DUOPOLY IN THE RAILROAD INDUSTRY:
BERTRAND, COURNOT, OR COLLUSIVE?

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Abstract: We develop an equilibrium model of entry in rail transportation markets for coal to test empirically one of the oldest controversies in economic theory: How are prices determined in duopoly markets? We find that competition between Union Pacific and Burlington Northern in the Powder River Basin of Wyoming and Montana is most accurately characterized by Bertrand’s theory that price-setting duopolists will sell their identical product at the competitive price. We identify the features of coal transportation markets that facilitate such behavior and briefly discuss the policy implications of our findings.

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Introduction

What will happen to prices when two producers of an identical good compete? Economists have debated this question for nearly 200 years, “narrowing” the outcomes to marginal cost pricing (Bertrand behavior), monopoly pricing (collusive profit-maximizing behavior), or something between these extremes based on the market demand for the output that is simultaneously offered by the two competitors (Cournot behavior).

It is standard practice in economics for theory to identify a wide range of possible behavioral outcomes in a market and for empirical work to indicate the most likely outcome. In the case of duopoly competition, however, relatively little empirical research exists. This paucity of evidence is particularly surprising because many antitrust and regulatory policy issues turn on whether consumer welfare will be significantly enhanced if an incumbent monopolist must face a competitor.

Competition in railroad markets offers a classic example of this situation. Like many industries deregulated in the past 25 or so years, railroads responded to their economic freedom in 1980 by consolidating through mergers. The most recent merger wave, which began in the mid-1990s, left two major railroads in the western United States, Burlington-Northern Santa Fe and Union Pacific, and two in the east, Norfolk Southern and CSX. As a result, most U.S. shippers have only two rail carriers competing for their business, and some have only one. Of course, even monopolist railroads will often face intense competition from motor or water carriers, so most shippers have gained substantially from deregulation of the surface freight transportation system (Winston (1998), Dennis (2001)). Nonetheless, so-called “captive shippers” and the various organizations that represent them complain that rail rates are not always reasonable and
that the Surface Transportation Board—the successor to the Interstate Commerce Commission with the authority to determine the legality of rates in accordance with maximum rate regulations—does little to protect them.\textsuperscript{1} Grimm and Winston (2000) point out that the Board’s rate complaint process is time-consuming, costly, and complex and that few rates are successfully challenged. In response to such charges, Congress has been considering legislation to increase rail competition. The legislation is not yet final, and one vital issue still pending is whether rail competition is sufficient if a captive shipper has access to an additional railroad.

Recent developments in rail transportation markets for coal shipped from the western United States provide a natural experiment for analyzing how rail prices are affected when a monopoly carrier is subject to competition from another railroad. In this setting, a rail transportation market is a route with a coal mine at the origin and an electric utility plant at the destination. Beginning in the late 1970s, Burlington Northern was the only rail carrier that shipped coal from the Powder River Basin in Wyoming and Montana to electric utilities nationwide. In 1985, the Interstate Commerce Commission authorized the Chicago & North Western railroad to build track into the southern end of the Powder River Basin—thus enabling its subsequent merger partner, Union Pacific, to compete in a growing number of markets with Burlington Northern in transporting Powder River Basin coal to the nation’s power plants.

In this paper, we develop a structural econometric model of Powder River Basin markets for coal transportation by rail treating Union Pacific’s entry as endogenous. Parameter estimates of the model enable us to simulate the behavior of market rates over time, isolating the effect of Union Pacific’s entry that creates duopolistic competition in

\textsuperscript{1} Under maximum rate guidelines, shippers can challenge a rate if it exceeds 180 percent of variable costs and if the railroad in question has no effective competition.
these markets. We find that the path of coal transport rates approaches the long-run marginal cost of rail service in markets that UP has entered, suggesting that duopoly railroad pricing in Powder River Basin markets is consistent with Bertrand competition. We identify the features of coal transportation markets that facilitate such behavior and briefly discuss the policy implications of our findings.

A Brief Overview of Powder River Basin Coal Transportation Markets

Coal from the Powder River Basin (PRB) in Wyoming and southern Montana burns cleaner than most coal mined in the United States because of its lower sulfur and ash composition. Demand for PRB coal increased substantially between 1988 and 1997 (figure 1) because the 1990 amendments to the Clean Air Act required electricity generating plants to reduce their emissions. By switching to PRB coal, a plant can remove sulfur dioxide for $113 per ton, whereas a plant burning eastern coal must spend $322 per ton to remove the pollutant by installing scrubbers.²

Because virtually all PRB coal shipped to electric utility plants moves by rail for most or all of the journey, railroads do not compete directly with trucks or barge transportation in these markets. Burlington-Northern Santa Fe (BN) began transporting substantial amounts of coal from the Powder River Basin in the late 1970s and enjoyed a monopoly. But in 1985, authorized by the ICC, Union Pacific (UP) began to build into the region. Competition between the carriers intensified as UP gave a growing number of plants alternative access to PRB coal. As power plants’ contracts with BN expired, they were able to renegotiate their contracts in a duopoly market. Given that mining and rail service in the Powder River Basin are relatively new, UP and BN have been able to

² These figures are from Coal Age, volume 104, August 1999.
employ the most efficient operations possible, unencumbered by the older rail infrastructure and outdated technology that railroads have been shedding since deregulation. In 1999, a third railroad, the Dakota, Minnesota & Eastern Railroad Corporation, indicated an interest in connecting its network to the Powder River Basin. Local landowners, however, have opposed the proposed rail line, and it has yet to be built.

In sum, Powder River Basin coal transportation markets provide a natural setting for an empirical test of duopoly behavior because the characteristics of PRB coal distinguish its supply and demand from other domestic coal markets and because utilities that receive PRB coal by rail transportation face either a monopoly supplier or a duopoly in which both carriers, BN and UP, offer nearly identical services.

**A Structural Econometric Model of Rail Transportation Markets for Coal**

Empirical industrial organization research has addressed the two key aspects of our problem, competition within a market and the impact of new entry, separately. Authors such as Porter (1983) and Parker and Roller (1997) have characterized the competitiveness of a duopolistic market, focusing on different sources of collusive behavior, while authors such as Bresnahan and Reiss (1990, 1991) and Berry (1992) have explored the determinants of entry, focusing on the number of competitors in a market and the impact of entry on costs.

A few authors have estimated compensating variations to test explicitly for alternative competitive outcomes in duopoly markets (e.g., Brander and Zhang (1990), Fischer and Kamerschen (2003)). Compensating variations, however, are based on static
competitive conditions, which make them unreliable in markets such as rail, where
dynamic changes in competition occur as contracts expire and a new entrant is able to
compete for a shipper’s business.\(^3\)

Our approach characterizes the duopoly behavior of Union Pacific and Burlington
Northern by analyzing the effect of UP’s entry—which creates duopolistic competition—
on coal transportation prices over time. We develop a model of demand and supply for
coal transportation by rail, where entry affects supply. We then specify a model of
carrier entry and derive the likelihood function to jointly estimate the central influences
on market prices, tons of coal shipped, and the decision to enter a market. Finally, we
isolate the effect of entry on equilibrium rail transportation prices and compare the
estimated price path with an independent estimate of the long-run marginal costs of
transporting coal by rail.

**Demand.** Our empirical analysis will be conducted on a panel of electric utility
plants. We specify power plant \(i\)’s demand for rail transportation, \(Q^D_{it}\), at time \(t\) as:

\[
Q^D_{it} = D(p^D_{it}, X_{it}, u_{it}),
\]

where \(p^D_{it}\) is the price of rail transportation (in dollars per ton-mile), \(X_{it}\) contains
exogenous influences on demand, and \(u_{it}\) is an error term that is assumed to be
distributed normally with mean zero and variance \(\sigma_Q^2\).

The exogenous influences on coal shippers’ demand for rail transportation that we
include are the length of haul from the mine mouth to the plant, which controls for

\(^3\) Brander and Zhang (1993) estimate conjectural variations over time for airline routes
involving competition between American Airlines and United Airlines but still invoke
assumptions that may prevent them from capturing the dynamic aspects of duopoly
competition.
service quality, and dummy variables to indicate whether the plant can receive non-PRB coal by rail or water transportation, which controls for alternative coal sources. Greater lengths of haul or an alternative source of coal should reduce the demand for rail shipments of PRB coal. Because rail transportation is derived demand (in this case, it is an input into the final production of electricity), we specify the maximum theoretical output—that is, nameplate capacity, of a given plant and the average national price of natural gas (to capture substitution with an alternative source of energy). We use nameplate capacity instead of electricity actually generated because capacity is not affected by the type of coal that a plant chooses to burn. We also include an index to capture the sulfur dioxide emission caps imposed in 1995 on some but not all plants to implement the standards set by the 1990 amendments to the Clean Air Act. The index takes on values between zero and one, with higher values indicating that specific plants are allowed to emit greater amounts of SO$_2$. Because the caps are based on a plant’s emissions and fuel use five years before passage of the 1990 amendments, it is reasonable to treat the caps as exogenous.$^4$

Nameplate capacity and natural gas prices should have a positive effect on the demand for PRB coal, thereby increasing the demand for rail transport. The sign of the emissions caps is indeterminate because in response to the caps, plants might reduce their demand for all sources of coal and produce less or substitute cleaner PRB coal for other coal sources and maintain output. The first adjustment would cause their demand for rail transportation to fall while the second would cause their demand to rise.

As noted, the passage of the 1990 amendments to the Clean Air Act increased demand for PRB coal by encouraging all electric utilities to seek low-cost ways to reduce

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$^4$ Schmalensee et al. (1998) provide a discussion of emissions caps.
pollution. Our demand specification captures this effect with a dummy variable indicating the years since the act’s passage. This dummy should have a positive sign. Finally, we specify a time trend, as well as fixed effects at the regional, utility (some utilities own multiple plants), and plant level to capture any unmeasured influences on rail demand in these dimensions.

Supply. In a market of homogeneous firms facing a demand elasticity $\eta$, profit maximization implies that firm $k$’s pricing behavior can be characterized as:

$$p \left( 1 + \frac{\theta_k}{\eta} \right) = MC(q_k),$$

where $\theta_k$ is firm $k$’s conduct parameter, $MC$ is its marginal cost function, and $q_k$ is its output. Following Porter (1983), we aggregate this condition across firms such that the relationship between market supply price, output, and entry effectively characterizes an industry supply curve. Thus, we specify the supply price of rail transportation to power plant $i$ at time $t$ as:

$$p_{it}^S = S(Q_{it}^S, E_{it}, Z_{it}; \varepsilon_{it}), \quad (2)$$

where the price is a function of the quantity of coal transported, $Q_{it}^S$, entry of the second carrier, $E_{it}$, and exogenous supply characteristics, $Z_{it}$. The error term, $\varepsilon_{it}$, is assumed to be distributed normally with mean zero and variance $\sigma_p^2$.

We measure entry with a dummy variable that indicates whether a plant can receive PRB coal from two rail carriers at time $t$. As noted, it may take time for a new entrant to influence rail prices because a shipper may be locked into a contract rate with the incumbent railroad for several years. Thus, we also include the number of years after entry that a second rail competitor offers a plant service from the Powder River Basin.
Both variables should have a negative effect on rail prices unless carriers engage in some form of collusive behavior.\textsuperscript{5} In contrast to some markets (e.g., airlines), potential rail competition is not likely to be a relevant factor in PRB markets because negotiations over contract rates occur only when actual entry is assured—that is, UP is committed to incurring the sunk costs of laying new track that connects a utility with the UP network.

Exogenous influences on rail prices consist of other sources of competition and variables capturing rail costs. We include two dummy variables to indicate whether plants can receive coal from outside the Powder River Basin by an alternative railroad or by water transportation. Both measures of source competition should have a negative effect on rail prices. We capture the influence of rail costs on prices by specifying rail industry operating expenses (which effectively amounts to a rail cost index) and the length of haul from the mine mouth to the plant.\textsuperscript{6} We expect higher operating costs to increase prices, while greater lengths of haul should reduce prices per ton-mile because of economies of distance in rail transportation. Finally, we include a time trend to account for technical change in rail transport, as well as fixed effects at the regional, utility, and plant level to capture unmeasured influences on prices in these dimensions.

\textit{Entry.} Union Pacific did not elect to serve all routes where a utility received PRB coal; thus, it is appropriate to treat its entry decisions as endogenous in our framework because they are undoubtedly based on specific market conditions for coal transportation. Generally, entry represents a strategic decision consistent with profit maximizing

\textsuperscript{5} Schmidt (2001) and Grimm, Winston, and Evans (1992) have found that an increase in the number of rail carriers in a market lowers rail rates.

\textsuperscript{6} Given that route specific operating costs were not available, we initially specified the cost index using industry operating costs per ton-mile. But we found that this measure performed poorly in the model, possibly because it was spuriously correlated with the dependent variable which is also denominated in dollars per ton-mile. Thus, we constructed the cost index using operating costs.
behavior. Berry (1992), for example, specified profit available to firm \( k \) by entering market \( i \) as:

\[
\Pi_{ik} = f(X_i, Z_{ik}, N),
\]

where \( X_i \) contains characteristics affecting demand, \( Z_{ik} \) contains characteristics affecting costs, and \( N \) is equal to the number of firms in the market. Entry is assumed to occur when \( \Pi_{ik} > 0 \), hence the probability of entry can be written in terms of the variables that comprise \( X, Z, \) and \( N \).

This specification of entry is a useful starting point, but it needs to be modified for our situation. First, Union Pacific’s entry decisions are confined to markets served by a single carrier of PRB coal. While this means that the number of rail carriers of PRB coal is equal to one and does not vary by route, it would be expected that UP’s entry is influenced by the presence of source competition from alternative rail carriers and water transportation that could supply a plant with non-PRB coal. We therefore use the rail and water source competition dummies to capture the presence of additional competitors in the market.

Berry does not specify price in his model, implicitly allowing its influence to be captured by the number of firms in the market and assumptions about competitive behavior. In our case, Union Pacific can expect that deviations from monopoly rail prices set by Burlington Northern reflect the presence of water or source competition, thus we too do not specify entry as an explicit function of price. Furthermore, in our model the equilibrium quantity of coal that is transported implicitly determines the
market price. We therefore posit that the revenue-related influences on entry simplify to the tons of coal that is shipped and the length of haul.\footnote{The quantity of coal that was shipped in a given market tended to be stationary throughout the period covered by our sample unless a second railroad entered the market. Thus, we did not specify lagged values of tons shipped in the entry equation.}

Finally, UP’s entry decisions are also influenced by the costs of entering and competing in a market. To enter a route, UP must incur the sunk costs of laying down new track that connects a utility with the UP network. We capture this cost by specifying the “build-out” distance from the plant to the closest non-incumbent rail line. We expect that as the required build-out increases, UP’s likelihood of entry decreases. Even if UP can enter a market, it must consider its operating costs. We control for this effect using a cost index based on industry operating expenses per ton-mile.\footnote{Industry operating costs denominated in dollars per ton-mile produced a more satisfactory statistical fit in terms of log likelihood than operating costs denominated in dollars. Note that in contrast to the supply equation, the dependent variable in this case is not expressed in dollars per ton-mile.} In addition, UP will clearly be at a competitive disadvantage against BN in a given market if it has to haul its freight a greater distance than BN has to haul its and vice-versa. To account for this, we specify the difference between UP’s length of haul and BN’s length of haul. Higher operating costs and relatively greater lengths of haul will lower UP’s probability of entry. Finally, we also include a time trend, as well as fixed effects at the regional, utility, and plant level to capture unmeasured influences on entry in these dimensions.

Given these considerations, we can specify UP’s entry decision in market $i$ at time $t$ as:

$$E_{it} = E(L_{it} \cdot Q_{it}, Y_{it}, \nu_{it})$$

(3)
where $L_i$, the length of haul, and $Q_{it}$, the quantity of coal demanded, yield ton-miles of coal transported, $Y_i$ captures exogenous cost and competition considerations, and the error term $\nu_i$ is assumed to be distributed normally with mean zero and variance $\sigma^2_E$.

(Without loss of generality, we can set $\sigma^2_E$ equal to 1.) In this formulation, we simply observe the number of railroads in a market, while profit is a latent variable. Thus, $E_i$ takes on a value of one or zero depending on whether UP has entered the market (indicating whether $\Pi_i > 0$).

**Likelihood function.** The system of equations ((1), (2), and (3)) can be jointly estimated by full information maximum likelihood, accounting for both endogenous and exogenous influences and the correlation of the errors across the equations. The appropriate likelihood function is obtained from the joint probability density function of each decision variable in our system. The dependent variables in the demand and inverse supply equations are continuous; because we observe entry instead of profit, the dependent variable for the entry equation is discrete. Accordingly, we take the following steps to join the three random variables. The joint distribution of the demand and inverse supply equations can be expressed as bivariate normal, conditional on entry. Given that entry is influenced by utilities’ demand for coal, we calculate the distribution of entry conditional on demand. We then construct the likelihood function by deriving the joint unconditional density for price, quantity, and entry.

Suppressing the time subscripts for simplicity, the distributions of the demand and inverse supply equations are given by:
\[ Q^D_i \sim N(\mu_Q(p_i, X_i), \sigma_Q^2) \text{ and} \]
\[ p^S_i \sim N(\mu_p(Q^S_i, E_i, Z_i), \sigma_p^2), \]
where \(\mu_Q\) and \(\mu_p\) are the means of quantity and price, respectively. Because price and quantity are distributed normally, we can express their joint distribution as a bivariate normal random variable conditional on entry as:
\[ f_{p,Q|E} \sim \frac{\exp\left(-\frac{1}{2}(\tilde{Q}^2 + \tilde{p}^2 - 2\rho_{p,Q}\tilde{Q}\tilde{p})/(1 - \rho_{p,Q}^2)\right)}{2\pi \sigma_p \sigma_Q \sqrt{1 - \rho_{p,Q}^2}}, \]
where the tilde designates that the normal random variable has been standardized (mean zero, variance one), and \(\rho_{p,Q}\) indicates the correlation between the errors of \(p\) and \(Q\).

We assume UP enters a route only when profits are positive; that is,
\[ \Pi_i = f(L_i \cdot Q_i, Y_i; \nu_i) > 0. \]
But profit is a latent variable; thus, we focus on the entry behavior that is observed and postulate:
\[ \Pr(E_i = 1) = \Pr(\Pi_i > 0) = \Pr(\nu_i > -\delta_0 + \delta_1 Q_i L_i + Y_i \delta_2) \]
where the \(\delta\)s are estimable parameters. Given that the error term \(\nu_i\) is distributed as a normal random variable with mean zero and variance \(\sigma^2 = 1\), it follows that
\[ \Pr(E_i = 1) = \Phi(\delta_0 + \delta_1 Q_i L_i + Y_i \delta_2), \]
where \(\Phi\) is the cumulative density function for a standard normal random variable.

However, because the error term \(\nu_i\) is undoubtedly correlated with quantity \(Q_i\), the entry probability equation (7) would yield biased parameter estimates in its current form. We address this problem by estimating these parameters as part of a system of

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9 See, for example, Greene (2003), Appendix B, pp. 867-8.
equations where we treat entry, price, and quantity as endogenous and obtain consistent estimates of their parameters in the appropriate equations using exogenous variables in the entire system as instruments.

Given that we can obtain a consistent estimate for $\delta_i$ accounting for the correlation between the errors of the entry and demand equation $\rho_{E,Q}$, we can write the conditional probability density function for entry as a binomial random variable:

$$f_E(E_i | Q_i) = E_i \Phi(\delta_0 + \delta_1(\rho_{E,Q}) \cdot Q_i L_i + Y_i \delta_2) + (1 - E_i) \left[1 - \Phi(\delta_0 + \delta_1(\rho_{E,Q}) \cdot Q_i L_i + Y_i \delta_2)\right].$$

(8)

If $E_i = 1$, only the first term in the equation is “switched on,” and if $E_i = 0$, only the second term is.

We can now derive the joint density of entry, price, and quantity as the product of the conditional density given in equation (8) and the marginal density of price and quantity, namely:

$$f_{E,P,Q} = f_{E|P,Q} \cdot f_{P,Q}.\quad (9)$$

The marginal density can be written as a weighted sum of bivariate normal random variables. In equation (6), supply price is conditional on entry. To obtain the unconditional distribution, we evaluate the price given in equation (5) for entry values of $E=1$ and $E=0$, which yields:

$$f_{P,Q} = \Pr(E = 1) \cdot f_{P,Q|E=1} + \Pr(E = 0) \cdot f_{P,Q|E=0}.\quad (10)$$

10 When we substitute entry into the stochastic formula for price given in equation (5), we account for $\rho_{p,E}$, the correlation of error terms in the inverse supply equation and in the entry equation.
Using equation (9), our joint probability distribution is then equal to the product of equations (8) and (10), which we denote as $f_{E,p,Q}$. As noted, we are simultaneously computing the entry probabilities as stochastic functions of instrumented quantity.

Given the joint probability density function, the likelihood function we wish to maximize with respect to the parameters of the demand (1), supply (2), and entry (3) models, $\Theta$ (including the $\rho$s), is the product taken over all $N$ observations

$$L(\Theta) = \prod_{i=1}^{N} f_{E,p,Q} ; \Theta.$$ 

In our estimations, the demand and supply equations take a logarithmic functional form, which is plausible (see, for example, Porter (1983)) and fits the data better than a linear functional form.

**Sample and Estimation Results**

Our empirical analysis is based on the shipping activity of the 48 electric utility plants in operation from 1984 to 1998 that burned at least one million tons of Powder River Basin coal in a representative year, 1995. The sample ends at 1998 because by 1999 electric utilities began to win a handful of maximum rate cases before the Surface Transportation Board, so recent reductions in coal rates could potentially be attributable to residual regulation.\(^{11}\)

The plants in our sample account for nearly 75 percent of all Powder River Basin coal shipped by rail. Of the 48 plants, 31 were served by a single railroad throughout the sample period and 17 experienced entry sometime between 1985 and 1998. Of the 17

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\(^{11}\) No utilities in our sample received a lower rail rate during 1984-98 by winning a maximum rate proceeding.
plants, 10 used only PRB coal. A few of the single-served plants came on line after 1984, thus our final sample consists of 696 observations.

The data sources for the variables used in our analysis and their sample means are presented in table 1. It is important to point out that virtually all railroad coal traffic is transported under private contracts that do not reveal the shipper’s rate. Thus, we collected publicly available data from the U.S. Department of Energy, Energy Information Administration, and estimated rail rates for electric utilities as the difference between the delivered price per ton of coal that is consumed at the plant and the price per ton of coal at the mine mouth. The delivered price of coal reported by the utility includes all the costs incurred by the utility in the purchase and delivery of the fuel to the plant (FERC (1995)). The mine mouth price reported by the mine is the total revenue received using the actual F.O.B. rail sales price (EIA (1995)). Dividing the difference by the length of haul yields price per ton-mile. Subsequent discussions that we had with railroad personnel confirmed that our estimates of rail rates in PRB markets were quite close to actual rail rates.

Based on these data, a simple comparison of freight rates in monopoly and duopoly markets from 1995 to 1998 suggests that a second entrant has reduced rates and that rates in duopoly markets have fallen over time as contracts between the incumbent carrier and shippers have expired (table 2). Of course, this comparison does not hold other influences on rates constant; we do so by estimating our model of rail transportation supply, demand, and entry in Powder River Basin markets.

Full information maximum likelihood (FIML) estimates of the model are presented in table 3. As noted, we specified a time trend to control for unobserved temporal effects and fixed utility and plant effects, but they were statistically
insignificant in the supply, demand, and entry equations and their exclusion had little
effect on the other parameter estimates so they are not included in the specification
presented here. Generally, the coefficients have their expected signs and are
statistically significant. The demand for rail transportation of coal is inelastic, which is
plausible. The demand elasticity of –0.38 is aligned with previous research and reflects
the small share of transport costs in the price of electricity and consumers’ inelastic
demand for electricity. Another factor that may limit plants’ response to coal rates is
that utilities tend to run their larger coal-fired plants at close to operational capacity—
which in most cases is fixed for the period covered by our sample. Given that the
marginal revenue associated with an inelastic industry demand curve is negative, it
appears that railroads are not engaging in single-period collusive profit maximization or
Cournot behavior. However, this conclusion may be premature to the extent that the
carriers’ conduct is consistent with either form of behavior subject to constraints imposed
by competition in wholesale electricity markets or the threat of maximum rate
regulation.

The elasticity of rail prices with respect to tons shipped in the inverse supply
equation, 0.02, is not statistically significantly different from zero, indicating that rail is
operating at constant returns to scale. Although railroads generally exhibit economies of
traffic density (Braeutigam (1999)), our finding indicates that they are able to exhaust

12 We also interacted the fixed effects with operating costs to allow this variable to vary
across plants, but the fixed effects were statistically insignificant.

13 Winston, Grimm, Corsi, and Evans’ (1990) estimate of the price elasticity of demand
for rail transportation of coal was –0.33.

14 It should also be noted that we have estimated the market, as opposed to individual
firms’, demand curve. Given the zero-sum nature of competition in the transportation
market, UP gains traffic at the expense of BN, a firm may enter a market only if it can
operate on the elastic part of its demand curve.
these economies in PRB markets by moving large shipments in unit coal trains. Bitzan and Keeler (2003) also find that railroads exhaust economies of density at some point.

The parameter estimates for the rail competition variables in the (inverse) supply equation are of central importance for our purposes. We find that the initial entry of a second carrier into a Powder River Basin market reduces rail rates 15 percent and that this effect becomes stronger over time, albeit at a diminishing rate.\textsuperscript{15} For example, after four years of entry, during which time some contracts are likely to have expired, a second entrant will have reduced rail rates by a third.\textsuperscript{16} As stressed throughout the paper, coal shippers negotiate contract rates with railroads that generally last for several years. According to our findings, contract rates dampen the initial impact that a new rail entrant has on observed prices. But as shippers’ contacts expire they are able to play one railroad off against another and obtain lower rates when they negotiate new contracts. Apparently, carriers have not been successful in reaching a tacit understanding to prevent such competition from developing.\textsuperscript{17} As noted, we did not expect potential competition to have an influence on rate rates. If it did, its effect would be partly captured in the time

\textsuperscript{15} We also estimated a model that lagged the initial entry variable, but this did not lead to a better statistical fit.

\textsuperscript{16} Based on our coefficients, this estimate is obtained by calculating:
\[ (1-exp(-0.161))+\ln(1+4\text{ years})\times0.117=33.7\text{ percent.} \]
We expressed the persistent effect of rail entry as \[ \ln(1 + \text{years of entry}) \] because \[ \ln(1)=0 \] and \[ \ln(0) \] is undefined. This specification captures diminishing marginal reductions in rail prices caused by the entry of a second carrier. We explored other functional forms for this variable including a Box-Cox transformation and also specified time dummies to indicate specific years since the entry of the second carrier, but this functional specification produced the best statistical fit.

\textsuperscript{17} Scherer (1990) provides examples in other industries where large buyers play one seller off against another to elicit price concessions.
trend or year dummies as UP entered more markets, but these variables were statistically insignificant.

The remaining parameter estimates reflect the workings of standard economic forces. Rail prices respond to operating costs, economies of distance, and other sources of competition. A 1 percent rise in rail operating costs increases rail rates roughly 2 percent. This finding is consistent with the railroad industry’s residual regulatory environment that allows carriers to set rates that are 180 percent above variable costs (Dennis (2001)). In addition, many markets in our sample are served by only one carrier. A 1 percent increase in the length of haul decreases rates 0.17 percent. Similar economies of distance have been found in other studies (Braeutigam (1999)). Rail source competition lowers rail rates almost 20 percent, while water source competition lowers rail rates 14 percent. However, each of these forms of competition has less impact on prices than a second entrant in the Powder River Basin has after just one year. This finding is consistent with Grimm and Winston’s (2000) estimate of the relative impact of direct and source competition on rail rates.

Utilities demand more coal shipped by rail from the Powder River Basin as their nameplate capacity increases, as natural gas prices rise, and after the passage of the Clean Air Act of 1990. We also find that electric utilities located in the South have a greater demand than other utilities in the country for coal shipped by rail from the Powder River

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18 It has been argued that shippers who provide their own rail cars reduce rail costs and thus receive a lower rate. We specified the percentage of a utility’s coal traffic that is shipped in its private cars in the inverse supply equation, but it had a statistically insignificant effect on rail prices and is not included here. We suspect that this finding is due to the fact that most of the plants in our sample ship large shares of their coal in private cars.

19 After one year, a second entrant in the PRB reduces rail prices by \(1 - \exp(-0.161) + \ln(1+1\text{ year})\times0.117=23\%\).
Southern power plants tend to be larger than others and face more rapidly growing demand, so they may have a preference for large shipments of coal that can be sent by unit coal trains. The Powder River Basin is able to accommodate this preference more easily than other coal-producing regions in the country because its mines generate more coal than other single mine mouths. Utilities demand less coal as their distance from a coal mine in the Powder River Basin increases, if they can receive coal from another source by water transportation, and as their sulfur dioxide emission caps become tighter (i.e., the index becomes smaller), leaving them to choose between reducing output or purchasing emissions permits.20 Apparently, maintaining output and emissions by substituting PRB coal for non-PRB coal is a less efficient option than reducing output.

Finally, Union Pacific’s entry into markets in the Powder River Basin balances potential revenues and costs in a manner consistent with profit-maximizing behavior.21 UP is attracted to markets with greater traffic, as measured by ton-miles, and discouraged from entering markets with higher operating costs and where it faces a cost disadvantage because it has to haul its traffic further than BN has to haul its.22 UP is also discouraged from entering markets that require higher capital requirements because of a longer build

20 Holding rail prices constant, we did not find that the presence of rail source competition had a statistically significant effect on rail demand. The presence of water source competition affects demand because it is less expensive to ship coal by water than by rail.

21 We could not obtain estimates for the water and rail source competition dummies in the entry equation because UP did not enter any markets that had these forms of competition; thus, the dummies were highly collinear determinants of UP’s entry decisions. As expected, there were no improvements from including price along with the quantity of coal shipped in the entry equation. In fact, the price coefficient had the incorrect sign.

22 By denominating industry operating costs in this equation by dollars per ton-mile, we capture the notion that UP would tend to be discouraged less from entering a given route as operating costs increased if it could achieve economies of distance.
out. As indicated by the estimated error correlation coefficients, the unobserved components of the entry and demand equations are most strongly related while the unobserved components of the entry and price equations are least strongly related.

FIML estimation produces the most efficient estimates of our parameters but all of the estimates could be contaminated if any of our equations are misspecified or if the errors are not normally distributed. Because we were particularly concerned that the coefficients for the entry variables could be affected by misspecification of the equations or the error distribution, we specified a simpler model by assuming entry is exogenous and estimated the supply and demand model by two-stage least squares (2SLS). These estimates, also shown in table 2, are generally similar to the FIML estimates. Compared with FIML, the 2SLS estimate of the impact of UP’s initial entry on prices is somewhat greater, and the estimate of UP’s persistent effect is less, but the FIML and 2SLS estimates of the combined effects are virtually the same. This is consistent with the small magnitude of the error correlation coefficient $\rho_{E,p}$. The similarity of the parameter estimates should mitigate potential concerns with specification errors that may arise from using FIML.
Characterizing Duopoly Behavior

We have argued that rail competition in the Powder River Basin provides a natural setting for testing theories of duopoly behavior because a monopolist railroad in the region, Burlington Northern, has gradually begun competing with a new entrant, Union Pacific, to supply a homogeneous service. We use the FIML parameter estimates to simulate the effect of UP’s entry on rail prices for coal transportation. This exercise is complicated by the fact that several other variables besides UP’s entry could affect rail rates. Thus, we hold all variables except UP’s entry variable and its persistent effect on prices at their 1984 levels—that is, before UP began entering PRB markets. We then use the inverse supply and demand equations to predict market equilibrium prices in response to the changes in UP’s entry behavior over time.

We can assess which theory of duopoly behavior is consistent with the evidence by comparing the simulated price path with an estimate of the long-run marginal cost of transporting coal by rail. It is reasonable to make this comparison because in PRB markets rail is characterized by constant returns to scale—which allows marginal cost pricing to be financially viable. In addition, shippers and carriers enter into rate negotiations with a view toward the long run because contracts typically last for several years. If UP and BN engage in collusive profit-maximizing behavior, simulated prices should remain at their monopoly (pre-UP entry) level. If the carriers engage in Bertrand competition, simulated prices should approach marginal cost. And if they engage in Cournot competition, simulated prices should stabilize between these extremes.

To maintain consistency with the predicted price path, we obtain an independent estimate of the long-run marginal cost of transporting coal by rail that does not reflect changes in rail markets after 1984 that may have affected costs. The estimated equation
for marginal cost is from Winston, Grimm, Corsi, and Evans (1990) and is based on data generated in the early 1980s. We assume that marginal costs are not affected by UP’s entry, which is reasonable because PRB coal transportation markets are relatively new, and both carriers have been able to employ the latest technology and most efficient operations. Thus, marginal costs are held constant in our simulation.

The price path and long-run marginal cost were converted to 1998 dollars using appropriate indices; the estimate for the marginal cost of transporting coal in 1984 (in 1998 dollars) is roughly 1.9 cents per ton-mile. Using Bitzan and Keeler’s (2003) railroad cost function yields a marginal cost estimate for unit train output of 1.8 cents per ton-mile (in 1998 dollars). Our estimate is also consistent with those obtained by Bereskin (2001) and Ivaldi and McCullough (2001) that are based on unit train operations. To repeat, the price path and marginal costs do not represent predictions of actual rail prices and costs following UP’s entry because other influences on rates and costs are held constant at their 1984 values.

Figure 2 shows that in the markets that UP has entered at some point between 1984 and 1998, duopoly railroad pricing behavior has evolved slowly, but it can be reasonably characterized by Bertrand competition because rail prices approach marginal cost. From 1985 to 1994, rail prices did not change much from their monopoly level. But since 1994, they have fallen sharply as UP has expanded service to a sufficiently

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23 The actual equation for marginal cost is: \( MC = -19.06 \times \text{Route Density} + 8.338 \times \text{Tons} + 0.0164 \times \text{Ton-miles} \), where route density is ton-miles/route miles; based on the size of the carriers’ networks, we assumed route miles were equal to 20,000. We use this equation to predict the marginal cost of shipping the amount of coal actually transported in each market where UP competes with BN. Because the parameter estimates were obtained using a sample of all commodities shipped by rail and given that we are interested in the marginal cost of transporting coal, the resulting estimate was adjusted by the ratio of the relatively lower cost of shipping bulk versus manufactured commodities using cost estimates in Friedlaender and Spady (1981) and by the relative increase in bulk traffic since deregulation in 1980.
large cohort of plants and as BN has been forced to compete with UP for shippers’ traffic because its contracts have expired.

Although our estimate of long-run marginal cost is consistent with other estimates in the literature, one could argue that if we (and others) have overestimated marginal costs by a modest amount, then rail competition would be better characterized by Cournot than by Bertrand. Recall, however, that Cournot behavior is inconsistent with our inelastic demand estimate unless railroads are constrained by the threat of maximum rate regulation—a view that is strongly disputed by captive shippers. Moreover, we estimate that roughly half of the 54 percent decline in actual rail prices from 1984 to 1998 could be attributed to the additional competition supplied by UP and, as shown in table 2, prices were still declining in duopoly markets in the final years of our sample. As time continues to pass following the entry of a second carrier and as contracts continue to expire after 1998, the price path would undoubtedly draw closer to marginal cost even if the latter were somewhat lower than we estimated.

Indeed, the pervasive use of contract rates in rail freight transportation is probably the most important reason why Bertrand’s prediction is realized. Each carrier faces the prospect of getting none of a utility’s business for several years unless it lowers its rate in response to a competitor’s bid. Given that a typical contract might call for five million tons of coal to be shipped annually for at least five years, a railroad has a lot to lose if it does not compete fiercely for a utility’s business and allows the utility to take its traffic elsewhere.

Another factor that facilitates Bertrand competition is that coal transportation is a homogeneous commodity. Both BN and UP use the same technology to transport coal
from the same source over similar routes, often using cars that are supplied by the shippers themselves. The average of and variability in their transit times are similar, and the low value of coal ensures that shippers place little weight on non-transport logistics costs. All these factors make it extremely difficult for either railroad to convince shippers that they are providing a different, let alone superior, service. Product differentiation, primarily through advertising, can explain why some oligopolists have been able to maintain high price-cost margins (e.g., Baker and Bresnahan (1985)). This strategy, however, is not effective in rail freight transportation.

Finally, given that BN initially provided rail service for all the utilities that demanded PRB coal, UP did not have any profits to lose by supplying additional capacity in this market. Moreover, UP could gain revenue from additional traffic only by cutting into BN’s traffic. Thus, the two were likely to end up as Bertrand competitors because it is more difficult to behave as Cournot competitors in zero-sum situations.

**Conclusions**

We have developed a model of railroad transportation markets for coal to test one of the oldest controversies in economic theory: How are prices determined in duopoly markets? Of the available theories, we have found that rail competition in the Powder River Basin is most accurately characterized by Bertrand’s theory that price-setting duopolists will sell their identical product at the competitive price.

This finding is of broad interest because recent theoretical work related to duopoly behavior has included game theoretic models that focus on outcomes between the polar cases of profit-maximizing collusion and marginal cost pricing. Perfectly
competitive outcomes are generally thought to be a rarity. Our results suggest that more theoretical attention should be given to the factors that generate Bertrand competition.

Empirical evidence of Bertrand competition is also of interest to policymakers as they ponder whether there is sufficient competition in the railroad industry. Grimm and Winston (2000) addressed shippers’ and carriers’ dissatisfaction with the Surface Transportation Board by recommending that policymakers encourage these parties to negotiate an end to the Board, which would allow full deregulation to go forward. As part of the negotiations, shippers and carriers would agree on conditions that would enable captive shippers to have access to another rail carrier. The evidence obtained here indicates that that the direct competition resulting between two rail carriers is sufficient to generate low rates for shippers.\(^\text{24}\)

In addition to railroads, policy issues surrounding duopoly competition have arisen in industries such as telecommunications and electricity as they slowly undergo the transition to partial deregulation. This paper has identified some of the competitive conditions that are conducive to Bertrand competition. Future work may be able to build on this evidence to identify other duopoly markets that are likely to be characterized by this type of behavior.

\(^{24}\) Negotiations would also recognize that although railroads’ profitability has improved since deregulation, the industry is not yet earning a normal rate of return.
References


United States, Department of Energy, Energy Information Administration (EIA), Form EIA-7A, *Coal Production Report*.


<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>Mean</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight charge</td>
<td>$/ton-mile</td>
<td>0.017</td>
<td>Energy Information Administration, <em>Cost and Quality of Fuels and Coal Industry</em>, Annual</td>
</tr>
<tr>
<td>Tons of coal shipped</td>
<td>1000 tons</td>
<td>2757</td>
<td>EIA, <em>Cost and Quality of Fuels</em>, Annual</td>
</tr>
<tr>
<td>Presence of second rail competitor</td>
<td>Dummy</td>
<td>0.068</td>
<td>Fieldston, <em>Coal Transportation Manual</em>, Annual</td>
</tr>
<tr>
<td>Rail source competition</td>
<td>Dummy</td>
<td>0.057</td>
<td>Fieldston, <em>Coal Transportation Manual</em>, Annual</td>
</tr>
<tr>
<td>Water source competition</td>
<td>Dummy</td>
<td>0.095</td>
<td>Fieldston, <em>Coal Transportation Manual</em>, Annual</td>
</tr>
<tr>
<td>SO₂ emissions caps</td>
<td>1000 tons</td>
<td>2.110</td>
<td>EPA, <em>Clean Air Act, Title IV</em></td>
</tr>
<tr>
<td>Natural gas price</td>
<td>$/1000ft³</td>
<td>2.449</td>
<td>EIA, <em>Historical Gas Annual</em>, 2000</td>
</tr>
<tr>
<td>Rail industry operating expenses</td>
<td>$ Billions</td>
<td>30.60</td>
<td>American Association of Railroads, <em>Railroad Facts</em>, Annual</td>
</tr>
<tr>
<td>Length of haul from mine to plant</td>
<td>Miles</td>
<td>1024</td>
<td>RDI, <em>Coal Rate Database</em>, 1997</td>
</tr>
</tbody>
</table>

*All values are in 1998 dollars where appropriate.
Table 2.  Comparison of Rail Rates in Monopoly and Duopoly Markets*

<table>
<thead>
<tr>
<th>Year</th>
<th>Average Freight Charge: Monopoly Markets</th>
<th>Average Freight Charge: Duopoly Markets</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>1.36</td>
<td>1.24</td>
</tr>
<tr>
<td>1996</td>
<td>1.29</td>
<td>1.11</td>
</tr>
<tr>
<td>1997</td>
<td>1.32</td>
<td>1.08</td>
</tr>
<tr>
<td>1998</td>
<td>1.28</td>
<td>1.06</td>
</tr>
</tbody>
</table>

*All freight charges are in 1998 cents per ton-mile
Table 3. Structural Supply, Demand, and Entry Parameter Estimates
(Standard Errors are in parentheses)
* denotes that the variable has been transformed by natural logarithm.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Supply</th>
<th>Demand</th>
<th>Entry</th>
<th>Supply</th>
<th>Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight charge ($/ton mile)*</td>
<td>-0.382 (0.150)</td>
<td>-0.812 (0.237)</td>
<td>0.19 (0.23)</td>
<td>0.071 (0.223)</td>
<td>0.076 (0.223)</td>
</tr>
<tr>
<td>Tons of coal shipped to plant (thousands)*</td>
<td>0.019 (0.023)</td>
<td>0.122 (0.056)</td>
<td>0.071 (0.023)</td>
<td>0.122 (0.056)</td>
<td>0.122 (0.056)</td>
</tr>
</tbody>
</table>

**Supply Characteristics**
- Direct rail competition dummy (1 if a plant can receive Powder River Basin coal from two competing railroads; 0 otherwise) -0.161 (0.051) -0.186 (0.076)
- Number of years after the onset of competition that a second rail competitor offers a plant service from the Powder River Basin; (1 + years of entry)* -0.117 (0.030) -0.085 (0.040)
- Rail industry operating expenses *** 2.032 (0.105) 2.157 (0.114)

**Demand Characteristics**
- Plant Nameplate Capacity (millions of KWH) -- 0.626 (0.049) 0.631 (0.054)
- Average national price of natural gas ($/1000ft³) -- 0.163 (0.085) 0.231 (0.108)
- Clean Air Act (1990) dummy (1 if the Clean Air Act has been passed; 0 otherwise) -- 0.640 (0.142) 0.515 (0.164)
- South regional dummy (1 if plant is located in the South; 0 otherwise)** 0.859 (0.098) 0.902 (0.127)
- Plant SO2 emissions cap index (defined as 1 – (emissions cap)¹ for plants subject to emissions caps; 1 for plants not subject to caps) -- 0.319 (0.149) 0.360 (0.143)

**Shipment Characteristics**
- Length of haul from mine mouth to plant (miles)* -0.173 (0.028) -0.602 (0.097) 0.122 (0.056) -0.178 (0.034) -0.693 (0.129)
- Difference in potential entrant’s and incumbent’s length of haul (miles) -- -0.006 (0.001) --
- Build-out distance circa 1984 (miles)* -- -0.296 (0.062) --

**Source Competition**
- Rail source competition dummy (1 if a plant can receive coal from a non Powder River Basin source by a competing railroad; 0 otherwise) -0.218 (0.055) -- -0.215 (0.110)
- Water source competition dummy (1 if a plant can receive coal from a non Powder River Basin source by water transportation; 0 otherwise) -0.156 (0.054) -1.218 (0.306) -- -0.078 (0.062) -1.322 (0.292)

**Other Parameters**
- $\mu_{pQ} = -0.125 (0.020)$
- $\mu_{pE} = 0.011 (0.027)$
- $\mu_{EQ} = -0.158 (0.123)$
- $\sigma_p^2 = 0.101 (0.006)$
- $\sigma_Q^2 = 1.208 (0.156)$

**Summary Statistics**
- Number of Observations 696 696 696 696 696
- Log likelihood at convergence -1373.02 -1373.02 -1373.02 -- --
- $R^2$ 0.42 0.32
Table 3. **Explanatory Notes**

a Operating expenses are denominated in dollars for supply, and dollars/ton mile for entry.

b The South region includes Alabama, Arkansas, Louisiana, Mississippi, Oklahoma, and Texas.

c Entry is assumed to be a function of ln(ton miles). Estimation can be facilitated by noting that $\beta \ln(\text{ton miles}) = \beta \ln(\text{tons}) + \beta \ln(\text{length of haul})$; that is, tons can be treated as endogenous in this specification if we constrain tons and length of haul to have the same coefficients in the entry equation estimation. We could not statistically reject this specification.
Figure 1. Share of coal used in the United States by origin

Source: EIA Coal Industry Annual, 1994-2000
Figure 2. Rail Freight Charges and Marginal Cost In Markets Experiencing UP Entry At Some Point Between 1984 and 1998