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

Mitch Kunce
University of Wyoming

Steve Hamilton
University of Central Florida

Shelby Gerking
University of Central Florida

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ABSTRACT

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Mitch Kunce
University of Wyoming

Steve Hamilton
University of Central Florida

Shelby Gerking
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In light of the U.S. Clean Air Act Amendments of 1990, the performance of markets for delivered low-sulfur coal to electric utilities is a subject of growing importance. This paper examines the efficiency of markets for delivered low-sulfur coal in a three-sector model of mines, railroads, and utilities. Lerner indices are derived for individual mine-utility pairs and market power is estimated along individual railroad routes using data on freight revenues and costs. The results indicate 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. An implication of this finding is that the introduction of marketable emission permits in the Clean Air Act had no effect on the utilization of low-sulfur coal at electric utilities. Instead, this outcome appears to be driven by declining costs in upstream mining and transport markets.

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1. Introduction

Over the period 1990-2002, low-sulfur coal production in the Powder River Basin (PRB) of Wyoming and Montana more than doubled, and utilities burning this fuel more than tripled. Also, since the 1970s, SO_2 emissions have been reduced by 50% at less than 10% of the originally estimated cost. To what extent was federal environmental policy responsible for these outcomes? On the one hand, studies by the Department of Energy (2000) and Kerr (1998) give much credit to environmental policy and especially to Title IV of the Clean Air Act Amendments of 1990, which made market mechanisms a prominent feature of the overall regulatory framework. On the other hand, the timing of the Amendments may simply have been serendipitous: As discussed more fully below, real PRB coal production and transportation costs have fallen by 57% and 32%, respectively, since the late 1980s.

This paper sorts out the effect of environmental policy on the increased utilization of low-sulfur PRB coal using a model of railroad behavior together with supporting empirical evidence. The analysis focuses on whether more stringent regulation of SO_2 emissions by electric utilities altered the incentive of railroads to haul low-sulfur coal.[1] Coal transportation is emphasized for two reasons. First, PRB coal is shipped almost entirely by rail and transportation costs can run as high as 80% of the delivered price. Second, as would be predicted by Just and Hueth (1979), performance of markets for inputs to the production of electricity turns out to have crucial impact on the effectiveness of federal polices to reduce SO_2 emissions. Additionally, because railroad behavior is emphasized, the paper not only

[1] Numerous recent studies (see, for example, Joskow, Schmalensee, and Bailey (1998), Montero (1999), and Carlson *et al.* (2000)) have examined performance of federal environmental policy by looking at the market for emission permits. For a detailed discussion of the political economy of allocating emission permits, see Joskow and Schmalensee (1998).

evaluates the efficacy of important environmental regulations, it also contributes to the literature on market performance in the transportation sector and provides a rare glimpse into how market power is exercised over space.[2]

The model demonstrates that if railroads are competitive, the introduction of SO_2 emission controls increases the effective cost of burning high-sulfur coal, and this bids up delivered PRB coal prices, increasing the quantity of low-sulfur coal delivered through an expansion of its geographic service region. With a monopolistic railroad sector, SO_2 policy likewise stimulates the delivery of low-sulfur coal to more distant utilities; however, because railroads face more elastic demand from utilities at greater shipping distances, the entry of new utilities in the service region alters the ability of railroads to spatially price discriminate with freight rates, and this leads to reduced shipments among existing buyers. In the case of perfectly substitutable fuels and constant marginal transportation costs, the effects are entirely offsetting, and SO_2 policy does not lead to a change in use of low-sulfur coal.

Because the model's predicted policy outcome depends on railroad behavior, the extent of railroad market power over delivered PRB coal prices is measured using data from the U.S. Department of Transportation, Surface Transportation Board's Carload Waybill Samples for the period 1988-1999. Lerner indices are estimated for 353 PRB coal shipment routes. Estimates suggest that railroads hauling PRB coal held a substantial degree of market power. Moreover, despite the intended effects of the Staggers Rail Act of 1980 and contrary to the arguments of Schmallensee *et al.* (1998), Ellerman and Montero (1998), Ellerman *et al.* (2001), railroad market power actually increased in the period. Consistent with the findings of Greenstone (2004), the results point to a general ineffectiveness of environmental

[2] Market performance has been examined in the airline industry (see, e.g., Borenstein 1989, 1990, Kim and Singal 1993) and in the trucking industry (Savage 1995). The potential to exercise market power in rail transportation has been recognized since at least the case of Standard Oil (see Granitz and Klein 1996).

policy in increasing the utilization of low-sulfur PRB coal. The observed expansion in the production and utilization of PRB coal appears to have been driven, instead, 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). The key aspects of the model are: (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 conceived in earlier studies. The purpose of this section is to reconcile 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 in 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. This view provided incentives for both mines and utilities 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 a 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 (e.g., trucking) or else do not exist (e.g., 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 severance taxes on production.

Since these early studies, 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. PRB coal production began to increase at a rate of 8.4% per year in that 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, and this suggests 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, large 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), and, even in nominal terms, the average extraction costs for PRB coal declined by nearly 40% over this period (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 coal producers. First, there has been a virtually complete turnover in mine ownership over the past 20 years, a feature that suggests narrow profit margins in the industry. Second, relationship-specific investments associated with the production of heterogeneous coal have 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 the increased potential for 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 initiate transportation of PRB coal out of Wyoming.[3] 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 transportation routes, the railroad hauling coal switched from BNSF to UP or vice-versa at least once over the period 1988-1999.[4] In 1999, the market share of the BNSF was 55.3%, while the UP shipped the remaining 44.7% of Wyoming coal.

3. Model

The model considers duopolistic railroad intermediaries. Each railroad purchases PRB coal at spot prices from a competitive mining industry and delivers it to a series of identical, spatially distributed utilities. The railroads deliver only a single product --coal--and hold no inventories. Railroad competition is in freight rates, and spatial price discrimination is possible in the sense that freight rates are allowed to vary over distance.

The model extends the framework of Greenhut and Ohta (1972) to consider spatial market power over endogenously determined service regions. Each railroad selects a freight schedule over distance and a terminal point that defines the extent of its service region. A

[3] The Chicago and Northwestern Railroad, which entered the Wyoming coal transportation market in the early 1980s, no longer serves the PRB. Also, the BNSF and UP do not complete deliveries to all utilities because coal is sometimes transshipped via other lines.
[4] A transportation route is defined as a railhead to a particular power plant.

change in economic conditions following SO_2 policy thus has the potential to alter both the freight rates and the equilibrium number of utilities served. To simplify the model, attention is limited to cases in which economies of scope do not exist in the transportation cost function. The data described in Section 4 on PRB transportation costs are consistent with this assumption. Each delivery of PRB coal is recorded in the data as a separate trip between a mine and a utility, so that the transportation cost of coal delivered to one utility is independent of the transportation cost of delivering coal to any other utility.

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 the PRB coal mines. To focus attention on railroad behavior, the source mines for PRB coal are consolidated to a single point in space --the origin-- and the location of utilities is measured continuously, in ascending distance, along a single rail line.[5] The utilities are assumed uniformly distributed with unit density over the support $[0, \overline{N}]$. This allows the maximum distance shipped by a railroad, $N^* \leq \overline{N}$, 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 coal an additional unit of distance is *t*.[6] Accordingly, the total cost of delivering the quantity, *q(x)*, to a utility at distance *x*, is $txq(x)$, and the total cost of procuring and hauling the aggregate quantity, $Q = \int_0^N q(x)dx$, is $c(Q) = \int_0^N (w + tx)q(x)dx$. Fixed costs, which are necessary to justify the existence of

[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.

[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 empirical analysis in Section 4.

railroad market power, play no role in the analysis and are consequently omitted.

In the downstream market, coal-fired electric utilities choose to burn one of two, perfectly substitutable fuels--high-sulfur coal or low-sulfur PRB coal. The model suppresses the possibilities that utilities may choose to: (1) burn fuels other than coal, such as natural gas and (2) control SO_2 emissions by installing post-combustion abatement equipment. High-sulfur coal is available to all utilities at unit price p_s. This assumption reflects the fact that this fuel is transported relatively shorter distances than PRB low-sulfur coal. Also, while the assumption of perfect substitution between the two types of coal is not descriptively accurate, it nevertheless serves as a useful benchmark case in understanding the effects of environmental policy on coal transportation.[7] Implications of relaxing this assumption are discussed later on.

In the railroad sector, the transportation of PRB coal is considered to be a homogeneous service. Implicitly, this assumes each railroad has the ability to serve all utilities and that each utility perceives the quality of service to be equivalent. Given that utilities have full information on freight rates, each utility then procures PRB coal from the railroad which offers the lowest delivered price.[8] 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

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

Condition (1) is a standard existence condition under oligopoly (see, e.g., Novshek (1985)) that guarantees that marginal revenue declines faster than price as quantity increases.

[7] Fixed cost of switching a boiler from bituminous high-sulfur coal to sub-bituminous low-sulfur coal is about $100,000 (Energy Ventures Analysis---).
[8] Individual utilities make discrete choices between railroads for delivery services, which rules out the possibility of a Nash-Cournot outcome in the transportation market.

Market structure in the railroad sector is characterized by either non-cooperative or cooperative duopoly. If the industry setting is characterized by non-cooperative duopoly, then the railroads compete to acquire individual shipping routes through their selection of freight rates (or equivalently delivered prices). This is because economies of scope do not exist in transporting PRB coal to multiple locations. Under non-cooperative duopoly, the model reduces to a series of spatially indexed, but independent markets with freight rates determined separately along individual routes. Accordingly, the equilibrium freight rate charged to a utility at distance x is the competitive rate, $f^c(x) = tx$. The freight schedule increases linearly over distance at rate t under non-cooperative duopoly, and the extent of the railroad service region is determined where the delivered price of low-sulfur coal equals p_s. This case is referred to subsequently as the competitive outcome.

Next, consider the cooperative case. Under cooperative duopoly, the railroads seek to maximize their joint rents, and this case is referred to throughout as the monopoly outcome. Under monopoly, 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, and these are referred to as region I and region II. In region I, utilities are located sufficiently close to the mine that the availability of high-sulfur coal 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 high-sulfur coal. The railroads may continue to serve utilities in this region; however, this only can be done under the binding constraint that $p(q^*(x)) = p_s$. This constraint implicitly defines a unique quantity delivered to each region II utility, 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

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

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

$$\left(p_s - tN - w \right) q_s = 0 \,.^{9} \tag{6}$$

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, a monopoly railroad selects a delivery quantity to each utility to equate marginal revenue with the sum of the mine price and marginal transportation cost.

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

This outcome depicted in Figure 1 for the special case of linear (inverse) demand. The horizontal axes, respectively, measure the utility demand at distance zero, $q(0)$, and utility demand at distance x, $q(x)$. 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 price of high-sulfur coal. The marginal revenue schedule 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 $q^*(x)$. Clearly, this must satisfy $q^*(x) < q^*(0)$ 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.

Equation (5) is the boundary condition that defines the extent of unconstrained monopoly pricing in region I. At a distance of n, the monopoly delivered price rises to $p(q(n)) = p_s$. Demand facing the railroad thereafter is perfectly elastic. A monopoly railroad 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 unit transportation cost, tN, and shipments to utilities beyond this point are no longer profitable.

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 the marginal revenue schedule at each utility does not change. A monopoly railroad therefore sells on successively more elastic portions of the demand curve as distance increases. Second, as the marginal cost of delivery increases over distance, the delivered price of PRB coal rises, and this facilitates substitution possibilities –here, discretely at the price p_s-- between PRB coal and high-sulfur coal.[10]

Unlike the competitive outcome, a monopoly railroad always serves utilities in region II. To see this, evaluate (4) at $x = n$. Substituting the region I boundary condition (5) into this equation, it follows immediately by inspection of (6) that $m^* > 0$.[11]

Let $q^*(x,t,w)$, $n^*(t,w,p_s)$, and $N^*(t,w,p_s)$ denote the solution to (4)-(6). The monopoly outcome PRB coal delivery can then be characterized by the freight schedule,

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

Notice that the monopoly freight schedule rises over distance in region I until the delivered price equates with the price of high-sulfur coal. Freight charges remain constant thereafter in region II until the freight rate equates with unit transportation cost, $f^*(N^*(t,w,p_s),t,w,p_s) = tN^*(t,w,p_s)$, at which point deliveries cease.

Comparative static results for the region I delivery schedule under monopoly pricing can be derived from (4). Consider, first, the delivered quantity schedule over distance. Dropping arguments for notational convenience, use of the implicit function theorem 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, tx, increases

[10] If high-sulfur coal and PRB coal were viewed as differentiated fuels, then input substitution would induce smooth changes in the demand elasticity over distance.
[11] 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 profit maximum.

over distance, the rate at which delivered quantity falls depends on both the slope and the curvature of demand. Differentiating the region I freight schedule (7) with respect to distance and making use of (8) gives

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

Monopoly freight rates rise over distance in region I to $f^*(n^*) = p_s - w$, and then remain constant thereafter in region II.

Figure 2 compares the freight schedule under competition and monopoly with the mine mouth price of low-sulfur coal normalized to zero, again for the special case of linear (inverse) demand. In the competitive case, the freight schedule, $f^c(x) = tx$, rises from zero at a rate of t over distance. In the monopoly case, the freight schedule is piecewise concave. Relative to the competitive outcome, the freight rate begins higher at $x = 0$, and rises over distance at the rate of $t/2$ in region I because the marginal revenue schedule is twice as steep as the demand schedule. Deliveries continue at the constant price p_s in region II. The terminal distance that defines the railroad service region, N^*, coincides in both cases by (6). Thus, the same number of utilities is served under both competition and monopoly, and except for the most distant utility served, the railroad hauls more coal to each under competition. Under both competition and monopoly, reductions in either w or t result in an expansion of the market area for low-sulfur coal.

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 competition, the freight rate per ton-mile is constant and equal to unit transportation cost t. Under monopoly, the freight rate per ton-mile is a decreasing and convex function of distance.

Railroad market power varies spatially and can be measured by the Lerner index schedule,

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

The Lerner index 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 monopoly freight pricing, 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). Because utility demand facing the railroad becomes more elastic as the delivery distance increases, railroad market power declines monotonically with *x*. This outcome also can be seen in Figure 2 in which the vertical distance between the monopoly freight rate schedule and marginal cost schedule diminishes with distance.

Effects of Emissions Limits and Emissions Trading

How does a cap-and-trade program, such as the one authorized by Title IV of the Clean Air Act Amendments of 1990 to control SO_2 emissions, affect the railroad's incentives to haul low-sulfur coal? In the model, there are two types of otherwise identical utilities: (1) low-sulfur coal uses located within N^* units of distance of the mines and (2) high-sulfur coal users located more than N^* units of distance from the mines. Assume that the emission ceiling constrains electricity production of high-sulfur coal users and that the government hands out emission permits for free to all utilities.[12] The ceiling would create a positive shadow price for SO_2 emissions, inducing high-sulfur coal users to buy permits from low-sulfur coal users served by the railroad. A positive price for permits would be established and the cost of using high-sulfur coal would rise, modeled here as an increase in p_s.

Under competitive freight pricing, the effect of the cap-and-trade program is straightforward. The increase in p_s expands the service region for PRB coal. The quantity shipped to incumbent utilities remains constant and aggregate output of PRB coal increases through entry by distant utilities into the service region.

Under monopoly freight pricing, it follows from inspection of (4) that $\partial q^*/\partial p_s = 0$. An increase in p_s can have 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 region I utilities, and this remains the case after the increase in p_s. Next substitute $q^*(x,t,w)$ and $n^*(t,w,p_s)$ into (5) to get

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

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

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

where the inequality holds by (1). The effect of the cap-and-trade program is to increase the number of region I utilities. An increase in the price of high-sulfur coal relaxes the pricing

[12] In the model, if permits were handed out only to the high-sulfur coal users, the policy would not differ from one that just limited emissions because utilities would have no incentive to trade permits. Trading could occur if these utilities were assumed to have different cost structures. This extension, however, would needlessly complicate the model, drawing attention away from the market for low-sulfur coal. Moreover, it still would lead to an increase in p_s, which drives the results discussed below.

constraint on freight rates, and this allows interior monopoly prices to obtain for a greater number of utilities.

For the effect on the railroad service region, substitute $N^*(t, w, p_s)$ into (6) to get

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

It follows immediately that

$$\frac{\partial N^*}{\partial p_s} = \frac{1}{t} \,. \tag{14}$$

The cap-and-trade program increases the geographic distance that the railroads ship coal by precisely the same amount under competition and monopoly.

An increase in the price of high-sulfur coal also changes the distribution of utilities between regions I and II. 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 p_s expands the railroad service area by adding shipments to more distant utilities, but the number of utilities served under a binding freight price constraint nonetheless decreases. In response to SO_2 policy, a larger proportion of utilities pay unconstrained monopoly freight rates in the low-sulfur coal market.

The cap-and-trade program has offsetting effects on total output. New utilities enter the service region for low-sulfur coal, and this increases the quantity delivered. Among incumbent region I utilities, the delivered quantity remains unchanged after the regulation. Among incumbent region II utilities, some of which are now re-designated as region I plants, freight rates increase, and the quantity delivered to each decreases.

The effect of an increase in p_s on total low-sulfur coal deliveries 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 the first term on the right-hand side of (15) vanishes, because $\partial q^*/\partial p_s = 0$ for all $x < n^*$. The remaining three terms represent, respectively, the increased quantity shipped to region I utilities given its expanded geographic boundary, the reduction in quantity from the geographic contraction of region II, and the effect of the price increase on reducing the quantity shipped to each region II plant. 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 $\partial q_s/\partial p_s = 1/p'$. An increase in p_s changes the delivery quantity to region II designated utilities according to the reciprocal of the slope of residual demand. Substituting this value and $q_s = q^*(n)$ into (15), and making use of (14),

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

This equation has a straightforward interpretation. By increasing the price of high-sulfur coal, the cap-and-trade program produces an expansion effect on the geographic service area of PRB coal, $q^*(n)/t = q^*\left(\partial N^*/\partial p_s\right)$. In a competitive railroad industry, this is the only effect at work. Under monopoly freight pricing, there is also a contraction effect. The railroad now makes smaller deliveries to each utility in region II, $m^*/p' = m^*\left(\partial q^*(n)/\partial p_s\right)$. Making use of (6), the quantity effect of a change in p_s can be written

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

By definition, $p_s = p(q^*(n))$, and it follows immediately from (4) that $\partial Q^*/\partial p_s = 0$. The expansion and contraction effects are entirely offsetting, and this implies that the cap-and-trade program has no effect on the total quantity of PRB coal delivered.

Two implications of this result easily can be developed. First, in the monopoly case, the cap-and-trade program increases average transportation costs per unit of coal. Railroads deliver the same quantity of coal as before the policy change, but on average ship each ton a greater distance. Second, the cap-and-trade program increases the market power of railroads (see equation (10)). By inspection of (7), this program has no effect on freight rates or market power in region I. In region II, freight rates rises by the same magnitude as the increase in the price of high-sulfur coal, $\partial f^*=\partial p_s$, while the cost schedule does not change. Thus, the Lerner index is unchanged in region I and increases in region II so overall, the railroad ends up with greater market power than it had before the policy change.

To more intuitively grasp why the cap-and-trade policy has no effect on output under monopoly, again normalize the mine price to zero and consider the outcome under the linear (inverse) demand function $p(x)=a-bq(x)$. In this case, the delivered quantity to a utility at distance $x = 0$ is $q(0) = a/2b$ by (4). The delivery quantity declines over distance at rate $-t/2b$ in region I, and then remains constant thereafter at q^s in region II. Figure 3 depicts this outcome for the case prior to SO_2 regulation (subscript 0) and the case after cap-and-trade is initiated (subscript 1). In the pre-regulated case, n_0^* defines the extent of region I, N_0^* defines the extent of region II, and q_0^s is the quantity shipped to region II utilities under the pricing constraint. The total delivered quantity of PRB coal is the area under the line $q_0(x^*)$. After cap-and-trade, region I expands to n_1^*, region II expands to N_1^*, the quantity shipped to each region II utility decreases to q_0^s, and the total delivered quantity of PRB coal is the area under the line $q_1(x^*)$. After the policy, the railroads make deliveries to new utilities in the expanded service region, and the gain in output is given by area $efN_1^*N_0^*$. This is the expansion effect. Because the total service region expands by $1/t$, the magnitude of the expansion effect is q_1^s/t. The railroads also reduce deliveries to incumbent utilities, and the loss in output is given by the trapezoid *abed*. This is the contraction effect. The contraction effect exactly offsets the expansion effect when the area of this trapezoid is q_1^s/t.

The contraction effect can be decomposed as the area of the rectangle *abec* less the triangle *adc*. The area of the rectangle is given by $m_0^*(q_0^s - q_1^s)$. The slope of the quantity schedule is $-t/2b$, so that the quantity decrease along rail line of length $n_1^* - n_0^* = 2/t$ is given by $(q_0^s - q_1^s) = 1/b$. The length of the region II service area, m_0^*, can be recovered in the linear case from equations (4) -(6). Evaluating (4) at n_0^* gives $a - 2bq_0^s = tn_0^*$. Making use of (5), this implies $p_s - bq_0^s = tn_0^*$. From (6), $p_s = t(n_0^* + m_0^*)$, and combining these equations and canceling terms gives $m_0^* = bq_0^s/t$. The area of rectangle *abec* is thus q_0^s/t. Now consider the triangle *adc*. Noting that the base of the triangle is $n_1^* - n_0^* = 2/t$, its area is $(q_0^s - q_1^s)/t$. The magnitude of the contraction effect, therefore, is $q_0^s/t - (q_0^s - q_1^s)/t = q_1^s/t$.

In the model, the expansion effect and contraction effect are exactly offsetting for several reasons in the model. First, utilities are identical in size, which allows the total market quantity to be expressed in terms of a downward-sloping delivery schedule over distance. Second, railroad transportation cost per unit of distance is constant, which makes changes in region I and II service areas proportional to t. Finally, utilities are uniformly distributed, which allows distance measures to be interpreted in terms of the number of utilities. In general, the net effect of cap-and-trade policy could diverge from this result in either direction. For example, if the density of utilities located between N_0^* and N_1^* was smaller than the density between 0 and N_0^*, the contraction effect would outweigh the expansion effect and the total quantity of PRB coal delivered would decrease in response to SO_2 policy. Nonetheless, the outcome of the present model with exactly offsetting effects can be viewed as a first-order approximation of the policy effect under monopoly freight pricing.

4. Empirical Analysis

This section examines the data on railroad costs and freight rates for hauling Wyoming PRB coal. The main purpose of the analysis is to test for railroad monopoly power. Accordingly, the 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 freight rates and costs to test the predictions derived in 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 when officially requested for a state-oriented research project (Gerking, Morgan, Kunce, and Kerkvliet 2000) 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, where 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.[13] The data form an unbalanced panel, with deliveries made to an increasing number of power plants over time. For example, there are 55 routes in 1988 sample and 150 routes in the 1999 sample. 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 railroad 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, rather than measuring costs directly, STB estimates them 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 expenses include fixed cost components, this generates an upward bias in the reported estimates of variable costs. These data show that mean average real variable cost (in year 2000 dollars) for all routes declined from 11.467 mills per ton-mile in 1988 to 7.460 mills in 1999, a decline of 32%. This finding of declining railroad costs over time is consistent with results presented previous studies (MacDonald and Cavalluzzo (1996), Wilson (1997), Ellerman *et al.* (2000, 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, p. 14), freight revenues may be

[13] Aggregation of individual shipments is necessary to comply with STB disclosure rules. These rules require data to be aggregated to the level of at least three shippers to prevent the identification of individual railroads (Code of Federal Regulations 2001). As indicated in Section 2, two railroads initiated all shipments of Wyoming PRB coal, but because of transshipments to other lines, a total of 16 railroads delivered coal to power plants along the 353 routes in the sample.

overstated due to this confidentiality mechanism. This potential problem is considered in the analysis below. Examination of the freight revenue data shows that annual average real freight rates per ton-mile (in year 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.* (2000) 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, as well as the one just presented, does 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 from 24% to 12% over 1988-1993) and 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 to 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. The Lerner index in equation (10) 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 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 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,

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

In (16), the unit of observation is a route from a railhead to a power plant in a particular year (n=1229) and route and time subscripts have been suppressed. 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, the estimated values of L^* always are positive and average 0.37 with a 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. This result should be interpreted with some caution in light of previously described data problems. For example, the calculated values of L^* may underestimate railroad monopoly power, because the average variable cost data contain components of fixed cost. Equation (16), however, suggests that this problem may not be serious: 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.[14] Additionally, the calculated values of L^* may overestimate market power, because of the possible upward bias in the reported figures for freight revenue. This problem appears to be more worrisome, so 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 corresponding with individual shipments. 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. 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 delivery of PRB coal.

In any case, the model predicts that the Lerner index for a monopoly railroad declines over distance and provides conditions under which it will change over time. Evidence that

[14] A plot of variable cost per ton-mile against route distance is consistent supports this outcome.

the Lerner index declines over distance 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 to divide the 353 routes into roughly equal sized groups. For the shortest routes that were less than or equal to 948 rail miles, values of L^* average 0.41. For the middle distance routes, with lengths between 948 and 1190 rail miles, values of L^* average 0.36. For the most distant routes that were greater than 1190 rail miles, 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 1% level. This result, which could be anticipated from previous results presented earlier in this section (i.e., that the freight rate per ton-mile decreases with distance while the marginal cost of shipping coal by rail is independent of distance), is consistent with spatial price discrimination in the determination of freight rates.

Additionally, the behavior of the Lerner index over time was assessed using a two-way fixed effects regression without covariates to control for route and time effects. Time effects from this regression are shown in Table 2. These coefficient estimates, which control for route-specific effects, are negative in the early years of the sample, turn positive in 1994, but do not display a consistently increasing pattern over the sample period. Nevertheless, annual average values of L^* were 15% larger in 1999 than in 1988, a difference that is significantly different from zero at the 1% level. Thus, despite of the intended effects of deregulation to make rail transportation more competitive, the monopoly power of railroads hauling Wyoming coal increased during the 1990s. Reductions in costs of mining coal (see Section 2) and in railroad variable costs (see Section 4a) as well as initiating a cap-and-trade program to control SO_2 emissions all would work together to produce this outcome.

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). 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, 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 demand and marginal revenue schedules at different points. On the other hand, a demand-side shock leaves 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. 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 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 competitively price freight services, a binding constraint on SO_2 emissions leads to an expansion of the spatial market with an accompanying increase in production of PRB low-sulfur coal. However, if railroads exert market power, the SO_2 emissions ceiling leads to an expansion of the geographic market with 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 railroad market power. This evidence is obtained by computing Lerner indices 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 stimulate competition, railroads hauling coal out of the PRB appear to have experienced an increase in market power. 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 railroad market power 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 by electric plants in 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 with an incentive to haul larger volumes of PRB 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 this also would lead railroads to haul an increased quantity of PRB coal to electric utilities. The extent to which these cost reductions contributed to the expansion of the geographic market for PRB coal is left for future research. Explanations based on reductions in the delivery cost of PRB coal appear promising in identifying the causal factors behind the dramatic substitution that occurred among electric utilities between inputs of high- and low-sulfur coal since the inception of the Clean Air Act.

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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 3: Behavior of Lerner Index over Time

Year	Sample Mean (Std. Dev.)	Coefficient (standard error)
=1 if year is 1988; 0 otherwise	0.044 (0.205)	**----[a]**
=1 if year is 1989; 0 otherwise	0.050 (0.219)	-0.005* (0.002)
=1 if year is 1990; 0 otherwise	0.060 (0.238)	-0.038* (0.002)
=1 if year is 1991; 0 otherwise	0.054 (0.226)	-0.019* (0.002)
=1 if year is 1992; 0 otherwise	0.063 (0.242	0.004 (0.002)
=1 if year is 1993; 0 otherwise	0.057 (0.231)	-0.009* (0.002)
=1 if year is 1994; 0 otherwise	0.099 (0.299)	0.038* (0.002)
=1 if year is 1995; 0 otherwise	0.104 (0.306)	0.076* (0.002)
=1 if year is 1996; 0 otherwise	0.097 (0.296)	0.052* (0.002)
=1 if year is 1997; 0 otherwise	0.116 (0.321)	0.066* (0.002)
=1 if year is 1998; 0 otherwise	0.133 (0.339)	0.060* (0.002)
=1 if year is 1999; 0 otherwise	0.122 (0.328)	0.056* (0.002)

[a] denotes omitted dummy variable

* denotes significance at the 1% level

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

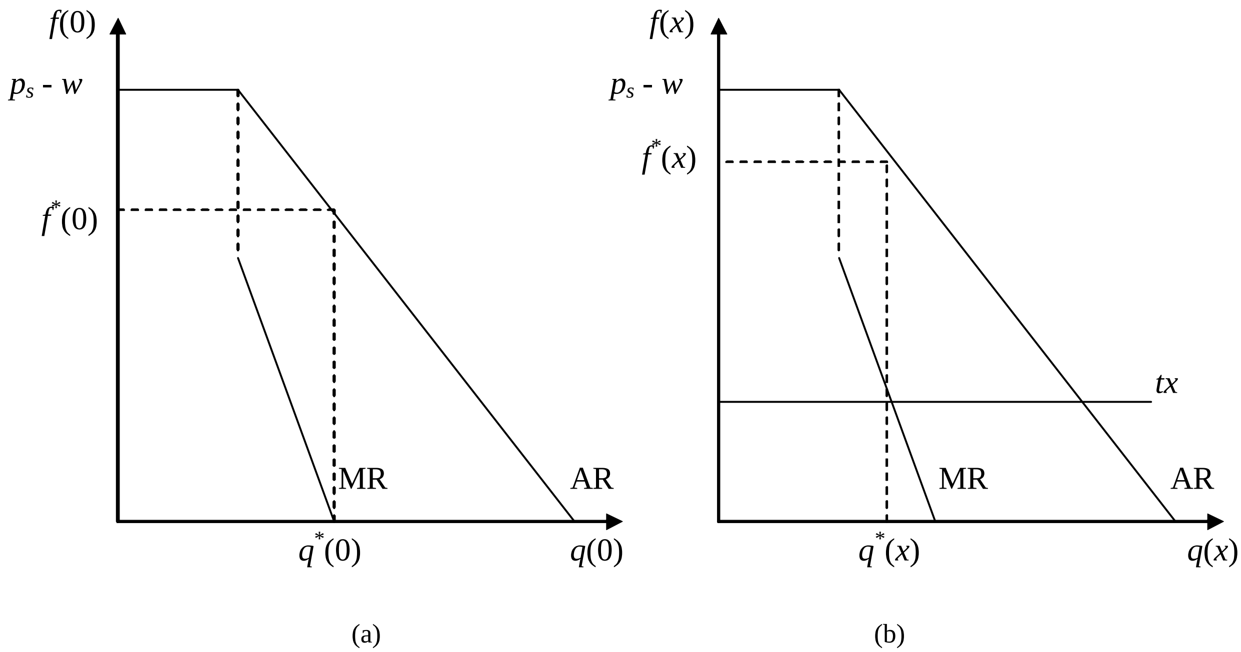

Figure 2: Freight rate per ton schedule over distance

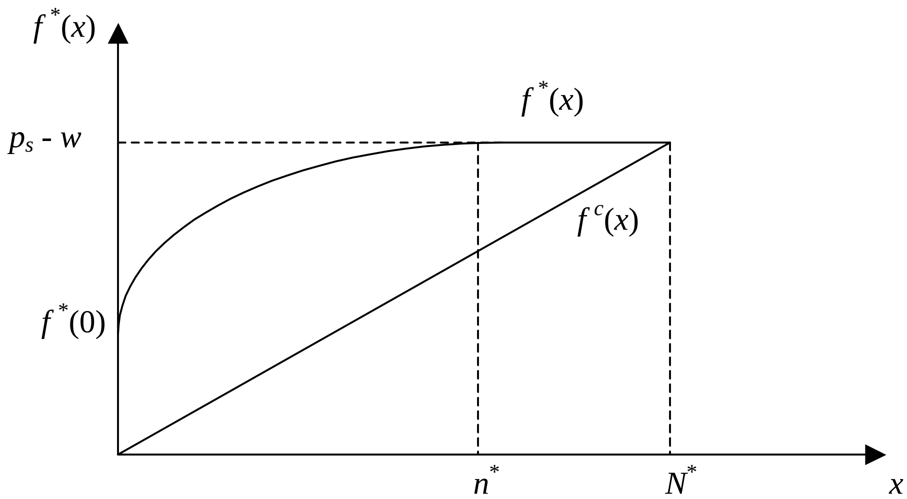

Figure 3: Total quantity delivered under monopoly freight pricing