerner index declines with shipment distance. This is consistent with railroad monopoly power in setting freight rates. Because the potential correlations between route-specific effects make the effect of shipment distance difficult to identify, this result should be interpreted with some caution. Nonetheless, the interpretation provided is consistent with the econometric estimates presented in the following subsection.

c. Econometric Analysis

An alternative test for railroad monopoly power rests on estimating the relationship between changes in marginal transportation costs and changes in freight rates using equation (7) (see Section 3). Under the null hypothesis of competition, the freight rate per ton-mile is always equal to marginal transportation cost per ton-mile, so a one unit increase (decrease) in marginal cost leads to a one unit increase (decrease) in the freight rate. Under the alternative hypothesis of monopoly power, as demonstrated in Section 3, a one unit increase (decrease) in marginal cost per ton-mile results in less than a one unit increase (decrease) in the freight rate per ton-mile. Thus, in a regression with freight rate per ton-mile as the dependent variable, the null hypothesis of competition should be rejected unless the coefficient of marginal transportation cost per ton-mile is equal to unity and the coefficients of all other explanatory variables (including the constant term) are equal to zero.

The outcome that marginal transportation cost per ton-mile is independent of shipment distance and tonnage (see equation (16)) simplifies estimation of the freight rate equation. On the one hand, it suggests that a shock to marginal transportation cost affects the freight rate as the marginal cost schedule intersects utility coal demand and marginal revenue schedules at different points. On the other hand, a demand-side shock will leave marginal transportation cost per ton-mile unchanged. Thus, equations for marginal cost per ton-mile and freight rate per ton-mile can be written as a triangular system with (possibly) correlated errors. Consistent and asymptotically efficient estimates of this system may be obtained by seemingly unrelated regressions (SUR) (Lahiri and Schmidt (1978)).

The SUR estimates of equations for marginal transportation cost per ton-mile and the freight rate per ton-mile are presented in Table 1. Both variables are measured in tenths of a cent (mills). Effects of variables that change over time, but not across rail routes, are accounted for by including a full set of time dummies in both equations. Effects of variables that change across shipment routes but not over time are controlled in both equations by expressing all variables as differences from their route-specific time means. Examples of time-specific variables in the cost equation might include railroad productivity improvements, changes in fuel costs, and the gradual switch from steel railcars to lighter aluminum railcars that occurred during the 1990s, while examples of route-specific variables in the cost equation include route length or distance. In the freight rate equation, examples of time-specific variables include trends in PRB mine productivity and in prices of alternative fuels such as oil, natural gas, and high-sulfur coal used to generate electricity. Examples of route-specific variables in the freight rate equation include heat (BTU) and impurity content of coal shipped, route length, and unobserved heterogeneity among utilities served.

Column (1) of Table 1 presents the estimate of the marginal transportation cost equation. Coefficients of time dummies reflect steadily and significantly decreasing marginal costs over the period 1988-1999. Additionally, variables for railcar ownership and the number of junctions between rail lines are significant determinants of marginal cost as well. Rail car ownership measures the percentage of railcars in the sampled coal shipments that were not owned by a railroad. These cars typically are owned by an electric utility. Use of these cars would be expected to lower railroad costs, and as shown in Table 1, this variable has a negative coefficient (-2.04) that is significantly different from zero at conventional levels. The number of junctions (interline transfers between railroads) along a route is expected to lead to increased costs and the coefficient of this variable is positive (0.43) and significantly different from zero at conventional levels.

In the freight rate equation, coefficients of the time dummies again reflect steadily decreasing rates between 1988 and 1999. Also, the coefficient of marginal transportation cost per ton-mile (0.13) is positive and significantly less than unity at conventional levels, indicating that a given reduction in marginal costs leads to a smaller reduction in freight rates. This outcome leads to rejection of the null hypothesis that railroads set freight rates competitively. Instead, it is consistent with predictions from the model regarding pricing behavior of a railroad with monopoly power. Two other explanatory variables in the freight rate equation indicate the extent of spot sales of coal and whether or not Phase I designated generating units were located at the destination of the shipment. As discussed previously, the model predicts that a railroad with monopoly power has no incentive to discriminate against particular coal purchasers, including those with generating units targeted under Phase I rules. Consistent with this prediction, the coefficient of this variable has a t-statistic that is less than unity in absolute value. Finally, Section 2 reported that long-term coal contracts with take-or-pay or price escalation provisions have become less important through the 1990s and that short-term contracts with re-opener provisions and spot sales are now more the norm. The coefficient of the variable measuring the percentage of spot sales among sampled shipments is consistent with this view in that it is positive and not significantly different from zero at conventional levels.

5. Summary and Conclusion

This paper has evaluated the role of the Clean Air Act Amendments of 1990 in encouraging electric utilities to burn low-sulfur coal from the Powder River Basin in Wyoming and Montana. Thus, it indirectly asks whether the cap-and-trade program authorized by Title IV of these amendments should be credited for the reduction in SO_2 emissions that was brought about by the increased use of this fuel. This question is addressed using a three-sector model of PRB coal production, transportation, and consumption that emphasizes the role played by railroads in hauling coal to spatially distributed utilities. The model predicts that if railroads behave non-cooperatively, a binding constraint on SO_2 emissions will lead to an expansion of the spatial market with an accompanying increase in production of PRB low-sulfur coal. On the other hand, if railroads behave cooperatively, the SO_2 emissions ceiling leads to an expansion of the geographic reach of PRB coal but production of coal will be left unchanged. Thus, in the cooperative case, binding emission limits have no effect on the production of PRB coal.

Estimates obtained from the 1988-1999 Carload Waybill Samples of Surface Transportation Board, U.S. Department of Transportation provide evidence of cooperative behavior among railroads. This evidence is obtained by computing Lerner indices of market power using available data on railroad costs and freight revenues for 353 rail routes from PRB mines to electric utilities in the Midwest and Southeast regions of the U.S. The mean value of Lerner indices for all routes and time periods tests significantly greater than zero at the 1% level and route-specific Lerner indices increase significantly (also at 1%) over time. Thus, despite the intended effects of deregulation to increase competition, railroads hauling coal out of the PRB appear to have experienced an increase in market power. Additionally, further econometric analysis reveals that a one unit increase (decrease) in railroad marginal cost per ton-mile leads to less than a one unit increase (decrease) in the railroad freight rate per ton-mile. This outcome also points to cooperative railroad behavior in that rents arising from cost reductions are not fully dissipated.

If SO_2 emissions limits had no effect on the production of low-sulfur PRB coal, then what explains the dramatic increase in utilization of this fuel to generate electric power during the 1990s? While this question is not fully analyzed in the paper, it is possible to speculate that two types of cost reductions played a prominent role. First, data from the Carload Waybill Samples indicate that real railroad marginal cost per ton-mile declined by more than 30% over the sample period. These cost reductions, which may have been at least partially brought about by increased efficiencies induced by deregulation, provide railroads an incentive to haul more coal to existing buyers and to expand their service territory. Second, over the period 1985-2000, average real variable costs of PRB coal extraction declined by 57% as mines achieved scale economies by substituting capital for labor. This cost reduction appears to have exceeded cost reductions in other U.S. coal producing regions and also would lead railroads to haul an increased quantity of PRB coal to an increased number of utilities. The extent to which these cost reductions led to an expansion of the geographic market for PRB coal is left for future research.

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Table 1: Effects of distance on Freight Rates and Lerner indices: Difference between means tests

	Power Plant Location is:	Less than 948 miles from PRB (1)	Between 948 miles and 1190 miles from PRB (2)	More than 1190 miles from PRB (3)
Freight Rate per Ton-Mile in Mills (in 2000 dollars)				
	Mean	17.679	13.369	12.899
	Standard error	0.348	0.157	0.218
	N	409	411	409
Difference between means		**(1)-(2)**	**(1)-(3)**	**(2)-(3)**
t-statistic		11.30	11.63	1.75
Lerner Index				
	Mean	0.414	0.364	0.331
	Standard error	0.007	0.005	0.008
	N	409	411	409
Difference between means		**(1)-(2)**	**(1)-(3)**	**(2)-(3)**
t-statistic		5.87	7.96	3.73

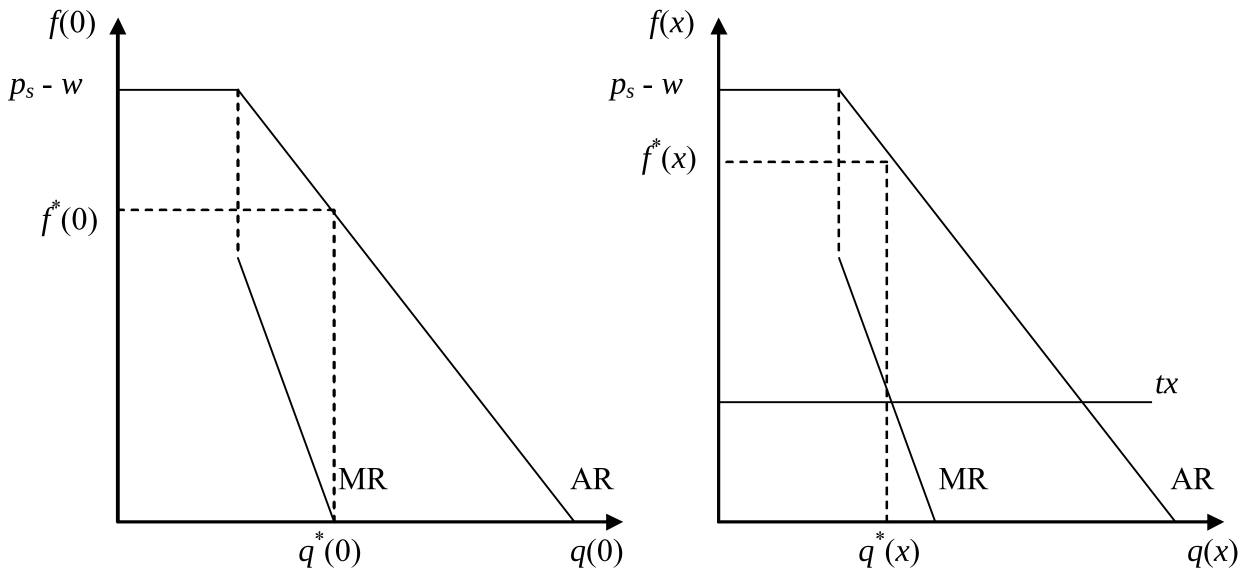
Table 2: Determinants of Marginal Cost and Freight Rates: Two-Way Fixed Effects Seemingly Unrelated Regression Estimates

Explanatory Variable	Sample Mean (Std. Dev.)	Marginal Cost per Ton-Mile Coefficient (standard error)	Freight Rate per Ton-Mile Coefficient (standard error)
=1 if year is 1988; 0 other wise	0.044 (0.205)	----[a]	----[a]
=1 if year is 1989; 0 otherwise	0.050 (0.219)	-0.122 (0.231)	-0.504 (0.390)
=1 if year is 1990; 0 otherwise	0.060 (0.238)	0.102 (0.229)	-0.952* (0.386)
=1 if year is 1991; 0 otherwise	0.054 (0.226)	-0.765* (0.229)	-1.901* (0.390)
=1 if year is 1992; 0 otherwise	0.063 (0.242	-1.471* (0.226)	-2.599* (0.389)
=1 if year is 1993; 0 otherwise	0.057 (0.231)	-1.356* (0.234)	-2.555* (0.400)
=1 if year is 1994; 0 otherwise	0.099 (0.299)	-2.334* (0.214)	-3.090* (0.377)
=1 if year is 1995; 0 otherwise	0.104 (0.306)	-2.525* (0.214)	-3.059* (0.381)
=1 if year is 1996; 0 otherwise	0.097 (0.296)	-2.156* (0.224)	-3.181* (0.384)
=1 if year is 1997; 0 otherwise	0.116 (0.321)	-2.164* (0.226)	-3.134* (0.380)
=1 if year is 1998; 0 otherwise	0.133 (0.339)	-2.485* (0.225)	-3.794* (0.380)
=1 if year is 1999; 0 otherwise	0.122 (0.328)	-3.032* (0.232)	-4.812* (0.399)
Real Variable Cost per Ton-Mile in mills in year 2000 dollars	8.877 (2.394)	----[a]	0.137* (0.044)
Real Freight Rate per Ton-Mile in mills in year 2000 dollars	14.718 (5.451)	----[a]	----[a]
Fraction of spot sales	0.350 (0.454)	----[a]	0.276 (0.227)
=1 if destination utility has Phase I generating units; 0	0.218 (0.413)	----[a]	-0.778 (0.880)

otherwise			
Number of Interline Transfers	0.660 (0.856)	0.431* (0.084)	----[a]
Fraction of Railcars Not Owned by a Railroad	0.762 (0.340)	-2.046* (0.202)	----[a]
Summary Statistics			
NT		1229	1229
OLS R^2		0.396	0.185

[a]Variable not included in regression
*Denotes significance at 1% level

Figure 1: The relationship between freight rate and distance



(a) (b)

Figure 2: Freight rate per ton schedule over distance