Long-Run Effects of Mergers: The Case of U.S. Western Railroads

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Abstract

We provide a retrospective assessment of the effects of the two recent major railroad mergers in the western United States (Burlington Northern–Atchison-Topeka-Santa Fe and Union Pacific–Southern Pacific) on the price of rail transport of export grain. Estimation accounts for selectivity bias that arises because rail prices are observed only for routes with traffic. Despite concerns that both mergers could harm consumers by reducing carrier competition, we find that, in the long run, the mergers have had negligible effects on grain transportation prices and consumer welfare.

1. Introduction

Assessing the welfare effects of mergers—either prospectively or retrospectively—is particularly challenging because it takes considerable time for the merging firms to integrate their operations successfully and for competition between the merged firm, other incumbent firms, and potential new entrants to reach a new equilibrium. Prospective assessments may be compromised by important and unanticipated effects on consumers' and producers' welfare that are attributable to a merger. For example, Peters (2006) finds that poor predictions of postmerger airline fares resulted from maintained assumptions about merged carriers' conduct that did not conform to the postmerger evolution of industry competition.

Retrospective assessments may also be misleading if the study is concluded too soon after the merger was consummated. For example, Ashenfelter and Hosken (2008) indicate that they do not account for the effects of consumer

We are grateful to Jessica Calfee, Robert Crandall, Jay Ezrielev, Robert Gallamore, Darius Gaskins, James MacDonald, Russell Pittman, seminar participants at Washington State University and University of Nevada, Las Vegas, a referee, and the editors for helpful comments. Our valued colleague, Scott Dennis, passed away before he could see this paper in print. He will be sorely missed.

[*Journal of Law and Economics,* vol. 54 (May 2011)]

product mergers on prices in the long run when operating efficiencies from those mergers may emerge. Focarelli and Panetta (2003) find that the long-run efficiency gains from mergers in the Italian banking industry dominate the increase in firms' market power in the short run.

Rail freight transportation offers a classic example of a U.S. industry whose structure has been strongly influenced by mergers that generate long-run effects only after firms have successfully integrated their networks and operations and have renegotiated contract rates that expired—a process that may take several years. The latest merger wave in the industry occurred in the mid-1990s, leaving only two major railroads (Burlington Northern–Santa Fe [BNSF] and Union Pacific–Southern Pacific [UPSP]) in the western United States, while Conrail's absorption by Norfolk Southern and CSX in 1999 left only two major railroads in the East.[1]

This paper provides a long-run retrospective assessment of the effect on rail prices of the BNSF and UPSP mergers, which created the two largest railroads in the country. Real rail prices have increased in recent years (Gaskins 2008), leading to concerns that the western mergers may be partly responsible. Union Pacific (UP) and Burlington Northern (BN) have, at long last, effectively absorbed their partners into their operations, pruned excess capacity, and now operate with potentially binding capacity constraints that may enable them to exploit market power, especially if they are able to raise rates that were kept low by contracts that have only recently expired. The effects of the western rail mergers on shippers are also of interest because those mergers raise issues about competition and efficiency that would also be raised by merger proposals to form transcontinental railroads, which Kwoka and White (2004) conclude are inevitable.

To facilitate our assessment, we focus on an important set of markets that were affected by both western mergers—rail routes carrying domestically grown grain that is bound for foreign export. The existence of rail transportation markets of a homogenous commodity provides a rare opportunity to assess the effects of mergers that often result in a duopoly-competitive environment. Despite concerns that the western rail mergers could reduce carrier competition, we find that, in the long run, the mergers have had little effect on the price of rail transport of export grain. Our findings, although certainly not definitive, suggest that mergers to form transcontinental railroads would have similar long-run effects on prices. A broader methodological caution for antitrust authorities that emerges from this retrospective study is that their prospective assessments may not capture important conflicts and synergies that develop after a merger is consummated.

[1] Kansas City Southern Railroad primarily serves shippers in the middle of the country from Minnesota to Texas, and Canadian National and Canadian Pacific Railroads serve Canadian shippers and certain U.S. markets, primarily in the northern tier of the country.

2. An Overview of the Burlington Northern–Sante Fe and Union Pacific–Southern Pacific Mergers in the Context of Export Grain Movements

The United States is one of the world's leading exporters of grain. Currently, the annual value of U.S. exports of grain and feed exceeds $15 billion. The key market participants are the foreign receiver, the international shipper, and the railroad. The foreign receiver purchases shipments from the owner of a domestic grain elevator (usually found in the Plains and Rocky Mountain states) or from an exporter. The receiver then works through the shipper, who negotiates a long-term contract with the railroad that moves the grain from the elevator to the port, where it is either loaded onto an awaiting bulk cargo ship or stored in a terminal grain elevator for future oceanic transport. A transportation market in our analysis is therefore defined by the origin of the grain elevator from which shipments of export grain are sent by rail to a destination port on the Gulf Coast (usually for European and African receivers) or in the Pacific Northwest (usually for Asian receivers). Because long-distance shipments of export grain in the United States tend to move by rail for most of or the entire journey, railroads typically do not compete directly with trucks, but they may compete with combined truck-barge service for part of the journey.[2]

As shown in Figures 1 and 2, prior to their merger in 1995, BN's network was much larger than that of Atchison-Topeka–Santa Fe (ATSF), but ATSF was by no means a weak competitor that was under financial distress. The carriers' networks served some of the same locations in the Midwest and Southwest and the port of Houston; BN's network also extended to the upper Midwest and to ports in the Pacific Northwest. Hence, BNSF's merger had vertical (end-to-end) components and some horizontal (parallel) components. The BNSF network is shown in Figure 3.

Vertical mergers enable the merged carriers to serve new markets as a single-line carrier and to preblock trains at their intermediate yard for their ultimate destinations, which reduces the number of car-miles, the number of car-hours, and classification time. Horizontal mergers enable railroads to consolidate traffic and make more efficient use of equipment by rerouting traffic to avoid congestion on routes, reducing the number of car-miles by choosing the shortest routes, and dedicating routes to specialized service (for example, using one route for high-speed service and another for low-speed service).[3] Because merger efficiencies affect variable and fixed costs, they could result in lower prices. Of

[2] Barges transport some export grain that is shipped from domestic origins with river access to New Orleans, but as discussed later, our sample consists of grain movements by rail to ports in Texas and the Pacific Northwest for export.

[3] Railroads have attempted to realize some of those efficiencies through various agreements. However, as noted by Grimm and Winston (2000), interfirm cooperation in the rail freight industry has met with mixed success at best.

Figure 1. Atchison-Topeka–Santa Fe network map before the merger, circa 1993

course, rail mergers could raise prices by eliminating a competitor from the market.[4]

As shown in Figures 4 and 5, prior to their merger in 1996, UP's network was much larger than that of Southern Pacific (SP). In addition, SP was widely believed to be a failing firm (among large rail carriers, it had the lowest returns on investment during the era of deregulation), and it was pursuing a merger to keep operating. Union Pacific's network included locations in the center of the country and the Northwest, and SP's network included locations in California and the Southwest, while both carriers served several destination ports on the Gulf Coast and in the Pacific Northwest. Hence, the UPSP merger could be characterized as having mainly vertical components, which could enhance efficiency and competition. Nonetheless, as a condition for the UPSP merger to receive approval from the U.S. Department of Justice, BNSF was given trackage

[4] Park et al. (2001) simulate the effects of rail mergers for movements of export wheat and conclude that mergers do not necessarily increase railroad market power or make railroad shippers worse off. Ivaldi and McCullough (2005) find that consumer surplus in U.S. rail freight markets increased about 30 percent between 1986 and 2001, despite dramatic industry consolidation.

Figure 2. Burlington Northern network map before the merger, circa 1993

rights in markets where that merger reduced the number of independent carriers from two to one. However, the number of independent (single-line) carriers in grain markets tended to increase because of the UPSP merger's vertical components. The UPSP network is shown in Figure 6.

The large and complex networks of the merging carriers suggested that it would take time for BN and ATSF and for UP and SP to integrate their networks and operations successfully and for the long-run economic effects of the mergers to materialize. Unfortunately, the UPSP merger got off to a rough start because shortly thereafter UP moved to eliminate employees whom it perceived to be redundant, including experienced managers at SP headquarters. By doing so, UP lost considerable knowledge about SP's (fragile) operations. Traffic began to back up on a single-track segment between Los Angeles and El Paso, known as the Sunset Route, which in turn affected shipments to Houston and New Orleans. As some UPSP shippers switched to BNSF, congestion and delays propagated to other parts of the western United States, resulting in a service meltdown that lasted for a few years. *Railway Age* (2000) reported that the Surface Transportation Board (STB) finally announced that the service problems that stemmed from

Figure 3. Burlington Northern–Santa Fe network map after the merger, circa 1995

UP's acquisition of SP—and that also affected BNSF's operations—were over as of January 2000. However, the long-run economic effects of those mergers are still an unresolved issue.

3. Empirical Framework

Prospective and, when possible, retrospective merger simulations are used to analyze the effect of a merger on prices. If the merger has yet to occur, a prospective simulation is used to predict postmerger prices based on information about premerger market conditions captured by a demand model and the (assumed) competitive behavior of the prospective merger partners and other firms in the market(s) of interest (Werden and Froeb 1994; Hausman, Leonard, and Zona 1994; Epstein and Rubinfeld 2001).

Because the western railroad mergers have already occurred, we conduct a retrospective simulation using market data without having to make strong assumptions about the nature of competition and the stability of demand and costs before and after the merger. We estimate a reduced-form model of the

Figure 4. Union Pacific network map before the merger, circa 1994

determinants of equilibrium rail prices to take a first cut at the data and then exploit exogenous variation in demand and supply to estimate the basic demand-supply model of industrial organization where rail competitors have distinct effects on the market supply price (see, for example, Porter 1983). The parameters of both models capture the premerger effects of BN, ATSF, UP, and SP on prices and the postmerger effects of BNSF and UPSP on prices, all else constant, which enables us to simulate the effect of the mergers on equilibrium prices.

We treat entry by rail carriers in the export grain market as exogenous. As pointed out by Carlton (2007), endogeneity is not likely to be an issue in analyzing railroad mergers because the decision to lay track was typically made decades ago. More important, entry solely at the route level is rare.[5] Large-scale entry and exit related to mergers are influenced by macroeconomic variables and government policy rather than by route-level variables. Qiu and Zhou (2007) point out that an endogenous merger occurs when an industry experiences a

[5] Winston, Dennis, and Maheshri (2009) analyze the case in which railroads entered Powder River Basin coal markets by building additional track, which made it appropriate to treat entry as endogenous.

Figure 5. Southern Pacific network map before the merger, circa 1994

shock. However, the U.S. western railroad mergers were exogenous mergers in the sense that partners and additional entry into routes through trackage rights were determined in large part by antitrust authorities.[6] In addition, Dafny (2009) argues that a selectivity problem might arise in a merger analysis because merged firms may be different from nonmerged firms in ways that are difficult to quantify. In our case, we are able to measure the impact of a rail merger by comparing the pre- and postmerger carriers' effects on prices across markets and over time, holding other influences constant.

3.1. Reduced-Form Specification

Our empirical analysis is conducted on a panel of movements of export grain by rail from a grain elevator's origin to a U.S. port. As noted, the foreign receiver

[6] As noted, Southern Pacific's (SP's) search for a partner was spurred by its long-term financial problems, and in fact its first choice, a merger with Atchison-Topeka–Santa Fe Railroad, was blocked by the Interstate Commerce Commission in 1983. Eventually, SP found a merger partner in Union Pacific, and the combined entity agreed to give Burlington Northern–Santa Fe trackage rights as a condition for receiving approval of its merger.

Figure 6. Union Pacific–Southern Pacific network map after the merger, circa 1996

chooses the quantity of grain to be shipped and works through the shipper, who negotiates a contract rate or price with the railroad. Our reduced-form model specifies the price of rail transportation as a function of exogenous route characteristics, which capture carrier competition and costs, and exogenous influences on demand.

We specify dummy variables to indicate the presence of UP, SP, BN, and ATSF in a market before merger and specify dummy variables to indicate the presence of UPSP and BNSF in a market after merger. In combination, the dummies capture the effects on prices of the change in the number of competitors and the efficiencies (or inefficiencies) caused by each merger. Although the carrier presence dummies, both before and after merger, should have a negative effect on prices unless carriers engage in some form of collusive behavior, the relative effects of those dummies on prices are not clear a priori (for example, the individual UP and SP dummies could be larger or smaller in absolute value than the combined UPSP dummy). We also specify the presence of an additional railroad competitor, Kansas City Southern (KCS), with a dummy variable. We do not include dummy variables for the presence of Canadian carriers. Although they operate in the origin states of some of the markets in our sample, they do not serve any of the destination ports.

Economic theory does not provide guidance on how the postmerger dummy variables should enter the specification to capture the effect of each merger on prices over time as merger partners' operations and industry competition adjust to a new equilibrium. A general specification would allow the effects of the mergers to vary over time by interacting the BNSF and UPSP dummies with time dummies that indicate each year after the merger. Alternatively, functional form restrictions could be imposed on the coefficients for the postmerger dummy variables, thus possibly improving the efficiency of the estimates. We obtain the best statistical fit by interacting the BNSF dummy with time dummies indicating each year after that merger for 6 years, at which time the merger's effects on prices stabilized, and by interacting the UPSP dummy with time dummies indicating each year after that merger for 10 years.

Finally, the effect of a carrier on price in a market could depend on the identity of the other carriers in the market, the number of other carriers in the market, and whether the carrier had a horizontal or vertical relationship in the market to its eventual merger partner. We therefore explored in preliminary estimations alternative specifications of the carrier dummies with interaction effects to allow the effect of a merger to vary across different types of markets. But we found that the interaction effects were generally statistically insignificant.

Intermodal competition supplied by truck-barge service for at least part of the movement could also affect rail prices if the grain elevator has access to a river. We therefore define a water source competition dummy as taking on a value of one if there is a navigable waterway within 100 miles of the origin, zero otherwise, and expect it to have a negative effect on rail prices. We also include the length of haul as an exogenous route characteristic that affects costs. We expect greater haul lengths to increase prices but at a rate that decreases with distance because of the fixed costs of loading and unloading shipments, so we specify this variable quadratically.

We now turn to exogenous influences on demand. Regardless of how grain shipments from the elevator reach the port, the remainder of the journey from the United States is made by ocean transportation. We therefore specify the ocean shipping rate, which should have a negative effect on the demand for export grain and rail prices. Because rail transportation of grain is an input in final agricultural production, we specify the market price of grain at the origin.[7] Higher U.S. grain prices should reduce a foreign receiver's demand for U.S. export grain, its transport by rail, and rail's price. The receiver's demand for rail transport could also be affected by other economic factors at the origin. In particular, the mix of crops planted by farmers varies in response to economic

[7] It is reasonable to treat this price as exogenous for a given receiver because, in the United States, wheat prices are determined to a significant extent at the commodities exchanges in Chicago and Kansas City.

conditions; hence, farmers could reduce the observed volume of export grain by planting less wheat and reducing stockpiles, thereby reducing the quantity of demand that can be satisfied at a given price.[8] We therefore control for annual wheat production in the origin state and elevator capacity at the origin and expect both variables to have a positive effect on demand and rail prices.

We specify year dummies to capture changes in input prices and productivity over time and include fixed effects for the destination ports to capture any unmeasured influences at the destination on prices. We also explore an alternative specification that includes route-level fixed effects, instead of only port-level fixed effects, to control for possible unmeasured route-level influences on prices (including additional sources of competition) more generally.

3.2. Structural Model

A structural model of supply and demand for rail transportation is particularly useful for analyzing mergers because it allows us to perform consumer surplus calculations based on changes in equilibrium prices that do not artificially hold the quantity of export grain traffic constant.

Because rail transportation is a derived demand, we can follow, say, Friedlaender and Spady (1981) and specify a receiver's cost-minimizing input demand for rail transportation in market i at time t, Q_{it}^{D}, measured in ton-miles as

$$Q_{it}^{D} = D\left(p_{it}^{D},\ X_{it}^{D};\ u_{it}^{D}\right), \tag{1}$$

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

We indicated the exogenous influences on foreign receivers' demand for rail transportation above. In addition, it is appropriate to include the water source competition dummy in the demand equation because the presence of a truck-barge alternative should reduce the demand for rail shipments. We also specify year dummies and fixed effects for the destination ports. Finally, additional variables that we included in the demand equation but found to be statistically insignificant are the elevator capacity at the destination, possibly because the port elevators rarely have binding capacity constraints; the length of haul, most likely because the rail movement accounts for a small portion of the time it takes export wheat to be shipped from a U.S. grain elevator to a foreign receiver; a North American Free Trade Agreement trade dummy, most likely because most foreign buyers are not in North America; foreign wheat production, possibly because of restrictive trade and agricultural policies abroad; and variables capturing major climate-related events such as a famine, wheat futures prices, and a trade-weighted dollar index.

Our specification of (inverse) supply is based on Porter's (1983) model. In a market for a homogeneous good that is produced by firms facing a demand

[8] In general, the production of wheat is determined by competition from other crops (such as sorghums); thus, wheat production may not increase much even if its price rises.

elasticity η, profit maximization implies that the pricing behavior of firm k can be characterized as

$$p\left(1 + \frac{\theta_k}{\eta}\right) = \mathrm{MC}(q_k), \quad (2)$$

where θ_k is the conduct parameter of firm k, MC 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. One strand of empirical work in industrial organization treats θ_k as a free parameter and directly estimates it to make inferences about the nature of market competition (Bresnahan 1989). In the rail industry, good firm-level cost data are available, and there is a long history of researchers obtaining plausible estimates of the marginal cost of rail service for manufactured and bulk commodities that could be used to directly calculate θ_k.

Our objective is to analyze the effects of mergers without making any explicit assumptions about competition or potentially erroneous inferences about oligopoly behavior; we therefore follow Porter's (1983) derivation and note that equation (2) can be aggregated across firms so that the relationship between market supply price, output, and rail competition effectively characterizes an industry supply curve. Namely, we express the supply price of rail transportation of export grain to a receiver in market i at time t as

$$p^{\mathrm{S}}_{it} = S(Q^{\mathrm{S}}_{it}, \boldsymbol{M}_{it}, X^{\mathrm{S}}_{it}; u_{it}) \quad (3)$$

where the price is a function of the quantity of grain transported, Q^{S}_{it}; a vector of dummies that reflect the presence of rail carriers in the market pre- and post-merger, $\boldsymbol{M}_{it}$; supply characteristics including marginal cost, X^{S}_{it}; and an error term, u^{S}_{it}. The specification does not include ton-miles of other commodities (which could capture possible joint economies) because grain shipments account for most of the traffic on the routes included in our sample, as we document below.

The specification of rail carriers in a market before and after merger and water source competition was described previously. Because large shippers are likely to have greater bargaining power than smaller shippers have, we include the elevator capacity at the shipping origin in the supply equation and expect it to have a negative effect on prices.

Exogenous supply characteristics capture rail costs. In much of the merger simulation literature, marginal cost is typically held constant under the assumption that all scale effects are realized before merger and changes in production after merger are sufficiently small to leave costs unchanged (see, for example, Dick 2002). However, if mergers enable the combined carrier to improve operations and reduce costs in markets that it serves, then it would be inappropriate to hold marginal costs constant when assessing the effect of a merger on prices. Hence, we do not use a rail cost function that includes unit train traffic at the firm level as a distinct output (Bitzan and Keeler 2003) to obtain plausible estimates of route-specific marginal costs. Instead, we include only those determinants of marginal costs that are truly exogenous—namely, the length of haul—in the specification. We included a dummy variable for routes that involved a mountain crossing, but it had a statistically insignificant effect on prices. Finally, we specify year dummies, and as in the reduced-form model, we specify a model with fixed effects for the destination ports and an alternative model that includes route-level fixed effects.

In our estimations, the reduced-form price equation and the demand and supply equations take a logarithmic functional form, which fits the data better than a linear functional form. Identification is achieved in the structural model by using exogenous variables that affect only (inverse) supply, the length of haul, and the carrier presence dummy variables, to identify the demand for export grain, and by using the exogenous variables that affect only demand, the price and production of grain at the origin, and the ocean shipping rate, to identify the rail price.

4. Sample

Grain is shipped both in non–unit train movements and in larger unit train movements that can consist of more than 100 cars, depending on the railroad. We focus on unit train movements of export grain so that rates, service quality, and technology are consistent across different rail transportation markets. We do so by including only origin-destination pairs with at least 100,000 tons of export grain traffic for at least 1 year in our sample. The sample begins in 1989, after UP gained control of the Missouri-Kansas-Texas railroad through merger in 1988, and ends in 2006, roughly a decade after the BNSF and UPSP mergers were approved. The sample accounts for nearly 40 percent of all domestically produced export wheat shipped by rail during the period. The data sources and sample means for the variables used in the econometric analysis are presented in Table 1.

The primary data set consists of annual rail movements of export grain from the STB's confidential Carload Waybill Sample. The waybill is a random sample of roughly 5 percent of all carloads including grain shipments. For each shipment, the STB provides a unique sampling weight that can be used to aggregate tonnage and revenues by route. All appropriate expansions of tonnage and revenues are conducted before estimation. Export grain is defined as a commodity movement with a standard transportation commodity code (STCC) of 01-137, which is predominantly (but not exclusively) hard red winter wheat. Virtually all export grain is transported under private contracts.

Because contract information is privileged, railroads may replace contract revenue in the waybill sample with a masked figure that is typically but not always higher than actual contract revenue. However, contract revenues for export grain movements in the confidential waybill have not been masked with

Table 1

Means and Sources of Data, 1989–2006

Variable	Mean	Source
Grain shipped (1,000 tons)	239	STB, confidential Waybill Sample
Rail shipping price ($/ton-mile)	.032	STB, confidential Waybill Sample
Length of haul (miles)	954	Rail carrier mileage files
Bulk ocean freight rate ($/ton)	27.05	Baltic Exchange
Wheat production in state of origin (1,000 bushels)	203	U.S. Department of Agriculture (1992–2007)
Wheat price at origin ($/bushel)	4.37	U.S. Department of Agriculture (1990–2007)
Elevator capacity at origin (1,000 bushels)	1,700	U.S. Department of Agriculture (1999)
Water source competition	.098	U.S. Army Corps of Engineers (2007)
Rail carrier dummies	. . .	Stover (1999)

Note. Means for variables are given only for routes with nonzero traffic (1,491 observations). All prices are in 2006 U.S. dollars and are adjusted for inflation using the producer price index for line-haul operating railroads shipping grain (industry code 4011) that is maintained by the U.S. Bureau of Labor Statistics. The water source competition dummy equals one if the origin elevator has river access and zero otherwise. STB = Surface Transportation Board.

pseudorevenues. Instead, actual revenues were reported, they do not imply implausibly high or low rates, and they appear to be accurate indicators of the actual transportation charges paid by receivers.[9] Although rail transportation contracts for export grain may last for 5 or more years, annual price and quantity data are appropriate to use in our model because rail contract rates vary annually because of minimum quantity provisions, quantity discounts, and cost and productivity adjustments.

Figure 7 presents the behavior of average real rail prices (in 2006 dollars) from 1989 to 2006 for export wheat shipments in the waybill sample that we use in our analysis (solid curve) and for industry-wide data reported by the Association of American Railroads (dotted curve). Prices are adjusted for inflation using the producer price index for line-haul operating railroads shipping grain (industry code 4011) maintained by the U.S. Bureau of Labor Statistics. Both series indicate that real rail prices periodically rose above 3 cents per ton-mile during the 1990s but have stabilized at that value since 2000. Of course, this summary does not isolate the effect of the western rail mergers or hold other influences on rates constant.

Export grain in our sample is shipped from 54 origins throughout 11 states to seven destination ports on the Gulf Coast and in the Pacific Northwest.[10]

[9] Transportation charges in the waybill do not include reservation charges that enable shippers to have a grain car guaranteed to be available for a particular month that they want to ship.

[10] The number of origins (in parentheses) by state is as follows: Arizona (1), Colorado (4), Idaho (2), Kansas (15), Missouri (2), Montana (13), Nebraska (5), North Dakota (3), Oklahoma (3), Oregon (1), and Texas (5). The destination ports include Beaumont, Galveston, and Houston, Texas; Portland, Oregon; and Seattle, Tacoma, and Vancouver, Washington. Export wheat is also shipped by rail to Corpus Christi and Brownsville, Texas, but the annual shipment volumes in our sample are less than our minimum annual cutoff of 100,000 tons. Our data do not include grain exports that are shipped to their final destinations by land (a relatively small amount of traffic is shipped by rail to Mexico, but those data do not include rail prices beyond the border.)

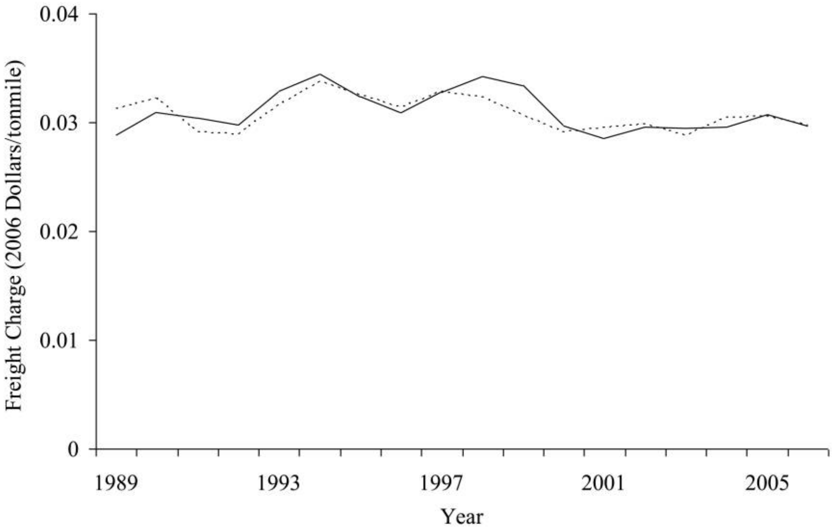

Figure 7. Real freight prices for wheat, 1989–2006

Origins and destinations are identified by six-digit standard point location codes. Our final sample consists of 378 distinct origin-destination pairs and 6,804 observations.

We noted that export grain accounts for most of the traffic in our sample markets; hence, it is not necessary to include ton-miles of other traffic in our specification of supply in the structural model. For example, data for all the routes in our sample from the 1998 Waybill Sample indicate that nongrain shipments represented less than 10 percent of the total traffic on all of our routes that year. Moreover, nongrain shipments represented less than 5 percent of the total traffic on all but three of our routes that year. The most common nongrain commodity shipped on the routes in our sample had an STCC of 4611110, which corresponds to "freight—all kinds" and appears to be a residual code.

An important feature of our sample is that we observe prices only for traffic that is shipped. However, most routes in our sample do not have any observed shipments during some years for the following reasons: exogenous variations in supply and demand for export grain may affect foreign importers' decisions of where to purchase grain; those market variations may result in annual traffic volumes that do not meet our threshold for unit train movements; and only a subset of all shipments are included in the waybill sample—although this is less problematic because the STB uses a random sampling methodology to include shipments in the waybill. In sum, we are unable to specify prices over time on all the routes in our sample. Specifically, 5,313 of the 6,804 observations in the sample are censored, which results in a selectivity problem whose econometric solution is described in the Appendix.

5. Estimation Results

The estimated coefficients of the two reduced-form price specifications, corrected for selectivity bias, are presented in Table 2. The first specification includes port dummies, and the second includes route fixed effects.[11] Because the reduced-form model does not allow us to make sharp interpretations of the influences on the demand and supply of rail transportation, we briefly summarize the main findings of this model and provide a more detailed discussion of the findings of the structural model, which allows rail traffic to change when we assess the affects of the mergers on prices.

The signs of the coefficients for the demand influences and route characteristics in the first specification are as expected, and most are statistically significant. Higher prices for grain and ocean shipping reduce the demand for rail transportation and rail rates, whereas greater wheat production and elevator capacity increase the demand for rail transportation and rail prices. Increases in the length of haul increase rail rates, albeit at a decreasing rate, and the existence of water competition reduces rail rates.

The estimates of the rail carrier dummies indicate that all of the premerger effects are negative (a constant is not included), UP and KCS have the largest effects, and postmerger BNSF and UPSP have large initial negative effects that fluctuate over time. Most of the signs and magnitudes of the coefficients in the second specification are aligned with those in the first.[12]

As noted, we are unable to calculate the effect of the mergers on consumers' surplus using the reduced-form model, but we are able to calculate their effect on average rail rates. To do so, we hold all variables except the rail carrier dummy variables at their premerger levels and simulate postmerger average rail rates on each route, allowing only the rail carrier dummy variables to change. We then calculate a traffic- (ton-mile-) weighted average of those simulated rates on each route for each year and plot that average over time.

The results are presented in Figures 8 and 9 for both specifications. The numbers in parentheses denote the reduced-form price specification in Table 2 used in the simulation. Figure 8 shows that the BNSF merger initially reduced prices, raised them during the service meltdown when shippers' demand for its

[11] We also explored specifications that divided the sample into competitive and less competitive routes; however, we found such divisions to be potentially arbitrary because the mergers occurred at different times, increased competition on some routes and decreased it on others, and created new routes that carried traffic. In any case, our specification with route fixed effects should control for any unmeasured competitive influences on prices. We also divided the sample by length of haul and estimated separate models for long routes and shorter routes. However, that proved problematic because we were not able to estimate the premerger effects of certain carriers for both models.

[12] Route characteristics could not be separately identified when we included route fixed effects in the second specification because they do not vary over time.

Table 2

Reduced-Form Price Estimates, 1989–2006

Variable	(1)	(2)
Demand influences:		
Elevator capacity at the origin (million bushels)	.01 (.01)	
Market price for grain at the origin ($/bushel)	−.89 (.15)	−.36 (.19)
Bulk ocean shipping rate from port to Japan ($/ton)	−.20 (.16)	−.60 (.13)
State-level annual wheat production at origin (1,000 bushels)	.04 (.01)	−.13 (.05)
Route characteristics:		
Length of haul (miles)	1.36 (.57)	
$(\text{Length of haul})^2$ $(\text{miles})^2$	−.14 (.04)	
Water source competition dummy	−.34 (.04)	
Rail competition dummy variables:		
ATSF	−.01 (.04)	.01 (.04)
BN	−.07 (.03)	−.06 (.04)
UP	−.31 (.09)	−.29 (.22)
SP	−.04 (.04)	−.01 (.06)
KCS	−.28 (.06)	−.44 (.07)
BNSF (ATSF + BN, after merger)	−.28 (.15)	−.30 (.22)
Plus 1 year	.43 (.15)	.53 (.22)
Plus 2 years	.02 (.12)	−.01 (.13)
Plus 3 years	.04 (.15)	.11 (.17)
Plus 4 years	−.17 (.11)	−.16 (.13)
Plus 5 years	.12 (.06)	.08 (.08)
Plus 6 years or more	−.20 (.05)	−.25 (.07)
UPSP (UP + SP, after merger)	−.22 (.06)	−.19 (.04)
Plus 1 year	.12 (.08)	.29 (.06)
Plus 2 years	.03 (.08)	−.09 (.06)
Plus 3 years	.17 (.10)	.12 (.05)
Plus 4 years	.01 (.13)	−.06 (.06)
Plus 5 years	−.20 (.11)	.17 (.06)
Plus 6 years	.25 (.09)	.27 (.08)
Plus 7 years	−.12 (.12)	−.20 (.10)
Plus 8 years	−.02 (.15)	.08 (.08)
Plus 9 years	.18 (.16)	.11 (.08)
Plus 10 years	−.18 (.13)	−.16 (.08)
Selection coefficient on inverse Mills ratio $\hat{\delta}$	.91 (.05)	−.01 (.01)
Port dummies	Yes	No
Route dummies	No	Yes

Note. The dependent variable is average freight rate ($/ton-mile). All nondummy variables are transformed by natural logarithm. The water source competition dummy equals one if the origin elevator has river access and zero otherwise. All regressions include year dummies. $N = 6{,}804$ observations and 1,491 uncensored observations. Huber-White Robust standard errors are in parentheses. ATSF = Atchison-Topeka–Santa Fe; BN = Burlington Northern; UP = Union Pacific; SP = Southern Pacific; KCS = Kansas City Southern; BNSF = Burlington Northern–Santa Fe; UPSP = Union Pacific–Southern Pacific.

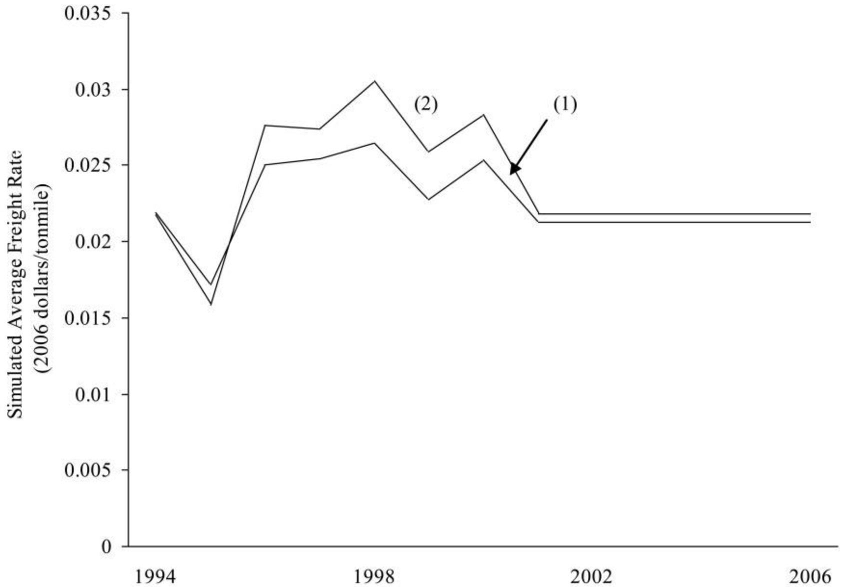

Figure 8. Simulated change in average freight rates due to the Burlington Northern–Santa Fe merger, 1994–2006.

capacity increased because UPSP's network was severely congested, and reduced them after the meltdown to the point where they have basically stabilized at their initial level. Figure 9 shows that the effects of the UPSP merger on prices appear to be more volatile, but the average freight rate appears to have declined to its initial level during the last year of our sample. In sum, the findings from our reduced-form specifications indicate that the western rail mergers have had a negligible long-run effect on rail prices.

5.1. Structural Model Estimates

Two-stage least squares estimates of the demand and supply parameters of our structural model, corrected for selectivity, are presented in Table 3. Estimates of the selection model parameters are presented in Table 4.[13] We begin with the results from specification (1) in the first and third columns of Table 3. In general, the coefficients have their expected sign, and most are statistically significant.

[13] With regard to the selection model, larger elevator capacities and greater wheat production at the origin and longer lengths of haul correspond to a higher probability that traffic is observed on a route, while higher grain prices at the origin, the existence of water source competition at the origin, and a higher minimum rail rate on routes having the same origin correspond to a lower probability that traffic is observed on a route. We also included the pre- and postmerger carrier dummies in the specification, but the coefficients for those dummies were statistically insignificant.

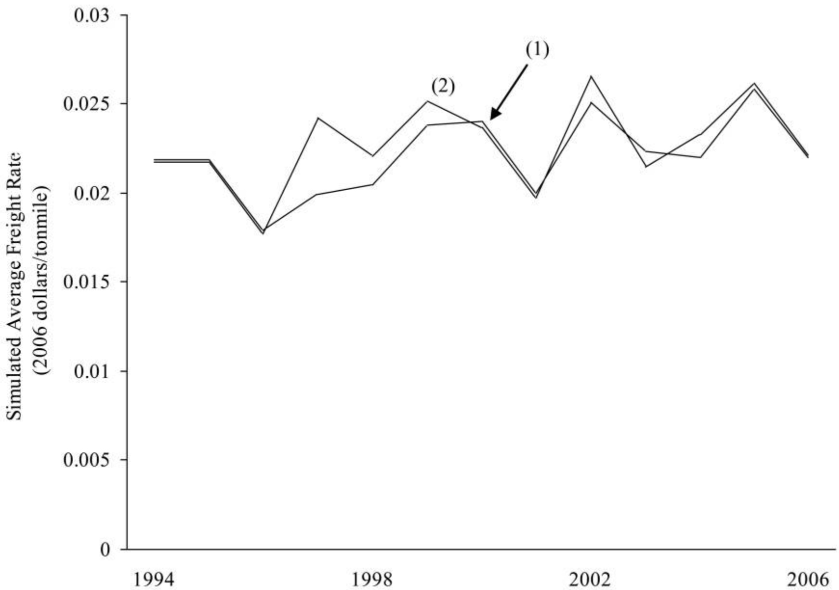

Figure 9. Simulated change in average freight rates due to the Union Pacific–Southern Pacific merger, 1994–2006.

The estimated price elasticity of demand for rail transportation, $\eta = -.84$, is plausible because export grain markets are frequently characterized by duopoly competition.[14] Ton-miles shipped in the inverse-supply equation have a positive effect on rail prices (the elasticity is .2), and we find, as expected, economies of length of haul. The upward-sloping supply curve appears to conflict with a large literature that finds increasing returns on a given rail route. However, as noted, traffic on the main lines of western rail routes for export grain was capable of straining available capacity and for a few years severely did so. Thus, our finding likely reflects the effect of congestion or capacity constraints on carrier costs.

The parameter estimates for the rail presence dummy variables in the supply equation are of central importance for assessing the effects of the mergers. They capture the price reductions associated with specific railroads serving a route, holding route characteristics constant. A railroad's effect on price may be greater than another railroad's effect because it tends to supply competition in different markets (for example, it serves markets that would otherwise be monopolies) or because it employs more efficient operations. When a merged railroad's effect on prices is greater than the effect of the two individual railroads, it is likely that the merger, despite possibly reducing the number of competitors, enabled

[14] The demand elasticity should be elastic in monopoly export grain markets. We note that our estimated demand elasticity is not statistically significantly different from -1.0.

Table 3

Supply and Demand Two-Stage Least Squares Parameter Estimates, 1989–2006

	Demand		Supply	
Variable	(1)	(2)	(1)	(2)
Average freight rate ($/ton-mile)	−.84 (.31)	−.88 (.16)		
Quantity of grain shipped to port (ton-miles)			.20 (.05)	.14 (.08)
Demand influences:				
Elevator capacity at the origin (million bushels)	.03 (.03)	.03 (.03)	−.002 (.001)	
Market price for grain at the origin ($/bushel)	−1.17 (.50)	−1.28 (.48)		
Bulk ocean shipping rate from port to Japan ($/ton)	−.72 (.91)	−.61 (.89)		
State-level annual wheat production at the origin (1,000 bushels)	.23 (.05)	.25 (.05)		
Route characteristics:				
Length of haul (miles)			4.15 (.44)	
(Length of haul)^2 (miles)^2			−.37 (.05)	
Water source competition dummy	−.51 (.11)	−.58 (.12)	−.21 (.07)	
Rail competition dummy variables:				
ATSF			−.08 (.04)	−.07 (.04)
BN			−.05 (.03)	−.02 (.03)
UP			−.30 (.05)	−.25 (.06)
SP			−.03 (.05)	.01 (.04)
KCS			−.23 (.05)	−1.02 (.35)
BNSF (ATSF + BN, after merger)			−.26 (.03)	−.34 (.14)
Plus 1 year			.35 (.05)	.54 (.16)
Plus 2 years			.0005 (.03)	−.13 (.13)
Plus 3 years			.04 (.02)	.06 (.17)
Plus 4 years			−.15 (.05)	−.12 (.17)
Plus 5 years			.12 (.02)	.08 (.19)
Plus 6 years or more			−.19 (.07)	−.25 (.18)

UPSP (UP + SP, after merger)			−.23 (.06)	−.18 (.08)
Plus 1 year			.13 (.03)	.23 (.11)
Plus 2 years			.02 (.08)	−.02 (.12)
Plus 3 years			.15 (.07)	.09 (.13)
Plus 4 years			.04 (.05)	.02 (.14)
Plus 5 years			−.21 (.06)	−.18 (.15)
Plus 6 years			.27 (.07)	.23 (.16)
Plus 7 years			−.16 (.12)	−.15 (.16)
Plus 8 years			−.04 (.13)	.03 (.15)
Plus 9 years			.17 (.14)	.09 (.13)
Plus 10 years			−.14 (.03)	−.08 (.12)
Selection coefficient on inverse Mills ratio $\hat{\delta}$	.30 (.37)	.20 (.12)	1.85 (.53)	.35 (.22)
Port dummies	Yes	Yes	Yes	No
Route dummies	No	No	No	Yes

Note. The dependent variable for the demand regressions is the quantity of grain shipped to port (in ton-miles), and the dependent variable for the supply regressions is average freight rate (in $/ton-miles). Huber-White robust standard errors are in parentheses. All nondummy variables are transformed by natural logarithm. The water source competition dummy equals one if the origin elevator has river access and zero otherwise. All regressions include year dummies. N = 6,804 observations and 1,491 uncensored observations. ATSF = Atchison-Topeka–Santa Fe; BN = Burlington Northern; UP = Union Pacific; SP = Southern Pacific; KCS = Kansas City Southern; BNSF = Burlington Northern–Santa Fe; UPSP = Union Pacific–Southern Pacific.

Table 4
Probit Selection Model Parameter Estimates, 1989–2006

Variable	Coefficient
Demand influences:	
Elevator capacity at origin (million bushels)	.009 (.001)
Market price for grain at origin ($/bushel)	−.38 (.11)
Bulk ocean shipping rate from port to Japan ($/ton)	.04 (.03)
State-level annual wheat production at the origin (million bushels)	.53 (.20)
Route characteristics:	
Minimum rail rate offered on routes with the same origin (cents/ton-mile)	−32.09 (10.07)
Length of haul (miles)	.002 (.0003)
(Length of haul)^2 (million miles squared)	−1.41 (.16)
Water source competition dummy	−.56 (.12)

Note. Robust standard errors are in parentheses. The dependent variable is equal to one if traffic was observed on the route, and zero otherwise. The water source competition dummy equals one if the origin elevator has river access and zero otherwise. All regressions include port and year dummies. N = 6,804 observations.

the combined entity to compete more intensely for traffic than the individual firms could, by leading to efficiency and financial improvements in their operations.

The premerger coefficient estimates generally indicate that a rail carrier's presence on a route reduces prices, but the magnitudes vary considerably by carrier. (We estimate coefficients for all carriers by not specifying a constant in the regression.) Because rates are specified in natural logarithms, a carrier's coefficient indicates the approximate percentage reduction in rates attributable to the carrier's presence in the market.

Union Pacific and KCS, which is the smallest major (class I) railroad and was not involved in the western mergers, reduce rail prices by more than 20 percent, while SP reduces prices by only 3 percent, and its effect is not statistically significant. Given that railroads do not employ markedly different technologies in grain markets and that no rail carrier could be characterized as a low-cost carrier, as with airlines, the variation in their effects on prices suggests that market structure is exogenous because carriers would presumably adjust their entry and exit decisions, which would result in less variation in their effects on prices than is indicated by our estimates. The coefficients are therefore consistent with an exogenous market structure and duly reflect carriers' relative financial health and efficiency.

Before their merger, ATSF's effect on prices was somewhat larger than BN's effect, but the difference was not statistically significantly different. In contrast, UP's effect on prices was much larger than SP's (statistically insignificant) effect. Southern Pacific did not originate as much grain traffic as the other carriers originated and, as noted, had a history of financial distress before it merged with UP. It is interesting that, among the large western rail carriers, a merger did not form between UP and ATSF, which had the greatest effects on prices, possibly indicating that the UPSP and BNSF mergers were not likely to have strong anticompetitive effects.

Following a large initial negative effect on prices that exceeded the effect of the individual BN and SF dummies, the combined BNSF dummy fluctuated considerably, with some large positive and negative effects. Six years after the merger was approved, its coefficient did not change statistically, and it appeared to have a stable negative effect on prices. The combined UPSP dummy initially had a large negative effect that fell somewhat short of the effect of SP's and especially UP's dummy. This combined dummy turned positive for the next few years and then alternated in sign until the tenth year after the merger was consummated, at which point the sample ended. The overall effect of the BNSF and UPSP mergers on prices reflects the cumulative effect of their merger dummies, compared with each carrier's individual dummies, and the allocation of traffic between the carriers before they merged. We determine the magnitude of this effect below by calculating the change in consumers' surplus.

We point out that the effect of KCS on rail prices was not affected by the UPSP and BNSF mergers. If the mergers had notable anticompetitive effects, it might be expected that KCS's coefficient would increase because KCS was preventing the merged carriers from fully exploiting their enhanced market power in markets that it served before the mergers and in markets that it entered following the mergers (assuming that it was easy for it to enter new markets). The fact that KCS's coefficient did not change is additional suggestive evidence that rail market structure is exogenous—that is, KCS's postmerger effect was limited because it was difficult for it to enter new markets unless it was granted trackage rights as a condition for a proposed merger to be approved—and that the western mergers did not tend to have strong anticompetitive effects.

The remaining coefficients in the supply equation indicate that intermodal competition supplied by truck-barge transportation reduces rail prices by some 20 percent, reflecting the benefits of additional sources of competition in grain transportation markets. They also indicate that shippers with larger elevator capacities at their origins are able to exert greater bargaining power to obtain lower rates.

The remaining coefficients in the demand equation reflect the workings of standard economic forces. The availability of an alternative mode of transportation and higher grain prices at the origin reduce the volume of export grain shipments by rail. Ocean rates have a statistically insignificant effect on demand, which may not be surprising because ocean freight charges amount to less than 7 percent of the wheat price at the port. Greater wheat production and elevator capacity at the origin enable farmers to satisfy receivers' demands for more export grain shipments by rail.

Finally, the positive sign of the selection coefficient in the (inverse) supply equation indicates that the unobserved determinants of the supply price of a grain shipment are positively correlated with the unobserved determinants of whether that grain shipment is actually measured in our sample. That is, carriers tend to charge higher prices on routes in the subsample with observed traffic relative to when traffic is not observed on those routes. The importance of controlling for the potential bias that could arise from observing prices only on routes with measured grain shipments is indicated by the statistical significance of the selection coefficient in the supply equation.

Estimation results of specification (2) with route fixed effects in supply are presented in the second and fourth columns of Table 3.[15] The demand coefficients are not affected much by the alternative specification. And with the exception of an inexplicably large coefficient for KCS, the rail carrier dummies in supply are relatively consistent with those in the second specification. We obtain a better sense of any important differences between the estimated models when we use them to calculate changes in consumers' surplus attributable to the mergers.

5.2. Consumers' Surplus

A farmer harvesting grain for export wants to sell it to the highest bidder. The foreign buyer wants to find the lowest delivered price. Because rail transportation is a substantial component of that price, a lower cost of moving the grain to the foreign buyer allows the farmer to benefit by either selling additional grain at a lower price (reflecting some of the rail cost savings) or keeping the delivered price constant (thereby earning greater profit for the same amount of export grain.) Hence, the western railroad mergers have potentially important welfare effects on U.S. farmers as well as on foreign buyers.

We measure those welfare effects by the change in consumers' surplus:

$$\Delta\text{CS} = -\int_{p_{it}^{0*}}^{p_{it}^{1*}} D(p)dp, \tag{4}$$

where $D(p)$ is the estimated log-linear route-level demand function given in equation (1), p_{it}^{0*} denotes predicted rail prices paid by foreign buyers before the merger, p_{it}^{1*} denotes predicted rail prices paid by foreign buyers after the merger, and asterisks indicate that the prices were computed after the estimated demand and supply functions were equilibrated.

The effects of the BNSF and UPSP mergers on consumers' surplus over time are shown in Figures 10 and 11 for our two estimated models. The numbers in parentheses denote the specification of demand and supply in Table 3 used in the simulation. In general, the findings indicate the potential pitfalls of making a premature judgment about a merged firm's performance and the importance of identifying a merger's long-run effects. The service meltdown that occurred shortly after the UPSP merger was approved in 1996 led to congestion and delays that effectively reduced rail capacity. But UP was unwilling to reduce congestion—and lose traffic—by raising rates when the service problems began because it was concerned about angering shippers so soon after its merger with SP (Span

[15] Again, route characteristics could not be separately identified when we specified route fixed effects because they do not vary over time.

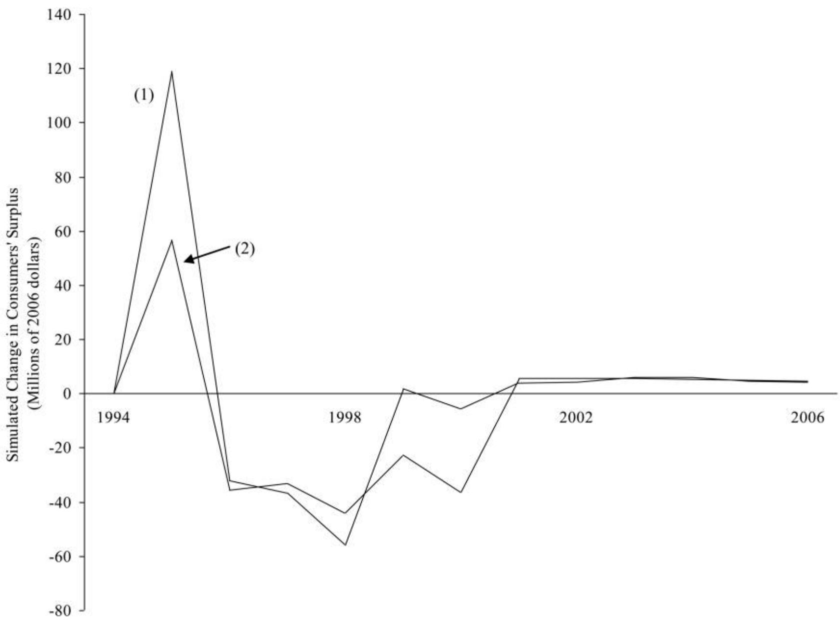

Figure 10. Simulated change in consumers' surplus due to Burlington Northern–Santa Fe merger, 1994–2006.

2004). Hence, as shown in Figure 11, the UPSP merger increased consumers' surplus associated with price changes throughout part of its initial problems. At the same time, shippers placed demands on BNSF's capacity to avoid using UPSP, causing BNSF to raise its rates and reduce consumers' surplus (Figure 10). Since 2000, when the STB indicated that the railroad industry's service problems had ended, the effects of the mergers on rail rates have tended to become more stable, and their long-run effect on consumers' surplus appears to be negligible based on either model.

To be sure, other factors related to the carriers' and shippers' adjustments to the mergers may have contributed to the initial volatility in consumers' surplus. For example, some contracts may have expired and were renegotiated during the period. We also note that the UPSP coefficient estimates had not stabilized by the end of our sample. Nevertheless, Figure 11 indicates that the change in consumers' surplus, which reflects the cumulative effects of the UPSP dummies, has stabilized for several years after the merger based on specification (1) and, to a lesser extent, on specification (2).

Notwithstanding our findings, some policy makers were concerned that the western rail mergers would reduce competition and significantly raise rates. Indeed, the U.S. Department of Justice's opposition to the UPSP merger raises

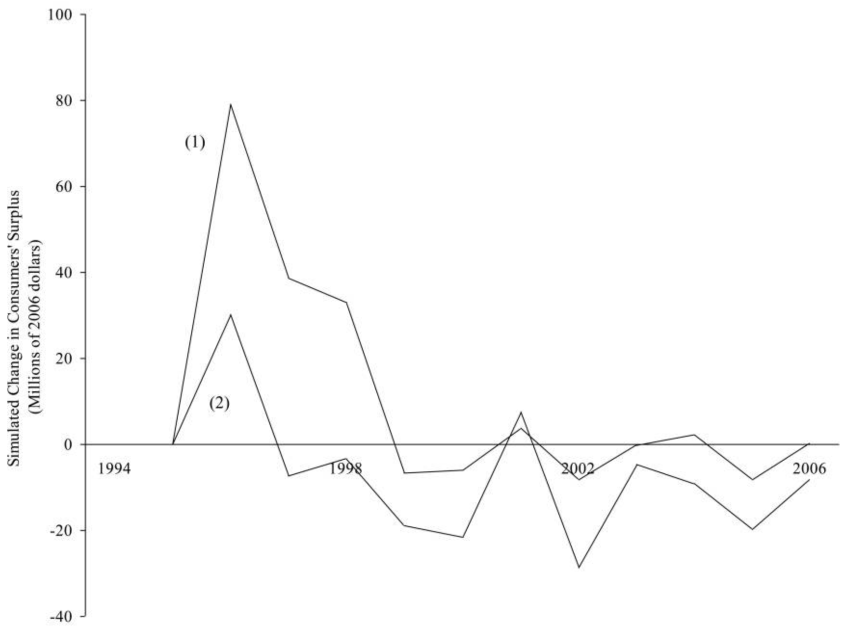

Figure 11. Simulated change in consumers' surplus due to Union Pacific–Southern Pacific merger, 1994–2006.

concerns about its prospective assessment. Although rail grain transportation markets tended to be characterized by duopoly competition following the western mergers, Winston, Dennis, and Maheshri (2009) and Park et al. (2001) argued that such intrarailroad competition is sufficiently intense to prevent rates from increasing in the long run because a railroad has much to lose if it allows a competitor to negotiate a contract with a shipper that locks in its business for several years. In addition, the homogeneous nature of grain transportation significantly limits a railroad's ability to differentiate its service to convince shippers that it is distinct from, let alone superior to, its competitor's service. Finally, any reductions in competition that may have occurred following the mergers appear to have been offset by carrier synergies that have kept prices from increasing.[16] Breen (2004) concludes that UP and SP's claim that their merger would lead to efficiencies was, in fact, eventually realized.

[16] Shippers have long claimed that maximum rate regulation, as enforced by the Surface Transportation Board, does little to prevent rates from increasing because of the cost and time involved in challenging a rate (Grimm and Winston 2000).

6. Conclusion

Controversy preceded and immediately followed the railroad mergers between BN and ATSF and between UP and SP. We focus on the transportation of export grain to provide a clean assessment of those mergers and find that, in the long run, they have not caused shippers to pay higher rates. We are unable to estimate the mergers' effect on service quality because data for most service quality variables are not publicly available at the route level. However, some suggestive evidence indicates that service quality has improved in the long run because shuttle train service has increased the velocity of shipments (Blaszak 2009) and because many switching junctions, which increase service times, have been eliminated.

To be sure, we focus on only a single, albeit important, commodity. However, our findings should also apply to rail transportation of other commodities, especially manufactured commodities where rail also faces strong intermodal competition from motor carriers. We concentrate on shippers of unit train movements, but shippers who make smaller shipments may also have benefited from the mergers to the extent that they were able to use, for example, third-party logistics firms to consolidate their shipments and to take advantage of expanded unit train service.

Gaskins (2008) opines that the STB may be under political pressure in the near future to make it more difficult for the rail industry to apply Ramsey pricing principles to cover its declining average costs arising from economies of traffic density. The western rail mergers may have addressed this problem to some extent by helping the industry to become more productive and revenue adequate without harming shippers. Berndt et al. (1993) find that from 1974 to 1986 both deregulation and mergers contributed significantly to rail industry cost savings, with most of the savings due to deregulation. But as the industry has shed the capital structure that it had inherited from the era of regulation and has adjusted more fully to deregulation in succeeding decades, rail mergers have become a more fruitful source of operating efficiencies and enhanced profitability. Our findings are consistent with this view and suggest that the welfare gains from the western rail mergers would be greater if they were assessed using a total surplus, as opposed to a consumer surplus, standard.[17]

Transcontinental railroads created by BNSF merging with Norfolk Southern and UPSP merging with CSX, or vice versa, could result in additional industry cost savings and service improvements that would benefit shippers while enabling the railroad industry to become revenue adequate. This is a likely scenario because the transcontinental networks would primarily consolidate end-to-end (vertical) operations and would not raise anticompetitive concerns by consolidating horizontal operations.

Roughly a century ago, the number of independent rail carriers in the United

[17] Carlton (2007) argues that antitrust policy should maximize total (consumers' and producers') surplus.

States peaked. Ever since, the industry has consolidated and may continue to do so until it becomes a national duopoly. The effects of the BNSF and UPSP mergers that we identify offer cautions about this industry structure in the short run—and about the reliability of prospective merger simulations of transcontinental consolidations—but they are cause for optimism in the long run.

Appendix

Selection Bias Correction

This Appendix describes our procedure to eliminate the selectivity bias that arises because we do not observe prices for all routes. It is explained for our structural model, but the correction is also applied to the reduced-form model. We adapt Heckman's two-step procedure (1979) to estimate the probability that a route will carry a nonzero amount of traffic and then include that probability in an estimation of the supply and demand functions that is conditional on routes carrying traffic to obtain unconditional estimates of supply and demand.

Formally, we have the log-linear (inverse) supply and demand functions and the selection equation (subscripts are omitted for simplicity):

$$\ln p = \varepsilon^{\mathrm{S}} \ln Q + \boldsymbol{X}^{\mathrm{S}\prime}\beta^{S} + \boldsymbol{u}^{\mathrm{S}}, \tag{A1}$$

$$\ln Q = \varepsilon^{\mathrm{D}} \ln p + \boldsymbol{X}^{\mathrm{D}\prime}\beta^{D} + \boldsymbol{u}^{\mathrm{D}}, \tag{A2}$$

and

$$\sigma = \mathbf{1}(\boldsymbol{X}^{\mathrm{sel}\prime}\beta^{\mathrm{sel}} + \boldsymbol{u}^{\mathrm{sel}} > 0), \tag{A3}$$

where ε denotes an elasticity; $\boldsymbol{X}$ is a matrix of exogenous variables that determine supply (S), demand (D), and selection (sel); $\boldsymbol{u}$ is a vector of independently and identically distributed error terms; $\boldsymbol{u}^{\mathrm{sel}}$ is taken from a standard normal distribution; and, for a given observation, σ takes on a value of one if the observation is not censored and zero otherwise. The simultaneity between supply and demand implies

$$E(\boldsymbol{u}^{\mathrm{S}}Q') \neq 0 \tag{A4}$$

and

$$E(\boldsymbol{u}^{\mathrm{D}}p') \neq 0. \tag{A5}$$

As noted, some variables in $\boldsymbol{X}^{\mathrm{S}}$ do not appear in $\boldsymbol{X}^{\mathrm{D}}$ and vice versa, which enables us to obtain consistent estimates of supply and demand by two-stage least squares estimation once we account for selectivity. To do so, we note that $\boldsymbol{X}^{\mathrm{sel}}$ contains some variables that do not appear in both $\boldsymbol{X}^{\mathrm{S}}$ and $\boldsymbol{X}^{\mathrm{D}}$ (such as the minimum price offered on other routes from the same origin).

We proceed with estimation by first using all of the observations in a probit estimation of equation (A3) to obtain $\hat{\beta}^{\mathrm{sel}}$. We then construct the estimated inverse Mills ratio defined as

$$\hat{\delta}^{\text{sel}} = \frac{\phi(X^{\text{sel}\prime}\hat{\beta}^{\text{sel}})}{\Phi(X^{\text{sel}\prime}\hat{\beta}^{\text{sel}})}, \tag{A6}$$

where ϕ and Φ are the standard normal probability density function and cumulative density function, respectively. We respecify the supply and demand equations by including the estimated Mills ratio to control for the omitted variable that effectively arises from the selection bias (Heckman 1979). Thus, the model becomes

$$\ln p = \varepsilon^{\text{S}} \ln Q + \boldsymbol{X}^{\text{S}\prime}\beta^{\text{S}} + \gamma^{\text{S}}\hat{\delta}^{\text{sel}} + \boldsymbol{u}^{\text{S}} \tag{A7}$$

and

$$\ln Q = \varepsilon^{\text{D}} \ln p + \boldsymbol{X}^{\text{D}\prime}\beta^{\text{D}} + \gamma^{\text{D}}\hat{\delta}^{\text{sel}} + \boldsymbol{u}^{\text{D}}, \tag{A8}$$

and we estimate it by two-stage least squares and report Huber-White standard errors to correct for heteroskedasticity.

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