DUOPOLY EQUILIBRIUM OVER TIME

IN THE RAILROAD INDUSTRY

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Abstract: We develop an econometric model of market equilibrium with endogenous entry to analyze rail transportation markets for coal in the Powder River Basin of Wyoming and Montana. Estimation is performed using nonparametric techniques to obtain consistent estimates of the effect of entry on prices. We illustrate a new approach to measuring equilibrium competitive behavior by determining how prices have been affected when a rail carrier enters a monopoly market and find that such entry has caused prices to fall substantially and close to the competitive price. We identify features of coal transportation markets that facilitate this outcome.

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Introduction

What will happen to market prices when two producers of an identical good compete? It is standard practice in economics for theory to identify a range of possible equilibrium outcomes and for empirical work to indicate the most likely outcome. More than two centuries of debate over this question has "narrowed" the outcomes to marginal cost pricing, collusive monopoly pricing, or something between those extremes. But little empirical research exists on the effect of duopoly competition on pricing behavior.[1] This paucity of evidence is particularly surprising because many antitrust and regulatory policy issues turn on whether consumer welfare will be significantly enhanced if a monopolist must face a new entrant.

Competition in railroad markets offers a classic example of this situation. Following deregulation in 1980 and various carrier consolidations thereafter, most shippers in the United States have only two rail carriers competing for their business, and some have only one. 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 regulation—does little to protect them.[2] In response to such charges, Congress has been considering legislation to increase rail competition. The legislation is not yet final, and

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[1] There is a long line of literature estimating reduced form models of the effect of the number of competitors in a market on price. Empirical studies of duopoly competition include Parker and Roller (1997), Wolfram (1999), and Armantier and Richard (2003).

[2] Under maximum rate guidelines (49USC 10707 (d) (2)), shippers can challenge a rate if it exceeds 180 percent of variable costs and if the railroad in question has no effective competition.

one vital issue still under debate is whether rail competition is sufficient if a captive shipper has access to an additional railroad.

Developments in rail transportation markets for coal shipped from the Powder River Basin in the western United States provide a rare opportunity to analyze pricing behavior during an extended period when duopoly competition was created because a rail carrier entered a monopoly market. A key feature of rail competition in those markets is that prices are determined by long-term contract rates negotiated between a power generating utility and a railroad. Because the contracts did not expire immediately when a carrier entered a given market, we analyze the effect of entry on rates in a dynamic setting by integrating the basic demand-supply model of empirical industrial organization (e.g., Porter (1983)) with a nonparametric model of entry behavior over time that explicitly accounts for market prices and quantities.[3] We estimate a nonparametric entry model because of the nonlinear relationship between unobservable determinants of supply, demand, and entry. Our approach to analyzing competitive behavior is facilitated by the rich data that are available to study the railroad industry; it sharply contrasts with approaches based on the conduct parameter θ defined by the price-marginal cost margin and the elasticity of demand that tends to be used in static settings (Bresnahan (1989)).

We find that a rail carrier's entry in a monopoly market causes the time path of coal transport rates to approach a plausible estimate of the long-run marginal cost of rail service, suggesting that a duopoly in Powder River Basin markets provides sufficient competitive pressure to substantially eliminate the price markups that one might expect in

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[3] Empirical analyses of entry using cross-sectional data include Bresnahan and Reiss (1991), Berry (1992), Cilberto and Tamer (2009), and Seim (2006). Cross-sectional analyses do not account for the possibility that entry's effect on equilibrium prices persists and may intensify over time. Toivanen and Waterson (2005) estimate a

this competitive setting. In contrast, we find that an estimate of θ, while qualitatively consistent with our findings over time, substantially understates the intensity of duopoly railroad competition. We discuss how our findings are facilitated by particular features of coal transportation markets, indicate the relevance of the findings for other markets, and briefly discuss their implications for public policy toward the railroad industry.

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. It is extracted by roughly 20 mines from a single, vast, 70 foot thick deposit at constant returns to scale, has homogeneous characteristics, and a uniform mine mouth price. 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 one ton of sulfur dioxide for \$113, whereas a plant burning coal from the eastern United States must spend \$322 to remove one ton of the pollutant by installing scrubbers.[4]

In our analysis, a rail transportation market is a route consisting of a coal producing region with multiple mines at the origin and an electric utility plant at the destination. Utilities purchase coal from one or more mines but they do not co-locate, so only one generating plant is at each destination. Because virtually all PRB coal shipped

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structural model of entry in U.K. fast food markets using a short panel, but they do not assess the effect of entry on the equilibrium determination of prices.

[4] Those figures are from *Coal Age*, volume 104, August 1999.

to electric utility plants moves by rail for most of or the entire journey, railroads do not compete directly with trucks or barge transportation in those markets.

In the late 1970s, Burlington-Northern (BN) began transporting substantial amounts of coal from the Powder River Basin and enjoyed a monopoly in many but not all markets. Union Pacific (UP) had a monopoly in a smaller set of markets, and the remaining markets were solely served by Kansas City Southern Railway or another carrier. Competition between BN and UP in particular began to intensify in 1985 and gave a growing number of plants alternative access to PRB coal, as UP and its partner, the Chicago and North Western Transportation Company, received authorization from the Interstate Commerce Commission (ICC) to build into the southern portion of the region. Those carriers also engaged in a joint venture to acquire a share in the main north-south track through the PRB, which had been formerly owned solely by BN. UP eventually acquired Chicago and North Western in 1995 and Southern Pacific Railroad (SP) the following year. Burlington Northern began to enter UP's monopoly markets during the 1980s, and was aided in the following decade in a few cases by trackage rights it received as part of the UPSP merger. BN acquired Atchison-Topeka-Santa Fe Railroad in 1995.

Given that PRB coal is very similar throughout the basin with slight mining cost differences, utility plants that were served by UP and BN had two alternative sources of PRB coal. However, because almost all PRB coal is transported under long-term contracts, the full impact of UP's and BN's entry on prices was not immediate; instead, it developed as power plants' contracts with both carriers expired and plants renegotiated their contracts in a duopoly market where UP and BN provided *direct* rail transportation of PRB coal from a mine to the plant.[5] To provide that service, those carriers operated a joint line that enabled them to ship coal from PRB mines to their network; each carrier then transported coal on one of its mainline routes and delivered it directly to a plant on a section of track known as a buildout, which connected the plant to the carrier's network. In this study, we define entry into a PRB market as occurring when a carrier is able to fully provide direct service. Because they operated a joint line from the mines and had extensive networks developed partly through mergers, UP and BN generally consummated their entry into specific markets when they completed a buildout that enabled them to provide direct service to a plant.[6] However, as discussed later, the decision to enter a market was determined by the overall profitability of that market.

Railroad technology is often thought of as characterized by high fixed costs, but entry into additional markets is not unusual or particularly costly in the situation we are studying. Electric utilities often provide their own coal cars (but not locomotives), while railroads are able to redeploy or lease their cars and locomotives for use in other markets. Because the incumbent railroad, BN or UP in almost all of the cases, owned the existing track into an electric utility's plant and could extract most, if not all, monopoly rents, effective entry by another carrier required it to build additional track to connect an electric utility's plant to its rail network. However, the additional track represents a tiny fraction of the distance from mine to plant (in our case, less than one percent). Hence,

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[5] In 1999, the Dakota, Minnesota & Eastern (DME) Railroad Corporation, indicated an interest in connecting its network to the Powder River Basin. Local landowners, however, have opposed the proposed rail line, and the carrier has been unable to secure private financing and has been turned down by the Federal Railroad Administration for a loan guarantee. The DME was acquired by the Canadian Pacific Railway in 2008, but it is not clear if Canadian Pacific will try to connect its network to the Powder River Basin.

[6] In a handful of cases, entry was consummated because a carrier secured access to another carrier's track on a mainline route.

the cost of a buildout is relatively modest and sunk costs are minimal (roughly two to three percent of the expected revenues over the life of the asset) because small sections of track are often sold to short-line railroads, and rails are frequently reused on other parts of a carrier's system or sold for scrap. Finally, given that mining and rail service in the Powder River Basin are relatively new, UP and BN have been able to employ the most efficient operations possible, unencumbered by the older rail infrastructure and outdated technology that railroads have been shedding since deregulation.

In sum, Powder River Basin coal transportation markets provide a natural setting for determining the quantitative difference in pricing behavior between monopoly and duopoly competition for several reasons. First, the physical characteristics of PRB coal distinguish its supply and demand from other domestic coal markets. Second, utilities that receive PRB coal by rail transportation face either a monopoly supplier or a duopoly of suppliers. Third, an entrant into those markets does not incur notable sunk costs. Fourth, consistent with Porter's (1983) study, the railroads in question provide a homogeneous service. Namely, the primary carriers, BN and UP, use the same technology to transport coal from the same source over similar routes; carry 10,000 to 15,000 tons of coal in unit trains that do not need to be assembled, disassembled, or switched en route; often use cars that are supplied by the shippers themselves; and offer very similar mean transit times and transit time reliability, while the low value of coal ensures that shippers place little weight on non-transport logistics costs or loss and damage. Fifth, given that coal power plants tend to have the common technological characteristics of operating at constant returns to scale (Sarica and Or (2007)) and exhausting their potential for technical efficiency (Olatubi and Dismukes (2000)), it

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seems plausible that shippers' demands for coal are likely to be characterized by the same functional form (up to a scaling factor). Lastly, although rail freight charges are determined through long-term contract negotiations between utilities and rail carriers, this feature does not detract from our analysis of duopoly competition. Utilities negotiate a number of contracts during any given year, often in response to market fluctuations. Each contract represents a small fraction of the coal transported from the PRB, and the contracts expire at different times.

An Econometric Model of Rail Transportation Markets for Coal

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 jointly estimate the central influences on market prices, tons of coal shipped, and the decision by a second rail carrier to enter a market. Finally, we isolate the effect of a carrier's entry on equilibrium rail transportation price markups by simulating a price path and comparing it with a plausible external estimate of the long-run marginal costs of transporting coal by rail.

Our modeling approach is appropriate because direct estimation of market supply and demand, when possible, remains the surest method to characterize market equilibrium with minimal assumptions on competitive structure. Moreover, we are able to enrich this framework by incorporating a model of endogenous entry behavior that explicitly accounts for the effect of equilibrium prices and quantities on entry decisions.

Demand. Our empirical analysis is conducted on a panel of electric utility plants. Because rail transportation is derived demand (in this case, it is an input into the final production of electricity), we can follow, say, Friedlaender and Spady (1981), and specify power plant *i*’s cost-minimizing input demand for rail transportation, Q_{it}^{D} , at time *t* as:

$$Q_{it}^{D} = D(p_{it}^{D}, X_{it}^{D}; \varepsilon_{it}^{D}), \qquad (1)$$

where p_{it}^{D} is the price of rail transportation (in dollars per ton-mile), X_{it}^{D} contains exogenous influences on demand, and ε_{it}^{D} is an error term.

We include the length of haul from the mine mouth to the plant among the exogenous influences on coal shippers’ demand for rail transportation of PRB coal. An electric utility presumably has an inventory policy in which it seeks to keep its stockpile of coal at a desired level and it must receive reliable deliveries by rail to do so. Data on the standard deviation of rail transit time, a common measure of service reliability, are not publicly available at the route level; hence, there is a long tradition in railroad economics of using the length of haul, which is highly correlated with rail service time reliability, to control for this effect (Grimm and Winston (2000)). Greater lengths of haul may result in less reliable deliveries of coal and should therefore reduce the demand for rail shipments of PRB coal.

We also include dummy variables that indicate whether the plant can receive non-PRB coal by rail or water transportation to control for alternative coal sources. Those sources can be observed because major coal-fired utility plants report the modes of transportation, including barge and the terminating rail carriers, which they are able to use for their coal deliveries. Effective competition could be provided by rail or water carriers that can ship non-PRB coal to utilities without using carriers operating from the Powder River Basin to complete the shipment. We specify separate rail and water dummy variables to measure access to non-PRB coal, thereby allowing for the possibility that the modes may have different effects on demand. An alternative source of coal should reduce the demand for rail shipments of PRB coal.

Because rail transportation of coal is an input into the final production of electricity, we specify the maximum theoretical output (nameplate capacity) of a given plant and the average price of natural gas nationally to capture substitution with an alternative source of energy. We use nameplate capacity because unlike the actual observed levels of electricity generated, capacity is unaffected by the type of coal that a plant chooses to burn.[7]

We include an index to capture the sulfur dioxide emission caps imposed in 1995 to implement the standards set by the 1990 amendments to the Clean Air Act. Those caps were imposed on some but not all of the plants in our sample, so our index takes on values between and including zero and one, where a value of zero indicates that the plant is entirely restricted from producing SO_2 (i.e., it must reduce its SO_2 emissions in a given year 100 percent from its 1985 level). The index can be entered directly into the specification because it increases smoothly and continuously**,** with a value of one indicating that the plant has no pollution cap. It is reasonable to treat the caps as exogenous to the extent that most of the plants in our sample did not engage in SO_2 emissions trading, which began in 1994 (Burtraw (1996)). We examined the transactions data in the Environmental Protection Agency's Clean Air Markets Division business system to check whether any of the 48 electric utility plants in our sample discussed later purchased emissions and we found that only one bought allowances in 1994 and only

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[7] Nameplate capacity is a better measure of derived demand than is the price of coal because in our sample it varies widely between plants in a given year by up to a factor of ten. In contrast, the price of coal varies very little across mines, so its effect on rail demand was statistically insignificant.

seven bought allowances in 1998, the last year of our sample. Thus, the vast majority of plants were effectively bound by their initial allocation of allowances.

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 for rail transportation from the PRB to rise. A plant could also install scrubbers to reduce emissions; but we indicated that this is likely to be a relatively costly option for plants that use low-sulfur coal. Plant level fixed effects should capture the variation among plants in the use of this option.

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 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 because the demand for electricity grew while the emissions caps were constant. 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 those dimensions.

Supply. Our specification of supply is based on Porter's (1983) model. In a market for a homogeneous good that is produced by firms facing a demand with elasticity η, profit maximization implies that firm k's pricing behavior can be characterized as:

$$p\left(1+\frac{\theta_k}{\eta}\right)=MC_k(q_k)\,, \tag{2}$$

where θ_k is firm *k*'s conduct parameter, MC_k is its marginal cost function (which may be the same as or different from other firms' marginal cost functions), and q_k is its output. This relationship holds under both cooperative and noncooperative assumptions about firms' strategic behavior.

Two approaches exist for using the first order condition in equation *(2)* for empirical analysis. In the first, θ_k is treated as a free parameter, and an estimate of the parameter is used to make inferences about the nature of market competition (Bresnahan (1989)). A second approach can be used if reliable estimates of marginal cost and the demand elasticity are available, which would enable θ_k to be computed directly as

$$\theta_k=-\eta\cdot\frac{p-MC_k(q_k)}{p}\,. \tag{3}$$

Genesove and Mullin (1998) illustrate this second approach in an analysis of the sugar industry. Because good firm-level cost data are available in the rail industry, it is not difficult to obtain a plausible estimate of the marginal cost of rail service for bulk and manufactured commodities, and there is a long history of doing so. Hence, we can also compute θ_k directly.

But, as we have stressed, we are analyzing competitive behavior in a dynamic context and other factors that are unrelated to firm conduct that change over time may affect prices and the price-marginal cost margin, which could bias any conclusions based on equation *(3)*. In addition, Corts (1999) argues that measuring θ_k by either of the preceding approaches will yield misleading conclusions if firms are engaged in a dynamic oligopoly game.

We therefore take an approach to measuring firm behavior that is appropriate for our dynamic setting and that takes advantage of our rich dataset. Following Porter, we note that equation *(2)* can be aggregated across firms so that the relationship between market supply price, output, and entry effectively characterizes an industry supply curve. Because we have plausible estimates of marginal costs, we specify the supply price of rail transportation to power plant *i* at time *t* as:

$$p_{it}^{S} = S(Q_{it}^{S}, E_{it}, X_{it}^{S}; \varepsilon_{it}^{S}), \qquad (4)$$

where the price is a function of the quantity of coal transported, Q_{it}^{S}, entry of the second carrier, E_{it}, supply characteristics including marginal cost, X_{it}^{S}, and an error term, ε_{it}^{S}.

The supply curve is estimated along with the demand curve and a model of entry discussed below, and the resulting parameter estimates are used to simulate the behavior of prices over time to characterize firm conduct as duopoly competition evolves. For purposes of comparison, we also calculate θ_k as given in equation *(3)* over time.

We measure the effects of entry with a dummy variable, treated as endogenous, that indicates whether a plant can receive PRB coal from two rail carriers at time *t* (it is defined for a given time period as 1 if two carriers can transport PRB coal to the plant and 0 otherwise). We are able to measure this variable because coal-fired utilities identify the rail carriers that provide direct service, as noted previously, and that have physical access to their plants.

We recognize that a new entrant’s impact on rail prices may intensify over a finite period of time because a shipper’s coal shipments are generally governed by several distinct contracts with the incumbent railroad that may last for several years. Because we did not know precisely how many contracts a shipper had with an incumbent railroad and when each contract expired, we explored alternative ways to capture the dynamic effects of rail competition. We obtained the best statistical fit of our model by interacting the rail entry dummy variable with a variable indicating the number of years the second railroad served the market for those plants experiencing entry. The value of this variable was held constant after three years to capture the fact that most contracts will have expired by that time, thereby making it unlikely that the entry effect continues to intensify. Holding this variable constant after five years produced a slightly worse statistical fit. Specifying time dummies to indicate each year since the entry of a second carrier produced an even worse fit, because more endogenous variables were effectively used to capture the same effect. The entry variable should have a negative effect on rail prices unless carriers engage in some form of collusive behavior.[8]

In contrast to some markets (e.g., airlines), potential rail competition is not likely to be a relevant factor in PRB markets. A common definition of a potential competitor in network industries is a carrier that provides service at the origin and the destination but does not offer service on the route (Morrison and Winston (1995)). Because negotiations over contract rates occur only when actual entry is assured by a carrier’s commitment to construct a buildout to connect a utility with its network, a carrier is effectively an actual competitor without ever being a potential competitor. As noted, the DME Railroad Corporation has indicated an interest in connecting its network to the Power River Basin, but it has not done so for various reasons and has had no effect on rail rates in that region.

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[8] Schmidt (2001) and Grimm, Winston, and Evans (1992) have estimated reduced form rail rate equations and found that an increase in the number of rail carriers in a market decreases rail rates.

Supply characteristics consist of other sources of competition and 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.

Route specific marginal costs are generally unavailable. Hence, we estimate those costs using Bitzan and Keeler's (2003) translog railroad cost function, which covers virtually the same years as our study and includes ton-miles of unit train traffic at the firm level as a distinct output, factor prices, and operating characteristics. Their cost function results in an expression for marginal cost that yields estimates that vary both across plants through the length of haul variable—they find economies of length of haul meaning that longer hauls reduce the marginal cost of a ton-mile—and over time through an estimated time trend, which captures technical change (productivity improvements) in rail freight transportation.[9] We expect higher marginal costs to increase prices.

Finally, we include a time trend and fixed effects at the regional, utility, and plant level to capture unmeasured influences on prices in those dimensions. Utility level fixed effects differ from plant level fixed effects because they account for potentially greater bargaining power that utilities with multiple generating plants may enjoy when negotiating rates.

Entry. Although the primary providers of rail service in the Powder River Basin, Union Pacific and Burlington Northern, have expanded their networks to serve more utilities, they have not elected to serve all markets where a utility receives PRB coal,

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[9] This approach may introduce measurement error because it holds variables other than unit train output and length of haul constant at industry means. But this error is likely to be small because output and length of haul account for the vast majority of variation in marginal costs (Bitzan and Keeler (2003)).

suggesting that their entry decisions are 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 behavior. We first discuss the relevance of dynamic considerations in modeling rail entry and then specify a model of entry based on a firm's profit function. Because of the nonlinear relationship between unobservable determinants of supply, demand and entry, our specification of entry must be nonparametric to obtain consistent estimates of the effect of entry on prices.

Two circumstances exist where a dynamic model of entry may be appropriate. First, because shippers and railroads negotiate contracts prior to a carrier actually providing service, a dynamic specification of the key determinants of entry (such as prices and quantities) may be appropriate unless future values of those variables can be determined from their current values. If current prices and quantities are sufficiently strong predictors of future prices and quantities, then a static model of entry is appropriate—although, as noted, the effects of entry on prices are likely to be dynamic.

In the case of rail transportation of coal, contracts reflect current and future supply and demand conditions. For example, contracts specifying negotiated rates contain standard cost escalation provisions based on independent regulatory findings, thereby reducing the uncertainty associated with the supply price. Little uncertainty is associated with transportation demand because the large base-load plants in this study run at full capacity. Accordingly, exploratory estimations showed that influences at time t are sufficient statistics for predictions of future influences. For example, 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.

Second, a dynamic specification might be appropriate if railroads enter and exit markets frequently. However, no railroads in our sample exit any of the markets—that is, they never relinquish the ability to serve a market. We therefore develop a model of entry behavior based on a static profit function.

As pointed out by Jia (2008), a convention (by convenience) in the empirical industrial organization literature on entry is to omit price, quantity, and sales variables from the specification because the relevant data are unavailable for most industries, and to assume that firms' profits decline in the presence of rivals. Because we do have data on prices and quantities, we explicitly include those variables in the specification of profit that determines firm entry.

The profit available to a given firm from entering market *i* at time *t* is simply the total revenue less the variable costs of providing service and the fixed costs of entry and can be specified generically as $\prod\left(p_{it}, q_{it}, X_{it}^{E}; \varepsilon_{it}^{E}\right)$ where X_{it}^{E} contains observable determinants of service and entry costs and ε_{it}^{E} captures the unobservable determinants of profits.

Assuming that entry occurs only in profitable markets (where $\prod_{it} > 0$) and that the unobservable term ε_{it}^{E} is an additively separable determinant of profit, the probability of observing a second competitor in a market can be written simply in terms of the variables that comprise revenue and cost. Namely,

$$\Pr\left(E_{it} = 1\right) = \Pr\left(\varepsilon_{it}^{E} > -\Pi\left(p_{it}, q_{it}, X_{it}^{E}\right)\right). \qquad (5)$$

Equilibrium prices and quantities are endogenously determined by our supply and demand equations, so the error terms in those equations indirectly enter equation *(5)*. Because those error terms are unobservable determinants of prices and quantities, they will also be unobservable determinants of profits; hence, ε_{it}^{E} contains components of both endogenously determined revenues and other unobservable exogenous determinants of entry.

Consistent estimation of the carrier's entry decision and its effect on prices requires that at least one element of X_{it}^{E} can be excluded from both the vector of supply covariates (X_{it}^{S}) and the vector of demand covariates (X_{it}^{D}). We meet his requirement by using an observed component of carriers' fixed costs of entry that is uncorrelated with the supply and demand error terms. As noted, a carrier must connect an electric utility plant with its physical network to enter a market that is defined by a coal mine at the origin and the plant at the destination. We capture the fixed cost of this connection by specifying the distance of the buildout from the plant to the closest non-incumbent rail line, which can be measured using a publicly available railroad atlas and commercial atlas to depict rail networks and plant locations. Those costs are a combination of one time set up costs and ongoing annual fixed costs. We expect that as the required buildout increases, the likelihood of a second entrant decreases. But crucially, the required buildout does not affect the supply and demand for rail service.

Estimation

Estimation of our model of demand, (inverse) supply, and entry is complicated by the fact that entry must be specified as an endogenous function of quantity (demanded) and (supply) price. Supply and demand are jointly identified by a vector of instruments comprising the exogenous determinants of the three endogenous variables. Because a consistent parametric approach to estimating the entry equation is likely to be vulnerable to misspecification that would yield inconsistent parameter estimates (Powell (1994), Rothe (2009)), we estimate the entry equation using a nonparametric approach (Matzkin (1992)) that uses the exogenous measure of the fixed costs of entry, the distance of the buildout, to identify the entry decision of the second carrier. The three equations are then estimated jointly using a generalized method of moments (GMM) approach for systems estimation, which also involves estimating an efficient and heteroskedasticity-robust asymptotic covariance matrix of all the estimated parameters.

We assume that supply and demand have a logarithmic functional form, which is plausible (see, for example, Porter (1983)) and fits the data better than a linear functional form does. We make no assumption on the functional form of the entry condition beyond the fact that the error term ε_{it}^{E} is additively separable. The system of supply, demand and entry equations to be estimated can therefore be written as:

$$\ln p_{it}^{S} = \beta_1^{S} \ln Q_{it}^{S} + \beta_2^{S} E_{it} + \beta_3^{S} X_{it}^{S} + \varepsilon_{it}^{S} \tag{6}$$

$$\ln Q_{it}^{D} = \beta_1^{D} \ln p_{it}^{D} + \beta_2^{D} X_{it}^{D} + \varepsilon_{it}^{D} \tag{7}$$

$$E_{it} = 1\left(\Pi\left(p_{it}, q_{it}, X_{it}^{E}\right) > \varepsilon_{it}^{E}\right), \tag{8}$$

where all variables are as defined previously.

Consistent estimates of the demand and supply parameters. Because the demand and supply equations contain endogenous independent variables, we require instruments to obtain consistent parameter estimates. Let us represent each endogenous variable by $N \times 1$ column vectors, and the exogenous variables (the X^{j}s) as $N \times q^{j}$ matrices for *j=D*, *S*, and *E*, where *N* is the number of observations in the panel data set (that is, *N* is equal to the number of plants multiplied by the number of time periods *T*). We construct a matrix of instruments, *Z*, by concatenating the three matrices of exogenous variables; i.e., $Z \equiv \left[X^{D}, X^{S}, X^{E}\right]$. Repeated columns of variables are omitted. Thus Z is an $N \times q$

matrix, where q is the total number of unique variables in all of the X's. Based on the orthogonality conditions $E\left[\varepsilon^{D\prime}Z\right]=0$ and $E\left[\varepsilon^{S\prime}Z\right]=0$, consistent estimates of the demand and supply parameters are defined as

$$\tilde{\beta}^D = \underset{\beta}{\arg\min}\left\|\left(\ln Q^D - \left[\ln p^D, X^D\right]\beta\right)' Z\right\|, \text{ and} \tag{9}$$

$$\tilde{\beta}^S = \underset{\beta}{\arg\min}\left\|\left(\ln p^S - \left[\ln Q^S, X^S\right]\beta\right)' Z\right\|, \tag{10}$$

where $\|\ldots\|$ is the Euclidean norm.[10] Initial predicted values of supply price and quantity demanded are likewise denoted $\tilde{p}_{it}$ and $\tilde{q}_{it}$ respectively, and predicted values of the first stage supply and demand residuals are denoted $\tilde{\varepsilon}_{it}^S$ and $\tilde{\varepsilon}_{it}^D$.

Initial consistent estimates of the entry equation. Because the likelihood of entry is a function of revenue, variable costs, and fixed costs—the first two of which are composed of endogenous variables—we take a control function approach in the spirit of Blundell and Powell (2004). Given consistent predictions of price and quantity,, we can use the first stage supply and demand residuals as control variables for endogenous price and quantity. Those variables can control properly for the endogenous influence of price and quantity on entry under the identifying assumption:

$$\mathrm{E}\left(\varepsilon^E \middle| Z\right) = \mathrm{E}\left(\varepsilon^E \middle| \tilde{\varepsilon}^S, \tilde{\varepsilon}^D\right). \tag{11}$$

The assumption states that deviations of observed entry probabilities from their conditional mean must be the same whether the mean is conditional on the vector of

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[10] The parameters, $\tilde{\beta}^D$ and $\tilde{\beta}^S$, obtained in this manner are asymptotically equivalent to three stage least squares (3SLS) estimates. Although we do not estimate them efficiently because we do not introduce a weighting matrix in the minimizations, we require only consistent parameter estimates at this stage.

instruments or conditional on the control variables. The assumption is satisfied because the control variables include the full portion of the covariates X^E that is correlated with the instruments Z. Accordingly, entry behavior is identified if we estimate the nonparametric entry equation

$$E_{it} = 1\left(\Pi\left(p_{it}, q_{it}, X_{it}^{E}, \tilde{\varepsilon}_{it}^{\ S}, \tilde{\varepsilon}_{it}^{\ D}\right) > \varepsilon_{it}^{E}\right). \qquad (12)$$

Because ε^E is a residual from a fundamentally nonlinear regression, the relationship between the observed determinants of entry and the control variables must be specified nonparametrically.[11] Estimating equation *(12)* is difficult because both the functional form of profits and the distribution of the unobserved ε^E are unspecified. In comparison, a standard parametric discrete choice estimation such as probit would require assumptions that enable Π to be fully specified, and would require an assumption that the distribution of the error is normal. Such assumptions are not sufficient to satisfy the identifying condition *(11)*; informally, under such assumptions the control variables may no longer be able to "control" fully for the endogeneity of price and quantity (see, for example, Blundell and Powell (2004)).

Matzkin (1992) provides a two step recursive algorithm to estimate the entry equation with minimal parametric and distributional assumptions. To implement her approach, we need only assume that the function Π is continuous, monotone, and weakly concave in the buildout distance and that the error term ε^E is drawn from a density with full support and finite variance. Thus we identify entry probabilities by mildly restricting the set of profit functions to which Π can belong. In the first step, the relationship

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[11] In contrast, if ε^E were a residual from a linear regression, then the relationship between X^E, $\tilde{\varepsilon}^S$ and $\tilde{\varepsilon}^D$ could be specified linearly, and the estimation procedure would be equivalent to two-stage least squares.

between the observable and unobservable determinants of entry choices is taken as given, and a vector of predicted entry probabilities that maximizes the likelihood of entry occurring in markets where entry actually occurs is computed. This enables us to avoid specifying the distribution of ε^E. In the second step, the relationship between observable and unobservable determinants of entry that maximizes the likelihood function is estimated. This enables us to avoid specifying the functional form of Π. The algorithm is recursive because the first step is embedded in the second step; that is, estimating the relationship between observable and unobservable determinants of entry requires re-computation of the vector of predicted entry probabilities at each step, which significantly increases the computational demands of the estimation process.

Formally, estimating the entry equation is equivalent to maximizing the log likelihood function with respect to a vector of entry probabilities, φ, and a vector of parameters, π, that relates the observable and unobservable determinants of entry through a series of constraints that ensure that profits and the observed entry choices satisfy certain basic conditions and that enable our estimated entry equation to be consistent with a profit function that satisfies the assumptions we made above. The log likelihood function is given by

$$\max_{\pi,\varphi} \sum_{i,t} \left\{ E_{it} \log \varphi_{it} + \left(1 - E_{it}\right) \log\left(1 - \varphi_{it}\right) \right\}. \qquad (13)$$

Define the matrix X^{E+}, which is formed by horizontally concatenating p, q, and the two control variables $\tilde{\varepsilon}^S$ and $\tilde{\varepsilon}^D$ to X^E. The first set of constraints

$$0 \le \varphi_{it} \le 1 \qquad \text{for all } i, t$$

$$\varphi_{it} \le \varphi_{js} \qquad \text{if } \pi_{it} \cdot X_{it}^{E+} \le \pi_{js} \cdot X_{js}^{E+} \text{ for all } i,t,j,s \qquad (14)$$

$$\varphi_{it} = \varphi_{js} \qquad \text{if } \pi_{it} \cdot X_{it}^{E+} = \pi_{js} \cdot X_{js}^{E+} \text{ for all } i,t,j,s$$

ensures that entry probabilities fall between 0 and 1 and that the probability of entry must be higher in markets with higher expected profits, conditional on X^{E+}. The second set of constraints

$$\pi_{it} \ge 0 \qquad \text{for all } i, t \qquad (15)$$

$$\pi_{it} \cdot X_{it}^{E+} \le \pi_{it} \cdot X_{js}^{E+} \qquad \text{for all } i,t,j,s$$

ensures a consistent relationship between the observable and unobservable determinants of entry assumed in the first stage of the estimation procedure. The two sets of constraints are implied by the assumptions that admit a class of permissible profit functions and they ensure that the entry equation is identified in the solution to equation *(13)*.

We accomplish the first step of the estimation procedure, maximizing the objective in *(13)* over the vector φ taking the vector π as given subject to constraints *(14)*, using an algorithm described in Cosslett (1983). We express the solution to the maximization as $\varphi^*(\pi)$. We accomplish the second step of the estimation procedure, maximizing the objective in *(13)* over the vector π subject to the constraints *(15)* and $\varphi = \varphi^*(\pi)$, using an algorithm described in Matzkin (1992). The solution to this step gives us $\tilde{\Pi}_{it}$, the scaled predicted profits in a market, given the observable variables.[12]

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[12] Predicted profits in a market are scaled according to the empirical distribution of the predicted unobservable determinants of entry. In comparison, the predicted parameter estimates in a probit model are scaled according to the distribution of the error term, which is assumed to be standard normal.

Generally, nonparametric estimation suffers from the "curse of dimensionality,"—that is, the inclusion of additional explanatory variables increases the complexity of the estimation process exponentially. Because of the recursive nature of the estimation procedure, the curse strikes twice. Each additional element complicates the optimization with respect to φ in the first step (through the constraints *(14)*) and complicates the optimization with respect to π in the second step (through the constraints *(15)*). Because the first step of the optimization is embedded in the second step of the optimization through construction of the intermediate function $\varphi^{*}\left(\pi\right)$, the computational complexity is scaled exponentially by the *square* of the number of elements of X^{E+}. In exploratory estimations, we found that the twin curses of dimensionality enabled us to estimate the entry equation only with the variables that ensured consistent estimation: price and quantity, with their associated control variables, and the instrument, specifically, the buildout distance, which is excludable from the supply and demand equations.[13]

Asymptotic Covariance Matrix. Given the initial consistent estimates $\tilde{\beta}^{D}$, $\tilde{\beta}^{S}$, and $\tilde{\Pi}$, we now turn to robust covariance matrix estimation. Define predicted residuals for the three equations as:

$$\tilde{\varepsilon}_{it}^{D} = \ln Q_{it}^{D} - \left[\ln p_{it}^{D}, X_{it}^{D}\right]\tilde{\beta}^{D}, \qquad (16)$$

$$\tilde{\varepsilon}_{it}^{S} = \ln p_{it}^{S} - \left[\ln Q_{it}^{S}, X_{it}^{S}\right]\tilde{\beta}^{S}, \text{ and} \qquad (17)$$

$$\tilde{\varepsilon}_{it}^{E} = E_{it}\left(\frac{\hat{f}\left(\tilde{\Pi}_{it}\right)}{\hat{F}\left(\tilde{\Pi}_{it}\right)}\right) + \left(1 - E_{it}\right)\left(\frac{1 - \hat{f}\left(\tilde{\Pi}_{it}\right)}{1 - \hat{F}\left(\tilde{\Pi}_{it}\right)}\right) \text{ for all } i = 1 \ldots N . \qquad (18)$$

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[13] Horowitz (2011) describes the computational limitation for nonparametric estimation with endogenous regressors in greater generality.

The functions $\hat{f}$ and $\hat{F}$ refer to kernel density estimates of the PDF and CDF of the distribution of predicted residuals in the entry equation.

Given those residuals, we compute, block-by-block, the familiar White heteroskedastic-consistent systems estimator

$$\Phi = \begin{bmatrix} \Phi_{SS} & \Phi_{SD} & \Phi_{SE} \\ \Phi_{DS} & \Phi_{DD} & \Phi_{DE} \\ \Phi_{ES} & \Phi_{ED} & \Phi_{EE} \end{bmatrix}. \qquad (19)$$

Each block of this matrix can be estimated with $\hat{\Phi}_{jk} = \frac{1}{N}\sum_{i,t} z_{it} z'_{it} \varepsilon^{j}_{it} \varepsilon^{k}_{it}$, where the z_{it} refer to the $1 \times q$ rows of the matrix of instruments Z. Denote the corresponding blocks of the inverse matrix as $\hat{\Phi}^{jk} = \left(\hat{\Phi}^{-1}\right)_{jk}$, and denote $\tilde{X}^{E} = -\hat{f}\left(\tilde{\Pi}\right)$. As with the White estimator for three stage least squares, the asymptotic covariance matrix of the parameter estimates is given by:[14]

$$\hat{\Sigma} = \frac{1}{N} \cdot \begin{bmatrix} X^{S\prime} Z \hat{\Phi}^{SS} Z' X^{S} & X^{S\prime} Z \hat{\Phi}^{SD} Z' X^{D} & X^{S\prime} Z \hat{\Phi}^{SE} Z' \tilde{X}^{E} \\ X^{D\prime} Z \hat{\Phi}^{DS} Z' X^{S} & X^{D\prime} Z \hat{\Phi}^{DD} Z' X^{D} & X^{D\prime} Z \hat{\Phi}^{DE} Z' \tilde{X}^{E} \\ \tilde{X}^{E\prime} Z \hat{\Phi}^{ES} Z' X^{S} & \tilde{X}^{E\prime} Z \hat{\Phi}^{ED} Z' X^{D} & \tilde{X}^{E\prime} Z \hat{\Phi}^{EE} Z' \tilde{X}^{E} \end{bmatrix}. \qquad (20)$$

Final Estimates. With the asymptotic covariance matrix in hand, we can now compute robust estimates of the supply and demand equation parameters and the predicted probability of entry, $\hat{E}$. The familiar White heteroskedasticity-robust estimator for this system of simultaneous equations is given by:

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[14] The construction of the asymptotic covariance matrix for a simultaneous system of equations estimated by GMM is explained in more generality in Greene (2003).

$$\begin{bmatrix} \hat{\beta}_P \\ \hat{\beta}_Q \\ \hat{E} \end{bmatrix} = \frac{1}{N}\hat{\Sigma}^{-1} \begin{bmatrix} X^{S\prime} Z\hat{\Phi}^{SS} Z'P^S + X^{S\prime} Z\hat{\Phi}^{SD} Z'Q^D + X^{S\prime} Z\hat{\Phi}^{SE} Z'E \\ X^{D\prime} Z\hat{\Phi}^{DS} Z'P^S + X^{D\prime} Z\hat{\Phi}^{DD} Z'Q^D + X^{D\prime} Z\hat{\Phi}^{DE} Z'E \\ \tilde{X}^{E\prime} Z\hat{\Phi}^{ES} Z'P^S + \tilde{X}^{E\prime} Z\hat{\Phi}^{ED} Z'Q^D + \tilde{X}^{E\prime} Z\hat{\Phi}^{EE} Z'E \end{bmatrix}. \quad (21)$$

Identification. Identification of price, quantity, and entry is achieved through the use of instrumental variables. Quantity in the supply equation is identified by exogenous demand variables such as nameplate capacity and SO_2 emissions caps that shift demand, but otherwise do not have a direct effect on price or entry. Price in the demand equation is identified by exogenous cost variables such as route-level marginal cost.

We identify the effect of entry in the supply equation with the entry specific variable buildout distance, which does not directly affect market equilibrium prices and quantities. Although computational complexities prevented us from including other variables that might influence entry, such as measures of variable costs, two points should be stressed. First, our estimates are still consistent. Second, such measures would inevitably involve the quantity of coal traffic shipped (e.g., variable cost per ton-mile multiplied by the number of ton-miles of coal), which we have controlled for in our analysis.[15] Finally, the entry equation is identified by the exogenous supply and demand shifters that are accounted for by the control variables.

Sample

The data sources for the variables used in our analysis and their sample means and standard deviations are presented in table 1. The data are annual observations. Our empirical analysis is based on the shipping activity of the 48 electric utility plants in

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[15] A measure of variable cost that would account for the difference between the incumbent carrier’s and the potential entrant’s length of haul does not appear to be useful because the differences are small, roughly 30 miles or 3% of the average length of haul.

operation from 1984 to 1998 that burned an average of at least one million tons of Powder River Basin coal per year. Those plants account for 75 percent of all Powder River Basin coal shipped by rail during the period. Plants burning less than one million tons were too small to have received unit train service on a regular basis or were engaged in small “test burns” of PRB coal. In either case, such plants did not receive rates that reflected regular unit train service. Almost all plants in the sample burned more than one million tons of PRB coal in all years. The table shows that only 5.7% of the plants receive non-PRB coal by rail and 9.5% receive non-PRB coal by water; thus, most plants rely on PRB coal for a fuel source. This does not pose a problem here because our interest is in rail competition for PRB coal transportation, the large plants in our sample account for a large fraction of PRB coal shipments, and it is not clear that the smaller plants that are not included in the sample receive a much larger share of non-PRB coal as a fuel source.

We began the sample in 1984 because it was the year before the Interstate Commerce Commission authorized entry into the Powder River Basin. We ended the sample in 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. However, no utilities in our sample received a lower rail rate during 1984-98 by winning a maximum rate proceeding. Of the 48 plants, 31 were served by a single railroad throughout the sample period and 17 experienced entry between 1985 and 1998. A few of the single-served plants came on line after 1984, thus our final sample consists of 711 observations.

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 PRB 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)). The price per ton-mile in each market is obtained by dividing the difference between the delivered price of PRB coal to the utility and the price at the mine mouth by the length of haul. Subsequent discussions that we had with railroad personnel confirmed that our estimates of rail rates in each PRB market were quite close to actual rail rates.

Rail transportation contracts for PRB coal might typically cover three million tons of coal per year for a period of five or more years. However, annual price and quantity data are appropriate to use in our model because rail contract rates have annual variation, minimum annual quantity provisions, and annual quantity discounts. Rail contracts specify a price per ton, which is adjusted annually based on railroad input costs and productivity. Minimum annual quantity provisions limit the impact of a new entrant on rates until the contract expires. Utilities receive annual quantity discounts that are reflected in the annual data on the delivered price of coal. Finally, rail contracts for PRB coal are *not* two-part tariffs.[16] As noted, utilities may negotiate a number of contracts

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[16] Two-part tariffs are not considered rates under Section 6 of the Interstate Commerce Act, and are therefore illegal in the railroad industry. (See *Grain by Rent-a-Train, IFA Territory to Gulf Ports*, 335 ICC 111 (1969); 339 ICC 579 (1971)). Hence ICC's

with a railroad during a year. Thus, data on the market price for a given year consists of a ton-mile weighted average of all existing PRB coal transportation contracts, each of which includes the preceding adjustments to reflect current shipping activity.

The presence of a second rail competitor that can deliver PRB coal and the existence of rail and water source competition that can provide non-PRB coal were obtained from the annual Fieldston *Coal Transportation Manual*, which maintains transportation service by specific rail carriers and barge transportation and coal delivery records for major coal-fired utility plants. As noted, entry of a second rail competitor occurred in a market only when that carrier could provide direct service, a condition that in almost all of the cases was met when the carrier constructed a buildout to the plant.

Route-specific marginal costs were derived from Bitzan and Keeler's (2003) translog cost function, specified as a second-degree polynomial in logs of the variables with all variables divided by their sample mean (the base point of approximation). Because Bitzan and Keeler's coefficients are estimated at the firm level not at the route level, substituting route-specific output would cause the output variable to be very far from the industry mean used in the translog specification and result in poor estimates of marginal costs. We therefore calculated route-specific marginal costs for each market in our sample by evaluating the marginal cost function at Union Pacific's mean unit train output divided by the industry mean, the actual length of haul in each market divided by the industry mean, and the year. The resulting estimates of route-specific marginal costs were consistent with industry operating expenses per ton-mile, cost estimates from other

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maximum rail rate guidelines (49 USC 10707 (d) (2)) are defined in terms of markups over average variable costs and not as two-part tariffs that require an entry fee to secure transportation.

studies, and evidence in railroad coal rate cases pertaining to the relationship between price and marginal cost.

Figure 2 presents a comparison of average annual real rail rates over time for the 31 plants in our sample that were served by a single railroad throughout the period and that did not experience entry (No Entry) and the 17 plants in our sample that experienced entry sometime between 1985 and 1998 (Entry). Because of improvements in rail productivity in growing PRB markets, real rates declined throughout the sample period for both types of plants;[17] but by the early 1990s rates were lower for plants that experienced entry of an additional railroad. Based on our data, in 1984, price markups above marginal cost were 1.3 cents per tonmile for plants that at some point during our sample experienced entry of another railroad, compared with price markups above marginal cost that were 1.1 cents per tonmile for plants that were served by a single (monopoly) carrier during our sample. By 1998, those margins decreased to 0.3 cents per tonmile and 0.5 cents per tonmile, respectively. Thus entry tended to occur in the most profitable markets; but by the end of the sample, market power was eroded in those markets such that they were less profitable than the remaining monopoly markets.

Figure 3 presents the average annual real rail rate at the time of entry for plants that experience entry of another rail carrier. Plants that experience entry obtain initial reductions of 24 percent in the year entry occurred (Year 0) and obtain much larger reductions of 44 percent by the third year after entry occurred. This finding suggests that rail entry reduces rates, but that its full impact takes time. Of course, our summary of rail rates in the sample for different market structures and over time does not hold other influences on rates constant, so it cannot isolate the effect of entry. We do so by using our model of rail transportation supply, demand, and entry in Powder River Basin markets to simulate the behavior of rates as market structure changes.

Estimation Results

As a first cut at the data, we present in the first two columns of table 2 estimates of the model by two-stage least squares (2SLS) that treat entry as exogenous. 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 and demand equations and their exclusion had little effect on the other parameter estimates so they are not included in the specification presented here.[18]

Generally, the coefficients have their expected signs and are statistically significant. The demand for rail transportation of coal is elastic ($\eta = -1.15$), which is consistent with actual price-cost markups for PRB coal traffic and the high percentage of monopoly routes in our sample. Given that rail freight transportation is derived demand, the elasticity also reflects the utilities' underlying demand elasticity for coal and the (high) share of rail transport costs in the total production costs of coal.[19] The positive elasticity of rail prices with respect to tons shipped in the inverse supply equation, 0.13, indicates an upward sloping supply curve at the route level that is likely to reflect the effect of congestion/capacity constraints on carrier costs.

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[17] Bitzan and Keeler (2003) find that productivity improvements reduced railroad costs nearly 45 percent during virtually the same period covered by our sample.

[18] As discussed previously, the route-specific marginal costs include a time trend to account for technical change.

[19] During our sample period, the average price paid by a utility for a ton of coal was $42 while the cost of shipping one ton of coal 1000 miles, roughly the average length of haul, at an average price of 1.7 cents per mile amounted to $17 for the movement. Thus transport costs account for 40% of the price and presumably the total production costs of coal.

The parameter estimate for the rail competition variable in the (inverse) supply equation is 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.[20] For example, after three or more years of entry, during which time many contracts are likely to have expired, entry of a second carrier will have reduced rail rates 30 percent.[21] 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 obtain lower rates when they negotiate new contracts, presumably by playing one railroad off against another. Apparently, carriers have not been successful in reaching a tacit understanding to prevent such competition from developing.[22] As discussed previously, we did not expect potential competition to have an influence on rail rates. If it did, its effect would be partly captured in the time trend or year dummies as UP and BN entered more markets, but those variables were statistically insignificant.[23]

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[20] Based on our coefficient, this estimate is obtained by calculating: *ln*(1+ 1 year)*0.215=15 percent. We expressed the persistent effect of rail entry as *ln* (1 + years of entry) for up to three years 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, but this functional specification produced the best statistical fit. We also estimated a model that lagged the initial entry variable, but this did not lead to a better statistical fit.

[21] This estimate is obtained by calculating *ln*(1+ 3 years)*0.215=30 percent.

[22] Scherer and Ross (1990) provide examples in other industries where large buyers play one seller off against another to elicit price concessions.

[23] As noted, UP and BN were involved in mergers during the period of our sample; but we did not find that those mergers lead to cost savings or rate reductions that were

The remaining parameter estimates reflect the workings of standard economic forces. Rail prices reflect marginal costs of production and other sources of competition.[24] We find that an increase in rail marginal cost is slightly more than fully passed on in higher rates, which is consistent with rates that are set as a markup over variable costs. (Recall from footnote 2 that rates cannot be challenged unless they exceed 180 percent of variable costs.) Rail source competition lowers rail rates 24 percent, but the effect of water source competition is statistically insignificant.[25]

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 have for coal shipped by rail from the Powder River Basin. Southern power plants tend to face more rapidly growing demand than other plants in the country face, 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 are able to 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

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realized in PRB markets because such effects would be captured in time trends or year dummies, which turned out to be statistically insignificant.

[24] 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.

[25] Water competition may have a negligible effect on rail rates because almost all plants with river access also have rail source competition and because rail must be used for part of any shipment of PRB coal by water.

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.[26] Apparently, maintaining output and emissions by substituting PRB coal for non-PRB coal is a less efficient option than reducing output.

Before turning to the GMM parameter estimates of our model that treats entry as endogenous, it is useful to provide empirical support for using the buildout distance as an instrument for entry in the supply equation. Although there is no test to satisfactorily determine whether buildout distance is a direct determinant of supply and demand, we did not find that it had a statistically significant effect on demand or inverse supply. Intuitively, that is not surprising because table 1 shows that compared with the length of haul on a route, which influences utilities' demand for coal because it captures the effect of rail reliability, the buildout distance is small and should not affect the reliability of a shipment. Turning to inverse supply, on routes that do not experience entry, marginal changes in the buildout distance and the associated costs incurred by a potential entrant, especially when annualized, are apparently not large enough to affect the incumbent's price, and on routes that do experience entry, marginal changes in (annualized) buildout costs are apparently not large enough to affect the entrant's price. As noted, entry is influenced by the profitability of the entire route and we provide evidence below that the buildout distance plays a role in that decision, and the entry equation is identified by the exogenous supply and demand shifters that are accounted for by the control variables.

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

The GMM parameter estimates are presented in the third and fourth columns of table 2, many of which are very similar to the 2SLS estimates. We also found that the time trend and the fixed utility and plant effects were statistically insignificant. Robust estimation of the covariance matrix accounts for error correlation across plants. The most important change in the estimates is that we now find that the initial entry by a second rail carrier reduces coal rates 9 percent and after 3 or more years rates have fallen 18 percent, which are still sizable effects but they suggest that treating entry as exogenous may cause an upward bias in those estimates. That bias goes in the expected direction because a second railroad is more likely to enter a route with more favorable unobservable characteristics, such as lower costs, which means that an entry dummy that is assumed to be exogenous would be picking up the effect of those unobservables on rates.

In figure 4, we indicate how the buildout distance affects the probability that a second railroad enters a route by graphing the findings of a nonparametric regression of the predicted probability of entry (which contains the actual values of the control variables) on the buildout distance. Consistent with our expectations, markets that require a greater buildout for a rail carrier to provide direct service are less likely to experience entry by a second competitor; twenty miles appears to be the threshold distance that virtually eliminates the likelihood of entry.

Characterizing Duopoly Behavior

We have argued that rail competition in the Powder River Basin provides a natural setting for analyzing duopoly competition because carriers that had monopolies in the region, primarily Burlington Northern and to a lesser extent Union Pacific, gradually experienced new entry from each other to supply a homogeneous service. We use the parameter estimates to simulate the effect of a carrier's entry on rail prices for coal transportation. This exercise is complicated by the fact that several other variables besides a carrier's entry could affect rail rates. For example, rates may fall in PRB markets because of exogenous declines in the marginal cost of rail transportation or productivity growth. To isolate the effect of entry, we hold *all* variables except the entry variable at their 1984 levels—that is, before carriers began to gradually enter PRB monopoly markets. We then use the inverse supply and demand equations to simulate *market equilibrium* prices in response to the changes in entry behavior over time.

We provide perspective on the quantitative effect of entry by comparing the simulated price path with a simulated long-run marginal cost of transporting coal by rail. We also directly compute the conduct parameter θ. It is reasonable to make the former 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. To maintain consistency with the price path, the long-run marginal cost does not reflect changes in rail markets after 1984 that may have affected costs.

The simulated marginal cost is derived from the same Bitzan and Keeler (2003) cost function we used to calculate route-specific marginal costs. However, in the simulation we set the cost function's explanatory variables at their 1984 values, thereby assuming that marginal costs are not affected by entry. This is a reasonable assumption because, as we pointed out, PRB coal transportation markets are relatively new, and the primary rail service providers have been able to employ the same technology and most efficient operations during the sample period.

The price path and long-run marginal cost were converted to 1998 dollars using appropriate indices; the simulated marginal cost of transporting coal in 1984 (in 1998 dollars) is 1.9 cents per ton-mile. Because all variables except entry are held constant in our simulation, marginal cost is not reduced by exogenous technical change that may have occurred after 1984. The simulated marginal cost estimate is plausible because it is consistent with previous estimates obtained by Bereskin (2001) and Ivaldi and McCullough (2001) for unit train operations as well as one obtained by Winston, Grimm, Corsi, and Evans (1990) based on data generated before 1984. To repeat, the price path captures the effect of a second entrant only; the simulated marginal cost is used for purposes of comparison; and all other influences on rates and costs are held constant at their 1984 values. Accordingly, the simulated price path and marginal costs do *not* represent predictions of actual rail prices and costs; it is appropriate for marginal cost to remain constant during the simulation because no other influences except entry are changing; and one should not expect the simulated rail price path to be aligned with the actual behavior of rail prices in figure 2 because the latter reflects changes in all influences on prices.

Figure 5 presents price paths based on the 2SLS and GMM parameter estimates and shows that in the markets that a second carrier has entered at some point between 1984 and 1998, duopoly railroad pricing behavior has evolved slowly, but it appears that rail prices approach marginal cost, and, as indicated, PRB market characteristics lend themselves to this competitive outcome. We have suggested that the 2SLS estimates may overstate the effect of entry by a second carrier on prices and, accordingly, its price path is steeper than the price path based on the GMM estimates, which may depict more accurately the time it has taken to generate intense rail competition. From 1985 to 1994, rail prices declined modestly from their monopoly level. But from 1994 to 1998, they have fallen faster—and by more than in the preceding ten years—as UP in particular has expanded service to a sufficiently large cohort of plants and as BN has been forced to compete more extensively with UP for traffic because shippers' contracts with the incumbent carrier 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, then rail prices may not be declining to the competitive level. However, based on the GMM coefficients, we estimate that 38 percent of the 54 percent decline in actual rail prices from 1984 to 1998 could be attributed to the additional competition supplied by a second entrant and, as shown in figure 5, simulated 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 GMM-based price path would undoubtedly draw closer to marginal cost before stabilizing, while the 2SLS-based price path may unrealistically fall below marginal cost, even if marginal cost were somewhat lower than we estimated.[27]

Indeed, the pervasive use of contract rates in rail freight transportation is probably the most important reason why the transition from monopoly to duopoly resulted in a significant reduction in rail rates. That is, each carrier faces the prospect of getting none

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[27] Both price paths would stabilize shortly after 1998 because the effect of the entry variable was held constant after three years. We also calculated the GMM price path based on a model that specified an entry variable whose effect on price was held constant after five years. The price path based on this model showed a later but steeper drop that nonetheless appeared likely to stabilize close to marginal cost.

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 three million tons of coal to be shipped annually for five or more 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. Scherer and Ross (1990) point out that, in general, lumpiness and infrequency of orders limit oligopolistic coordination.

Another factor that facilitates—but does not ensure—intense rail competition is that coal transportation is a homogeneous service. As discussed previously, rail carriers use the same technology to transport coal from the same source over similar routes and offer similar transit time and reliability. A railroad is unlikely to convince shippers that it is providing a different, let alone superior, service. Product differentiation, primarily through advertising, might explain why some oligopolies have been able to maintain high price-cost margins (e.g., Baker and Bresnahan (1985)). Our findings, however, are not consistent with a successful strategy of product differentiation.

Finally, given that BN initially provided rail service for many utilities that demanded PRB coal, UP had less (existing) profits to lose by supplying additional capacity in this market. Moreover, UP could primarily gain revenue from additional traffic by cutting into BN's traffic. In such a "market stealing" environment, the two were likely to end up as intense competitors because it is more difficult to compete in quantities in zero-sum situations.[28]

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[28] Such network level considerations may be analogous to multimarket contact in airline markets, which Morrison and Winston (1995) have found to have both positive and negative effects on prices depending on the business cycle.

For purposes of comparison, figure 6 shows the time path of the average value of the conduct parameter θ for routes that experienced entry at some point during the sample period. (Those are the same routes from which we constructed the simulated price path in figure 5.) The average value of θ was computed using equation *(3)* and then weighted by the amount of traffic on the routes in the subsample.

Before entry evolved, θ was approximately 0.8, suggesting that sources of non-PRB coal stood in the way of an incumbent setting profit-maximizing monopoly prices. As entry expanded during the period of our analysis, θ dropped by roughly one-half, reflecting the increase in competition. But the terminal value of θ that appears to stabilize at approximately 0.4 indicates slightly greater competition than a Cournot duopoly, in contrast to our simulated price paths that shows prices approaching marginal cost. The difference arises because in coal transportation markets markups over marginal cost routinely occur and movements in prices and costs are highly correlated; hence, changes in exogenous variables over time, such as productivity, will tend to keep the price-cost margin constant and limit the extent that θ falls. Our method simulates the effect of entry on prices, holding other influences on prices (and costs) constant, to characterize competitive behavior; changes in θ appear to understate the increase in competitive behavior over time because they do not hold constant changes in other influences on prices and costs.

Consistent with our findings that rail entry has generated intense competition, we note that BN and UP recently decided to make their rates publicly available, thereby reducing the use of confidential contract rates. In fact, BN and UP acknowledged that long-term contract rates were leading to lower revenues from shipping coal to utilities from the Powder River Basin.[29]

Conclusions

We have developed a model of railroad transportation markets for coal to analyze empirically one of the oldest controversies in economic theory: How are equilibrium prices determined in duopoly markets? We have found that rail transportation prices set in Powder River Basin duopoly markets approach the competitive price. Although we cannot conclude that our evidence unambiguously supports the marginal cost pricing outcome predicted by Bertrand's theory of duopoly behavior because small perturbations in our estimates of the price paths and marginal cost could cause us to reject this theory, it is clear that at the very least; entry into monopoly markets has caused rail prices to fall significantly. Taking a broader perspective, our findings may be particularly relevant to markets that feature a homogeneous product and consumers who make "lumpy" purchases, thereby causing competitors to compete fiercely for infrequent business.

Evidence that indicates the existence of intense duopoly competition in the markets we studied is also of broad interest because game theoretic work has focused on outcomes between the polar cases of profit-maximizing collusion and marginal cost pricing, and because previous cross-section studies have not found that prices decline substantially when a competitor enters a monopoly market. Our results suggest that more theoretical attention should be given to the factors that generate highly competitive outcomes. In addition, our methodology bridges the gap in the empirical industrial organization literature between models of firm entry and models of basic market

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[29] Daniel Machalaba and John R. Wilke, "Railroads Face Probe Over Prices For Shipping

conditions to reflect the richness of duopoly equilibrium over time and provides a better way to measure competitive behavior in dynamic settings that overcomes problems with methods that simply measure the conduct parameter θ.

Our empirical findings are also of particular interest to policymakers as they ponder whether there is sufficient competition in the railroad industry. Because a large fraction of rail markets throughout the country consists of homogeneous coal or grain shipments, our evidence suggests it is likely that direct competition between two rail carriers is sufficient to generate low rates for shippers. 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.

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. We have identified some of the conditions that are conducive to a highly competitive outcome. Future work may be able to add to those conditions to identify other duopoly markets that are likely to be characterized by intense competition.

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Table 1. Sample Means and Data Sources of the Variables*

Variable	**Units**	**Mean**	**Std. Dev.**	**Data Source**
Freight charge	$/ton-mile	0.017	0.008	Energy Information Administration, *Cost and Quality of Fuels* and *Coal Industry*, Annual
Tons of coal shipped	1000 tons	2757	2058	EIA, *Cost and Quality of Fuels*, Annual
Presence of second rail competitor	Dummy	0.068	0.256	Fieldston, *Coal Transportation Manual*, Annual
Rail source competition	Dummy	0.057	0.191	Fieldston, *Coal Transportation Manual*, Annual
Water source competition	Dummy	0.095	0.246	Fieldston, *Coal Transportation Manual*, Annual
Nameplate Capacity	Million KWH	1.172	0.755	EIA, *Annual Electric Generator Report, form EIA-860*, Annual
SO_2 emissions caps	1000 tons	2.110	13.0	EPA, *Clean Air Act, Title IV*
Natural gas price	$/1000ft^3	2.449	0.650	EIA, *Historical Gas Annual*, 2000
Route-level marginal cost	$/ton-mile	0.012	0.003	Authors' calculations based on Bitzan and Keeler (2003)
Length of haul from mine to plant	Miles	1024	339	RDI, *Coal Rate Database*, 1997
Length of "Build-Out" for entrant in 1984	Miles	9.204	7.34	Rand McNally, *Railroad Atlas* (1982) and *Commercial Atlas and Marketing Guide* (1991)

*All values are in 1998 dollars where appropriate.

Table 2. Supply and Demand Parameter Estimates, 1984-1998

(Huber-White Robust Standard Errors are in parentheses)

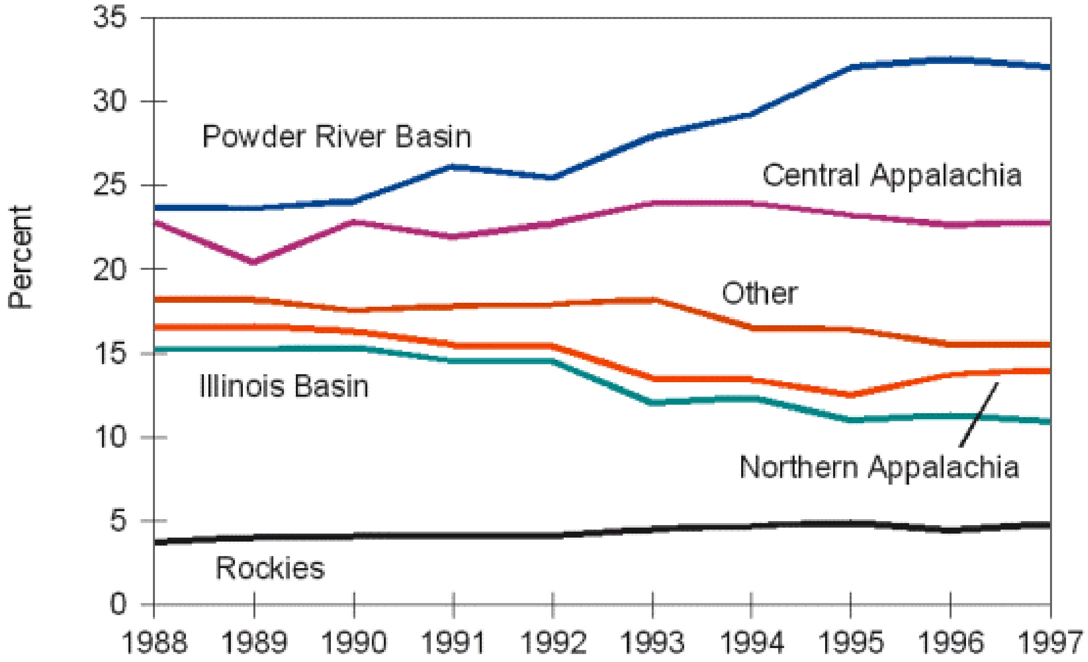
	2SLS		GMM	
Variable	**Supply**	**Demand**	**Supply**	**Demand**
Freight charge (\$/ton mile)*	Dep. Var.	-1.147 (0.327)	Dep. Var.	-1.415 (0.105)
Tons of coal shipped to plant (thousands)*	0.129 (0.020)	Dep. Var.	0.119 (0.007)	Dep. Var.
Total revenues on the route (millions of dollars) [b]	--	--		--
Supply Characteristics				
Rail competition dummy (1 if two carriers serve the route, 0 otherwise) interacted with number of years a second rail competitor offered service from the Powder River Basin. Three years after entry, the variable stays unchanged.[a]*	-0.215 (0.042)	--	-0.129 (0.013)	--
Route level marginal cost (\$/ton mile)*	1.087 (0.055)	--	1.078 (0.022)	--
Demand Characteristics				
Plant Nameplate Capacity (millions of KWH)	--	0.136 (0.011)	--	0.134 (0.004)
Average national price of natural gas (\$/1000ft^3)	--	0.309 (0.101)	--	0.414 (0.040)
Clean Air Act (1990) dummy (1 if the Clean Air Act has been passed; 0 otherwise)	--	0.299 (0.151)	--	0.367 (0.049)
South regional dummy (1 if plant is located in the South; 0 otherwise)[b]	--	0.944 (0.160)	--	0.959 (0.049)
Plant SO_2 emissions cap index (defined as 1 – (emissions cap)$^{-1}$ for plants subject to emissions caps; 1 for plants not subject to caps)	--	0.381 (0.231)	--	0.439 (0.080)
Shipment Characteristics				
Length of haul from mine mouth to plant (miles)*	--	-0.751 (0.160)	--	-0.959 (0.350)
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)	-0.219 (0.079)	--	-0.280 (0.027)	--
Water source competition dummy (1 if a plant can receive coal from a non Powder River Basin source by water transportation; 0 otherwise)	0.025 (0.070)	-1.542 (0.185)	0.050 (0.022)	-1.674 (0.114)
Constant	-5.186 (0.157)	5.658 (1.123)	-5.119 (0.057)	4.394 (1.059)
Number of Observations	711		711	

* denotes that the variable has been transformed by natural logarithm.

[a] We add one to the number of years of entry, ensuring that when we take the natural logarithm, the variable takes on a value of zero for routes without a second competitor.

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

Figure 1. Share of coal used in the United States by origin



Source: EIA *Coal Industry Annual*, 1994-2000

Figure 2. A Comparison of Plants’ Rail Freight Charges over Time, 1984-1998

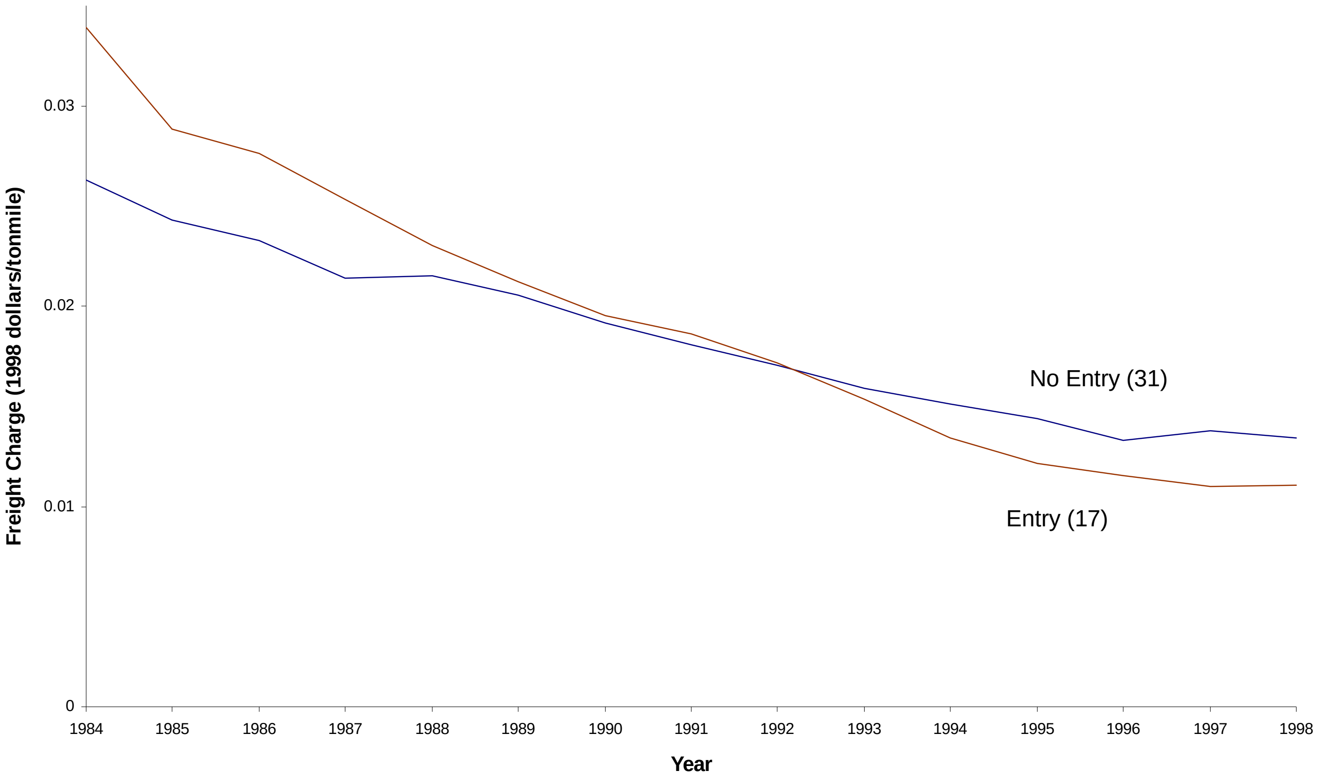
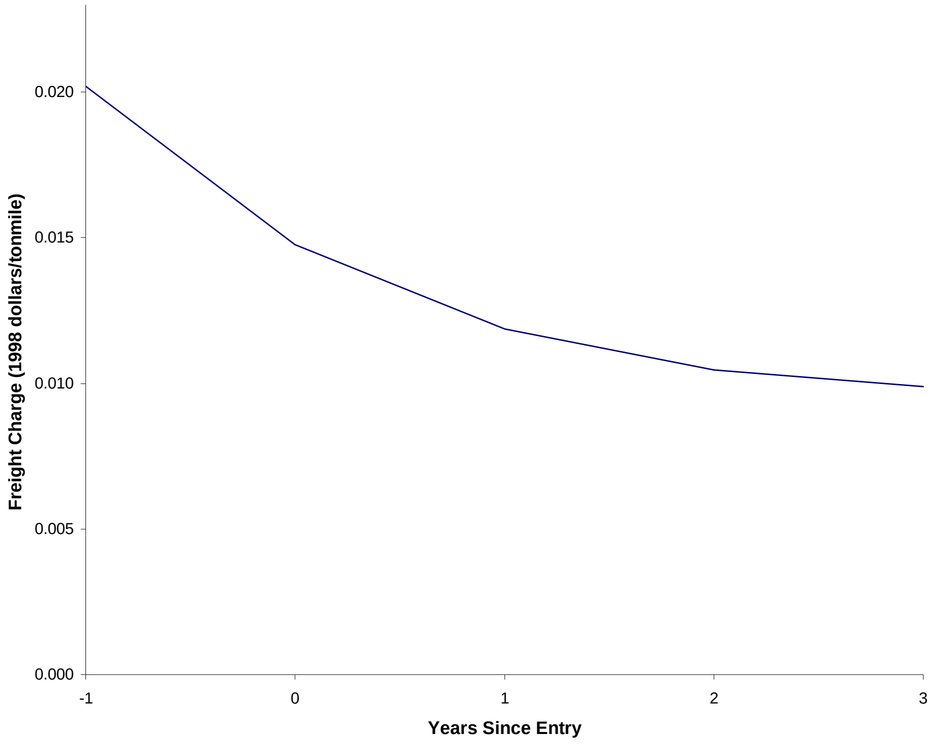
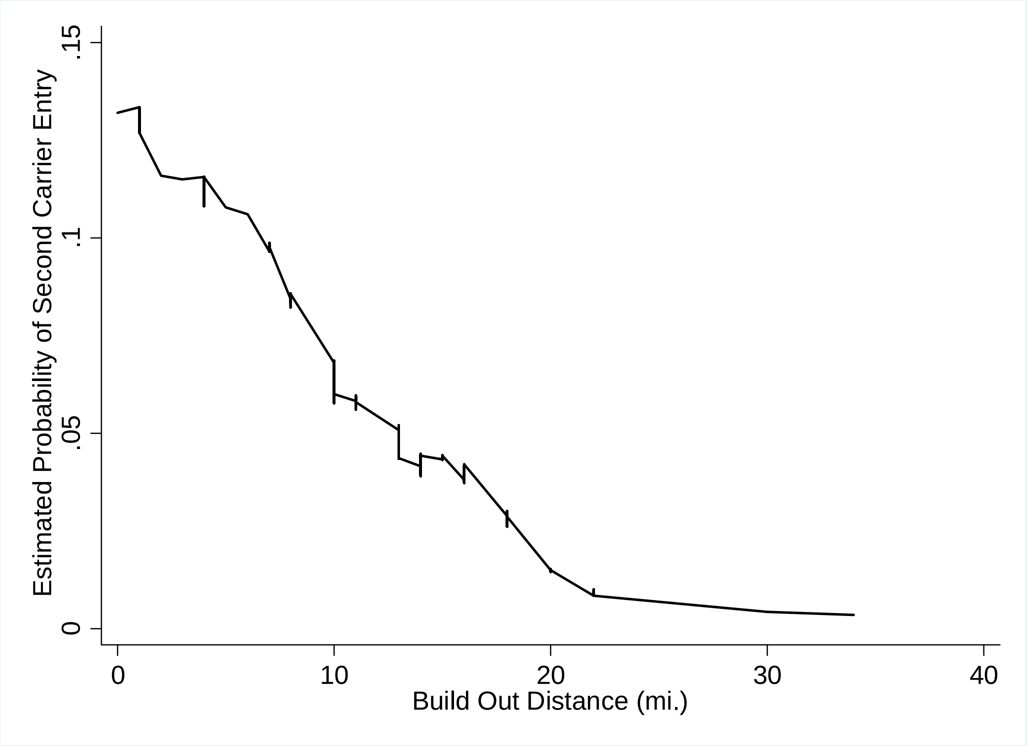


Figure 3. Rail Freight Charge Reductions and Years Since Entry*



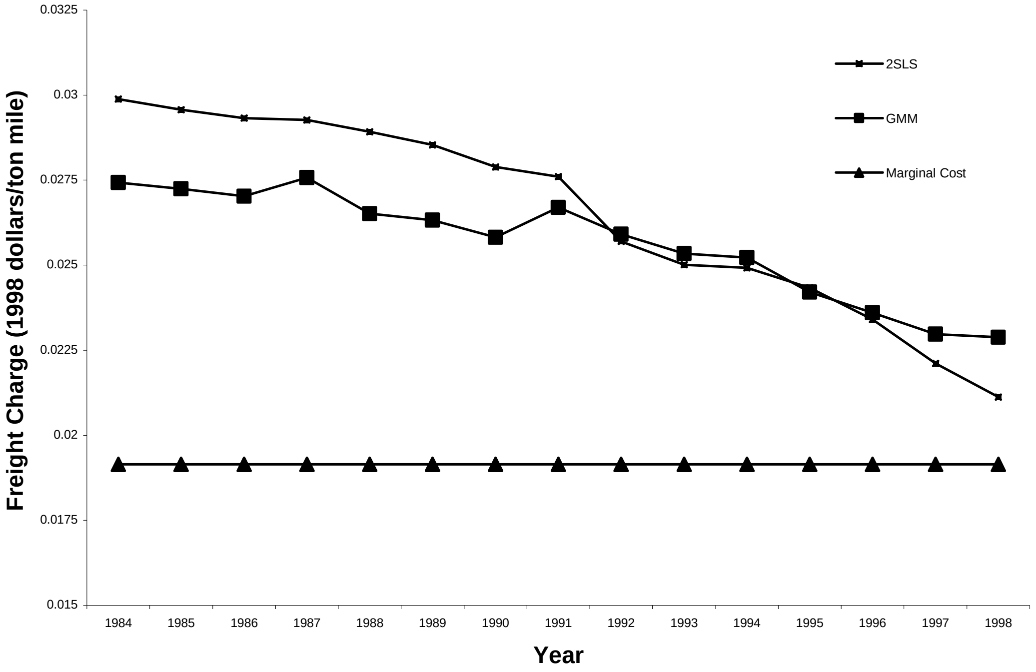
*Entry occurs at time 0 on the x-axis; hence, the initial drop from -1 to 0 represents the instantaneous effect of entry on prices.

Figure 4. Nonparametric Estimate of Entry Probability, 1984-1998



Locally weighted least squares regression of the predicted probability of carrier entry on build out distance, bandwidth = 1 mi.

Figure 5. Simulated Rail Freight Charges and Marginal Cost in Markets Experiencing Entry, 1984-1998



Rail freight charges are simulated by holding all non-entry variables constant at 1984 values and solving for market equilibrium prices using indicated specifications for supply and demand. All markets that experience entry during the period 1984-1998 are included.

Figure 6. Average Value of Conduct Parameter (θ) in Markets Experiencing Entry