Efficiency Gain from Mergers: Evidence from the U.S. Railroad Network *

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Abstract

Increased efficiency is generally cited as the primary reason why mergers are good for both consumers and industry, but there is typically little evidence showing the mechanism of cost efficiency following a merger and how it interacts with incentives to raise prices. This paper studies the mechanism of cost efficiency following railroad mergers. Unlike many other industries, metrics of efficiency can be directly observed in railroad transport. First, reduced-form evidence suggests that following a merger, the average shipment price decreases by 9% and that the price effect of merger is 11% where railcars must be switched between two companies. However, the interdependent nature of railroad networks means that merger efficiency cannot be fully understood by comparing individual markets in a simple regression. Therefore, I further estimate a structural model that endogenizes firm pricing, routing, and investment decisions. Counterfactual simulations based on that model decompose the sources of cost efficiency into elimination of interchange cost, consolidation of traffic, and reoptimization of investment.

Keywords: Merger, Cost Efficiency, Railroad, Optimal Transport Network

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1 Introduction

There has been a recent debate about why there is an increase of market concentration in many industries in the United States, where a small number of firms gain a very large share of the market. David et al. (2017) documents an upward trend of market concentration over time, and industries have become more concentrated on average.[1] For example, the literature documents that,[2] in the airline industry, a wave of consolidation happened during a short period of time in the late 1980s; in the telecommunication industry, over 6,000 acquisitions occurred between 1996 and 2006; a dozen global hard-disk manufacturers consolidated into only three in the last 20 years from 1996 to 2015; 190 hospital mergers occurred between 1989 and 1996, and in the dialysis industry, more than 1,200 acquisitions occurred between 1998 and 2010. One explanation for this phenomenon is that there is strong network effect such as Google, Amazon, Walmart, and Federal Express in their sectors. Another explanation is that consumers have become more sensitive to price and quality through globalization and new technologies, hence it results in a "winner takes most" situation.

U.S. freight railroad is no exception. From 1980 to 2005 there was a wave of mergers as the number of Class I railroads has dropped from 39 to 7, and market share of the top four firms has increased from 66% to 94%.[3] Railroad mergers have received a great deal of attention from economists and antitrust enforcement agencies, in part because the freight railroad industry plays a vital role in the U.S. economy. According to Department of transportation, in 2017, railroads are the second largest transport mode in providing freight service, carrying 1,675 billion ton-miles of freight, and accounts for around 30% of total freight transportation. According to the Association of American Railroads (AAR), in 2016 the railroads transported about 40% of intercity ton-miles, more than any other mode of transportation.

One puzzle following these railroad mergers is that although concentration has gone up a lot

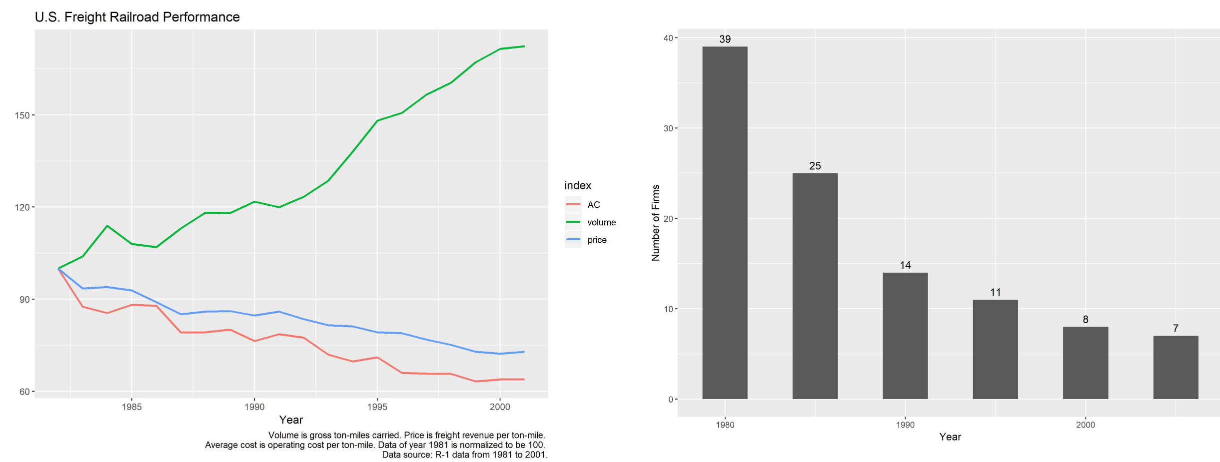
[1]According to David et al. (2017), the finding of increased market concentration is consistent by using multiple measure of market concentration. They measure industry concentration as the fraction of total sales that is accrued by the four largest firms in an industry (denoted CR4) or the fraction of sales accrued by the 20 largest firms (CR20), and the industry's Herfindahl-Hirschman Index. In addition, they also compute the CR4 and CR20 concentration measures based on employment rather than sales.

[2]Here is a short list of literature that documents and analyzes mergers in different industries: Airline: Peters (2006); Telecommunication: Leeper (1999), Jeziorski (2014); Hard-disk: Igami (2017), Igami and Uetake (2016); Hospital: Dafny (2009), Bazzoli et al. (2002), Dranove and Lindrooth (2003); Dialysis: Eliason et al. (2018).

[3]Class I railroads are defined as "having annual carrier operating revenues of $250 million or more in 1991 dollars." According to Association of American Railroads, Class I railroads account for more than 95% of revenues generated in the U.S. freight railroad industry in 2016.

in this industry, prices have decreased steadily. As illustrated in the left panel in Figure 1, from 1980 to 2005, prices per shipment have decreased by 20%, while shipment have doubled. Given there is limited technological change in the studied period,[4] and the railcars we see today are similar to what we would see thirty years ago, we have reasons to suspect there are efficiency gains following these railroad mergers.

Figure 1: U.S. Freight Railroad Performance and Number of Class I Railroads



Source: AAR, Analysis of Class I Railroads Annual Issues

Understanding the mechanism that generates these efficiency gains after a merger is important, because these merger efficiencies are generally cited as the primary reason why mergers are good for both consumers and the industry (Williamson (1968)). Based on the argument of efficiency gain, antitrust enforcement in the railroad industry was relatively lax, and almost every proposed railroad merger received regulatory approval in the studied period.[5] Claimed efficiencies include alleviation of capacity constraints, mileage reductions that the integration of track networks would make possible along major routes, more single-line service, and improved deployment and utilization of equipment (Kwoka and White (1997)). However, there is typically little evidence showing the sources of cost efficiency following a

[4]Until the late 1990s, the vast majority of rail lines in the U.S. still relies on the human crew for complying with all safety rules. One accident that highlights this fact is the Big Bayou Canot rail accident, where a tow of heavy barges collided with the rail bridge and later caused the derailing of an Amtrak train on the CSXT Big Bayou Canot bridge with 47 people killed and 103 more injured. The accident happened partly because no technology was implemented to monitor the real-time condition of tracks and train movements, and the Amtrak engineer was not notified of the collision in time. Positive Train Control system that monitors and controls train movements was required by rail safety law in 2008, but full implementation is still underway and is supposed to be done by the end of 2020.

[5]One exception is the Santa Fe–Southern Pacific merger, which was denied by the Interstate Commerce Commission in 1987. But in 1995, the Santa Fe railroad merged with the Burlington Northern Railroad to form the Burlington Northern and Santa Fe Railway, and the Southern Pacific was bought out by the Union Pacific Corporation the following year.

merger and how it interacts with incentives to raise prices. Considering the scope of mergers that have received regulatory approval, evaluating efficiency gain ex-post is valid and necessary.

The difficulty in studying cost efficiency for a merger is that it is hard to find good metrics of efficiency that are observed before and after a merger. Unlike many other industries, we can observe some of these for railroad transport. The ratio of switching hours to road service hours measures proportion of train hours spent in sorting and switching in railyards. The less time a train spends switching in yards, the more efficient the operation is. Length of haul is another metric of efficiency, because it is more fuel efficient for a train to run a longer distance. I first use Class I Railroad Annual Report R-1 data to provide reduced-form evidence that the ratio of switching hours has decreased by 11.5%, and length of haul has increased by 5.3% after railroad mergers. Then using detailed waybill data, which contains detailed information of a shipment such as name of carrier, point of origin and destination, shipment price, date of shipment, and attributes of shipped commodities, I look at another two metrics of efficiency, number of interchanges and utilization of unit trains, and examine how they change following railroad mergers. Interchange means when railcars need to be switched between two companies. Former Southern Pacific Railroad president Krebs (2018) states "Every time you interchange with another railroad, you add to the cost and delay", and my estimation result suggests interchange cost accounts for 21% of shipping expense on average. Reduced-form evidence suggests number of interchanges reduce significantly after a merger. Last, I look at utilization of unit trains. A unit train is a train in which all railcars carry the same commodity and are shipped from the same origin to the same destination, without being split up or stored en route. The use of unit trains saves time and money by avoiding the complexities and delays that are involved with assembling and disassembling trains at railyards. Reduced-form result suggests that utilization of unit train has increased significantly following railroad mergers.

Because we not only care about costs but also the incentives to raise prices after mergers, I further examine change in prices. The reduced-form results show that on average shipment price decreases by 9%, and price effect is greater for route with interchanges and price decreases by 11% after merger. For other types of route, the price effect of merger is only 6%. I find these price changes occur both for commodities that are mostly transported by rail such as coal, and commodities that are also largely transported by other modes such as electrical machinery. This finding suggests that the price effect does not come from competition from other transportation modes.

However, looking only at individual route is insufficient for understanding mergers in this industry because markets are interdependent in this industry. For instance, it may make sense to consolidate traffic onto more efficient main lines, and it is difficult to understand this motive of consolidation by simply looking at route-level evidence. Therefore, to better understand the sources of cost efficiency and how it interacts with price incentives in an entire railroad network, I propose a structure model by endogenizing pricing, routing, and investment of track maintenance and locomotives decisions of firms. Counterfactual simulations based on that model decompose sources of cost efficiency into elimination of interchange cost, re-optimization of routing and consolidating traffics, and reallocation of resources. The results suggest that elimination of interchange cost is the predominant source, which accounts for 41% of the cost reduction. Network efficiency that comes from routing and consolidation of traffic is also important, which accounts for 33% of the cost reduction. Given that cost efficiency depends on features of the merger such as ownership of networks, I conduct the counterfactual simulations for each merger among the eleven mergers in my studied period, and show how the importance of these three sources change in different mergers. In general, the level of cost efficiency depends on the number of interconnecting services provided by the two merging parties, and it also depends on how traffics can be consolidated between the two merging parties.

Last, I use the model to examine the trade-off between efficiency gain and increased market concentration, and study the implied welfare changes in different geographic markets. On one hand, the degree of overlap between the two networks of the merging parties determine the incremental of market power, because the number of firms providing freight service decreases in the overlapped regions. On the other hand, the topographic of the network and distribution of demand across regions affects how the traffics can be consolidated, hence affect the degree of efficiency gain. By combining these two forces, I show that there is a large degree of heterogeneity of welfare changes in different geographic markets, depending upon the location of each market within the network.

This paper is related to multiple branches of literature. First, the price effects of mergers are extensively studied in the literature. Borenstein (1990) and Kim and Singal (1993) analyze the effects of airline mergers, and Kim and Singal (1993) find that airfares increase by 9.44% on airline routes served by the merging firms. Dafny (2009) evaluates the impact of independent hospital mergers between 1989 and 1996 and finds evidence of sharp increases in rivals' prices of about 40% following a merger. In comparison, my paper finds that on average price decreases by 9% after a railroad merger, and price decreases by 11% for interconnecting routes.

By contrast, the literature on the cost efficiency of mergers is sparse. One good exception is Ashenfelter et al. (2015), the authors use panel scanner data and geographic variation in the U.S. beer industry, and find that the average predicted increase in concentration leads to price increases of 2% but that this is offset at the mean by a nearly equal and opposite efficiency effect. Some other paper includes McGuckin and Nguyen (1995), which use an unbalanced panel of plants from the Longitudinal Research Database to examine the relation between ownership changes and productivity growth, and they find that plant productivity growth is positively related to a change in ownership.[6] My paper contributes to the literature on the cost efficiency by not only providing reduced-form evidence on improvement of metrics of efficiency and price reduction after mergers, but also uncovering the mechanism of efficiency gain and how it changes with features of the merger through a structural model.

The existing literature on the freight railroad industry examines multiple aspects of the effect of deregulation and mergers. Casavant et al. (2012) study the rail rate structure for agricultural commodities and compare it with rates for other commodities. Friebel et al. (2014) investigate the restructuring of the U.S. freight railroad after deregulation and document both network reductions (the abandonment of redundant rail lines) and labor downsizing after mergers. Prater et al. (2012) examine the sufficiency of rail freight competition and the effects of intramodal competition on rail rates. Chapin and Schmidt (1999) find that merged firms are larger than efficient scale. McCullough (2005) documents that changes in output composition along with line abandonment and a significant degree of industry consolidation lead to longer haul lengths and higher traffic densities. Event studies on special merger cases in the literature also provide explanations on the origination of merger efficiency. Kwoka and White (1997) study the Union Pacific–Southern Pacific merger, and Pittman (2009) examines the Santa Fe and Southern Pacific merger proposal. However, most of the literature studies change of some aggregate cost or price index, or examine merger effect by looking at

[6]Given the fact that direct metrics of efficiency is hard to define and measure, some other literature calculates cost savings through merger simulations. Jeziorski (2014) uses a dynamic oligopoly model to estimate the cost savings resulting from mergers in the U.S. radio industry, with the estimated resulting savings amounting to $1.2 billion per year. Pesendorfer (2003) examines mergers in the U.S. paper and paperboard industry, comparing equilibrium investment decisions before and after the merger wave and finding that total welfare increases by $583.5 million as a result of the mergers.

individual markets in a regression. Virtually no research looks at merger effect by considering the interdependent nature of railroad networks. My paper contributes to filling in this gap by considering the interaction of cost efficiency and incentives to raise prices in railroad network, and understanding welfare implications in different geographic markets.

I jointly model firm pricing, investment, and routing decisions by employing an optimal transport network method, which is similar to the method used in Fajgelbaum and Schaal (2017). I differ from their paper by adding competition and routing choices of each railroad company. My research is also broadly related to other papers that use spatial analysis in understanding distributional impact of economic activities, such as Buchholz (2015), Donaldson (2010), and Brancaccio et al. (2017).[7] In both Buchholz (2015) and Brancaccio et al. (2017), the network interdependence comes from the fact that once I drop somebody off, I end up in the location where I drop them off for future ride, which is more limited than what I am considering in my paper here.

The remainder of the paper is organized as follows. Section 2 describes the industry background and explains sources of cost efficiency. Section 3 outlines the three datasets used in the paper. Section 4 provides reduced-form evidence on how shipment prices and metrics of efficiency change after railroad mergers. Section 5 constructs the structural model of firm pricing, routing and investment decisions in a rail network. Section 6 shows the estimation results and assesses the validity of the model. Section 7 shows the counterfactual simulations that decompose the sources of cost efficiency, and explains why there is tremendous heterogeneity of welfare changes after mergers in different geographic markets. Section 8 concludes.

2 Industry Background

2.1 Deregulation and Background

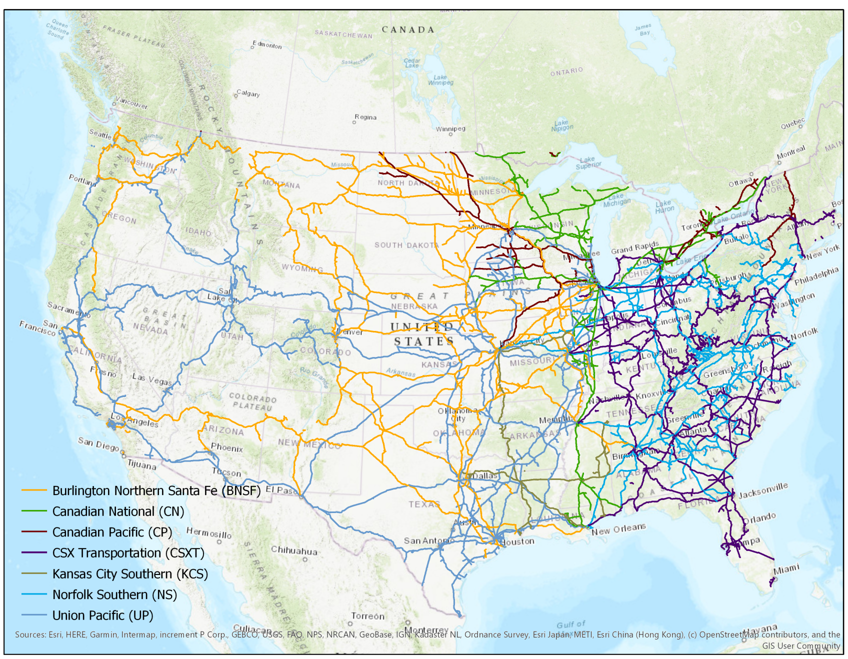
As explained in Section 1, the freight railroad industry plays a vital role in the U.S. economy. The railroad industry, however, has not always enjoyed financial success, and in recent decades it has undergone a remarkable evolution. Following a cycle of decline that began

[7] Buchholz (2015) analyzes the dynamic spatial equilibrium of taxicabs and shows how common taxi regulations lead to substantial inefficiencies; Donaldson (2010) uses archival data from colonial India to investigate the impact of India's vast railroad network; Fajgelbaum and Schaal (2017) study optimal transport networks in spatial equilibrium; and Brancaccio et al. (2017) use detailed data on vessel movements and shipping contracts to study world trade costs and trade flows.

in the 1960s, many freight rail carriers faced liquidation.[8] At the start of 1980s, the U.S. railroad industry accounted for only a small proportion of total ton-miles of freight, around 20%, and carrying less than pipelines.

In response, a series of laws to deregulate the industry followed in the years 1973–1980. Among them, the 1980 Staggers Act formally deregulated the industry, by offering railroad companies much greater pricing and operating freedom. The deregulation sparks a wave of mergers of railroad companies: from 1980 to 2005, the number of Class I railroads decreased from 39 to 7. Figure 2 illustrates the network of current seven Class I railroads: the Burlington Northern and Santa Fe railway (BNSF) competes with the Union Pacific railway (UP) in the west, the CSX Transportation (CSXT) and the Norfolk Southern railway (NS) competes in the east. Two Canadian Class I railroads the Canadian Pacific railway (CP) and the Canadian National railway (CN) connect freight shipment between Canada and U.S., and have presence in central United States near Chicago, the railroad capital of the United States. Last, the Kansas City Southern railway (KCS) locates in the south and connects freight shipment between Mexico and the United States.[9]

Figure 2: U.S. Class I Railroads



[8]In 1970 the nation's largest railroad Penn Central declared bankruptcy along with a dozen other northeastern railroads. See Grimm and Winston (2000) and Gallamore and Meyer (2014) for more discussions.

[9]Figure A.2 and A.3 plots the total ton-miles of freight carried by mode and how it changed from 1980 to 2011, appendix A.4 provides details of regulation changes, and appendix A.1 shows a complete history of railroad mergers.

Since the mergers, the U.S. freight railroad industry has enjoyed a renaissance, becoming not only self-sustaining but one of the most efficient railroad systems in the world. Proportion of total ton-miles of U.S. freight carried by rail increased after the deregulation of 1980. According to Department of transportation, in 2017, railroads are the second largest transport mode in providing freight service in the United States. Railroads carry 1,675 billion ton-miles of freight, accounting for 30% of total freight transportation.

A majority of the freight revenues in the U.S. freight railroad industry are generated by so called Class I railroads. According to AAR, in 2012, the seven Class I railroads generate $67.6 billion freight revenues, which accounts for around 95% of the total freight revenues generated by railroad transport.[10] In this paper, I focus on mergers of Class I railroads.

The U.S. railroad industry ships various types of commodities, but the majority of carloads are generated by bulk shipments like coal, chemical, and farm products. According to AAR, in 2012, the top four commodities measured by share of total tonnage are coal (37%), chemicals (10%), non-metallic minerals (9%), and farm products (8%). If we look at share of revenues, each of these four commodities accounts for 17% (coal), 14% (chemicals), 5% (non-metallic minerals), 8% (farm products) of total freight revenues. Coal has been the most important commodity in freight railroad industry ("King Coal"), but the revenues generated by shipping coal are decreasing. Instead, the carloads of intermodal shipping[11] (Misc. mixed shipments such as containers) are increasing nowadays, and intermodal shipment accounts for 13% of total freight revenues in 2012.[12]

2.2 The Story of Train 9-698-21

To better explain sources of cost efficiency and my model in the later sections, here I introduce three concepts of railroading: interchange cost, interconnecting route versus competing route, and investment decisions regarding track maintenance and locomotives. I use the example of train 9-698-21 to explain these three concepts.[13]

[10] The rest of the revenues are generated by regional and short lines. Check Appendix A.2 for more details on regional and short lines.

[11] Intermodal is the use of two modes of freight, such as truck and rail.

[12] Check Appendix A.2 for more details on carloads originated by different types of commodities.

[13] Train 9-698-21 runs from Birmingham, Alabama to Los Angeles. To explain the concepts, I focus on the section between Los Angeles and Memphis, Tennessee. The original story provides more details on why interchange is costly and why coordination is a problem when two railroads are involved in a shipment.

Figure 3: Story of train 9-698-21

Source: Original story from *Trains* magazine "Twenty-four hours at Supai Summit"

Train 9-698-21 went from Birmingham to Los Angeles, and it begun with Burlington Northern via the Avard gateway in summer 1994. This was before the Burlington Northern railway and the Atchison, Topeka and Santa Fe railway discussed merging. The main customers of train 9-698-21 are UPS and J.B. Hunt, and the train is an express freight train and initiated to "reach downtown L.A. in time for UPS to deliver the next morning". The contract is for Santa Fe to be given haulage rights over BN to Memphis and Birmingham. Haulage rights means Santa Fe sold the service, then paid BN to run the trains east of Avard. However, according to Rollin Bredenberg, BNSF's vice president of transportation at that time, everything has not gone right with 9-698 though:

> *"It was very unreliable under the haulage agreement, pre-merger," reports Bredenberg, "BN's internal measurement of how well they ran trains did not include the performance of the Santa Fe haulage trains, so you can guess what happened." In an interview last year, Krebs (chairman of Santa Fe railway) said he finally had to tell key customers such as Hunt that they were free to go elsewhere until Santa Fe and BN could get their acts together.*

First, interconnecting and competing routes are both shown in this example. In Figure 3, the route from Los Angeles to Memphis is an example of an interconnecting route, because the train needs to ride both Santa Fe and Burlington Northern tracks. If a shipment originates in Claremore, Oklahoma, and is bound for Memphis, the owner has a choice of riding the Union Pacific or the Burlington Northern line, which is an example of competing routes. Second, this example shows the micro-foundation of interchange cost. When train 9-698-21 arrives at Avard gateway in Oklahoma, it needs to exchange crews and rolling stocks (railcars and locomotives) between the Burlington Northern railway and the Santa Fe railway. However, because BN and SF have different priorities over this train, it usually results in delays to finish this process. Moreover, check the condition of railcars and exchange rolling stocks take time and efforts, which further add to the interchange cost.

Last, I want to introduce the definition of investment in track maintenance and locomotives here. If more locomotives are available in the Avard gateway, the waiting time of train 9-698-21 will be shortened to finish the interchange. Meanwhile, adequate and constant maintenance of tracks and rollings stocks is essential for railroad operation, and more frequent track maintenance increases route efficiency. For example, according to a Bloomberg report,[14] a New Jersey Transit safety project costs more than $320 million, but the agency still fell behind on rail maintenance, let its ranks of train engineers dwindle and triggered a federal operations audit. To perform regular maintenance, railroad companies need to operate track evaluation cars to evaluate track geometry, performance based track geometry, rail wear etc and other things. Then the track evaluation cars will report the data for capital and maintenance planning. Railroad companies decide on the frequencies of track evaluation in each region. In our example of train 9-698-21 here, if the railroad companies invest more in the route of Los Angeles to Memphis by allocating more locomotives and conducting track maintenance more frequently in this region, the route efficiency from Los Angeles to Memphis will increase.

2.3 Sources of Cost Efficiency

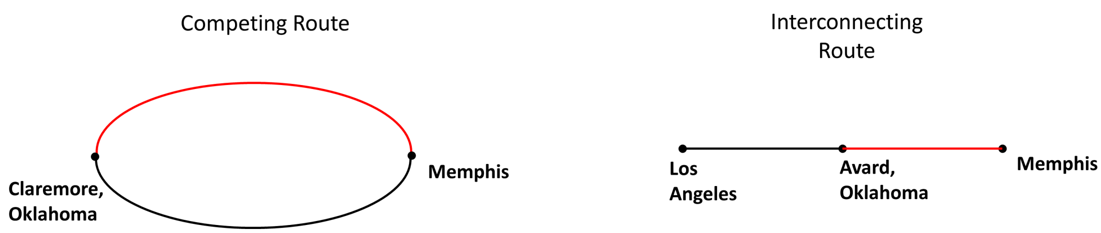
I categorize sources of cost efficiency into route efficiency and network efficiency. Route efficiency is achieved by each individual market after merger and does not depend on other markets. Network efficiency comes from the interdependent nature of railroad networks and depends on the topography of network and locations of each market.

Route Efficiency

There are two types of individual routes: interconnecting route and competing routes, as illustrated below:

Figure 4: Route Efficiency

[14]https://www.bloomberg.com/news/articles/2018-10-18/how-nj-transit-s-lifesaving-rail-task-dragged-while-cost-doubled



In the case of competing routes, both merging parties provide freight service serving the market from o to d before the merger. After the merger, firms can consolidate resources to one of the parallel lines and abandon[15] the other to achieve greater cost efficiency. In other words, firm can get rid of redundant rail lines by combining resources of the two merging firms. The downside is that market power increases after merger in the case of competing routes.

By contrast, in the case of interconnecting route, firms remove interchange costs following a merger, but their market power does not change. Based on the story of train 9-698-21 in Section 2, interchange is costly. Interchange cost will be eliminated following a merger. Besides the evidence provided in the story, I interviewed with Terminal Superintendent of Conrail and Terminal Operations manager of Lake State Railway Company (a short line that interchanges a lot with CSXT and NS), they confirm that interchange usually means more delays and higher operational cost, and they provide more explanations on why interchange is costly.[16]

Network Efficiency

Given that markets are interdependent in the railroad industry, firms can achieve greater cost efficiency by optimizing over routing decision and consolidating traffic. The Chief Operating Officer, Cindy Sanborn of CSXT states that "An essential feature of that operating plan is to consolidate traffic over a smaller number of efficient, high-volume routes."[17] The idea of achieving greater cost efficiency by consolidating traffics is also supported by the former CEO of the Southern Pacific railway Krebs (2018) and the former CEO of the Canadian National railway Harrison (2005).

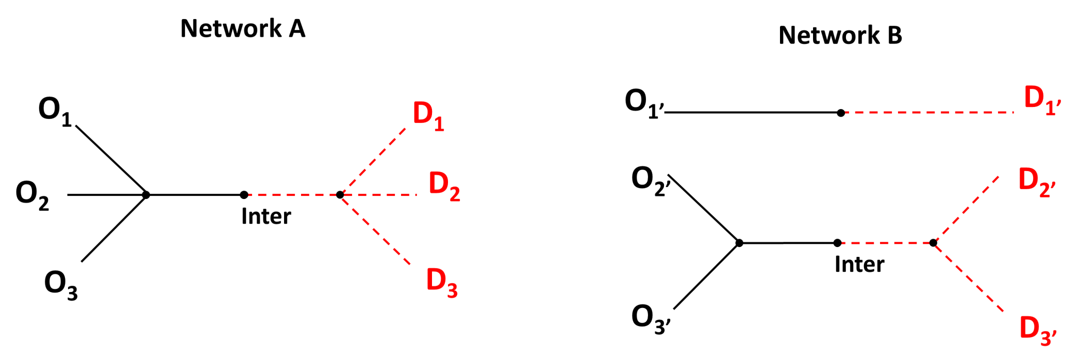
[15] In my model firms cannot physically abandon rail lines, but they can choose where to allocate the resources, which is denoted as investment in track maintenance and locomotives. Firms are allowed to allocate 0 resources to a rail line.

[16] Check more details of the interviews in appendix A.3

[17] Ex Parte No. 711 (Sub-No.1) Reciprocal Switching, Opening Comments of CSX Transportation INC.

To elaborate how does topography of network affect network efficiency and cost efficiency of individual markets after a merger, Figure 5 depicts two networks: both network A and network B consist of three individual routes. Firm 1 owns all black lines and firm 2 owns all red lines, hence all three routes are interconnecting routes and are jointly served by firm 1 and firm 2. I further assume that for each individual route, such as route O_1 to D_1, the travel distance from O_1 to D_1 is exactly the same in network A as the travel distance from $O_{1'}$ to $D_{1'}$ in network B, and the total mass of demand of market O_1 to D_1 in network A is the same as total mass of demand of market $O_{1'}$ to $D_{1'}$in network B. Therefore, the only difference between these two networks are the topography of the network.

Figure 5: Network Efficiency



If we examine merger effect by only looking at individual markets, we should expect route O_1 to D_1 and route $O_{1'}$ to $D_{1'}$ have the same level of efficiency gain after merger, because the market characteristics of these two individual markets are exactly the same. However, given the topography that is different, resources will be consolidated more intensively into network A than network B after merger. Therefore, route O_1 to D_1 will have greater efficiency gain than route $O_{1'}$ to $D_{1'}$ after merger. That being said, cost efficiency depends on the topography of the network, network ownership of the two merging parties, and the location of each market within the network.

3 Data

I use three main datasets to document the changes in cost efficiency following railroad mergers. The confidential version of the Carload Waybill Sample provides detailed information on shipment price and corresponding shipment attributes; the Class I Railroad Annual Report R-1 dataset contains information on firm attributes and aggregate operational statistics; and a Department of Transportation database provides geographic information on all U.S. rail lines and their associated railroad companies. I also observe the ancestry of each rail line, which enables me to trace back to any given time between 1984 and 2010 and reconstruct the rail network for any particular period.

The Carload Waybill Sample is a stratified sample of carload waybills for all U.S. rail traffic submitted the to Surface Transportation Board[18] by those rail carriers terminating 4,500 or more revenue carloads annually. The data contain detailed shipment information on such attributes as commodities carried, total billed weight, equipment used, participating railroads, and origin, destination, and interchange locations (BEA Economic Areas) of each load. Railroad companies conduct point-on-point pricing, and the price information I observe is at firm-origin-destination level. I obtain the confidential version of this dataset, which has price information and location of origins and destinations, from 1984 to 2010. Table 1 shows the summary statistics of variables used in the reduced-form analysis. The median of price per ton is $38, and the median of travel distance is 854 miles, which converts into a price of 4 cents per ton-mile. The number is comparable to the price per ton-mile reported by AAR in its annual reports.[19]

Table 1: Summary Statistics of Covariates

	Mean	Std. Dev.	25th Percentile	Median	75th Percentile
Price Per Ton ($)	$ 62	$ 3,736	$ 19	$ 38	$ 70
Freight Revenue ($)	$ 14,369	$ 50,427	$ 762	$ 1,441	$ 3,645
Billed Weight (ton)	983	3,222	17	26	106
Number of Carloads	9	27	1	1	1
Travel Distance (miles)	1,045	773	404	854	1,647
Waybills (Carrier-Origin-Destination-Date)				12,113,581	

Source: STB, Carload Waybill Sample

Table 2 reports the descriptive statistics of selected commodities that are mainly shipped by rail. We can see that a large number of waybills involve shipment of coal. Meanwhile, railroad carries a lot of bulk shipment such as chemicals, agricultural products, and construction ma-

[18]The Surface Transportation Board (STB) is an independent adjudicatory and economic-regulatory agency charged by Congress with resolving railroad rate and service disputes and reviewing proposed railroad mergers. STB is created on January 1, 1996 by the ICC Termination Act of 1995, the Board is the successor to the former Interstate Commerce Commission.

[19]In year 2001, according to AAR the average price per ton-mile in the U.S. is 2.32 cents.

terials such as concrete and clay.[20] Table 2 also shows descriptive statistics of car ownership category. There are three categories of car ownership: privately owned, railroad owned, or trailer train. If a shipper uses its own railcars in a shipment (privately owned), railroad companies will give the shipper a discount. Trailer train is mostly used when shipping containers.

Table 2: Descriptive Statistics of Commodity Types and Car Ownership Category

	Number of Waybills	Percentage
Commodities		
Field Crops	466,584	3.85%
Coal	1,002,580	8.28%
Nonmetallic Minerals	371,109	3.06%
Lumber or Wood Products	487,386	4.02%
Chemicals	635,119	5.24%
Petroleum or Coal Products	158,794	1.31%
Clay, Concrete, Glass or Stone Products	323,923	2.67%
Primary Metal Products	354,360	2.93%
Containers	660,513	5.45%
Car Ownership Category		
Privately Owned	5,349,791	44%
Railroad Owned	3,621,221	30%
Trailer Train	2,202,838	18%
Non-Categorized	939,731	8%
Waybills (Carrier-Origin-Destination-Date)	12,113,581	

Source: STB, Carload Waybill Sample

Second, every Class I railroad operating within the United States must submit the Class I Railroad Annual Report R-1. This dataset contains information on financial statistics (income statement, balance sheet, total operating expense breakdown etc.), wage and equipment expenditures, and summary of operations (traffics, operating statistics etc). I use the dataset to document operational changes before and after mergers. The data ranges from 1981 to 2001.

I obtain geographic information from the Federal Transit Administration. The dataset contains the coordinates of rail lines and rail stations and provides information on the affiliation of each rail line and its ancestry, which permits me to geocode and reconstruct the rail network at any time between 1984 and 2010. I use the reconstructed network in the structural model to calculate the optimal routing of each origin-destination pair and estimate the transportation cost.

[20] For full information of commodities shipped by rail, check Table A.3.

4 Reduced-form Evidence

I first examine price effect of mergers by using detailed waybill data. Through comparing shipment prices before and after mergers, I show that on average shipment price has decreased by 9.4%. I further decompose these price effects by route types. As a robustness check, I examine these price changes for commodities that are mostly transported by rail such as coal, and commodities that are largely transported by other transportation modes such as food and kindred product. The robustness results show that these price effects are not driven by competition from other transportation mode like trucking. To better understand the sources of these price changes, I examine four measures of efficiency, which includes two aggregate operational statistics and two shipment attributes. The two aggregate operational statistics are the ratio of switching hours to road service hours and average length of haulage. The two aggregate operational statistics come from the Class I Railroad Annual Report R-1, which is data is at firm-year level. The two shipment attributes are number of interchanges and the use of unit trains. The shipment attributes are obtained from the confidential Waybill data, which is at carrier-origin-destination-date level. By examining all four metrics of efficiency, the results provide evidence of efficiency gain after mergers.

4.1 Price Changes

The regression model studying change in price is specified as:

$$\log P_{iodt} = \mu_{od} + \gamma_i + \lambda_t + \delta_1 D_{iod,t} + X'_{iodt}\beta + \epsilon_{iodt}$$

where: γ_i = firm fixed effect

λ_t : year fixed effect

μ_{od} : route fixed effect (from origin o to destination d)

$D_{iod,t}$: indicator of if a merger has happened to firm i that carries shipment from o to d before or equal to time t

X_{iodt} : shipment attributes: commodities carried, ownership of railcars, total billed weight

Table 3 shows the estimation result of price effect of mergers. The result suggests that on average a railroad merger reduces the shipment price by 9.4%. By opening up the mergers and examining each individual merger, I find that the price effect is largely consistent across individual mergers.[21] Then, to further decompose the effect of railroad mergers on price changes by different route types, I interact the merge dummy with three route types: interconnecting, competing, and non-interconnecting, noncompeting. As explained in section 2, an interconnecting route is a route in which two firms conduct interchange and finish the shipment jointly. Results in column 2 of Table 3 show that the interconnecting routes have the largest price reduction among all route types, with price decreasing by 11% after mergers. In comparison, the other route types have a price reduction of about 6.5% following mergers.

Table 3: Effect of Mergers on Price Change (by Route Types)

	(1) Log Price	(2) Log Price
Indicator of Merger	-0.0935***	
	(0.0142)	
Indicator of Merger × Indicator of Interconnecting Route		-0.107***
		(0.0178)
Indicator of Merger × Indicator of Competing Route		-0.0690***
		(0.0180)
Indicator of Merger × Non-interconnecting, Noncompeting Route		-0.0641***
		(0.0171)
N	12,110,107	12,110,107
Firm FE	Y	Y
Year FE	Y	Y
O-D Route FE	Y	Y
O-D Route Cluster	Y	Y

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Source: Surface Transportation Board, Carload Waybill Sample

However, there might be concerns that these price effects are driven by competition from other transportation modes such as trucking, not from the effect of railroad mergers. Because comparable origin-destination-level shipment data for trucking is lacking, I cannot directly run the price regressions by controlling for competition of trucking. Instead, to address this concern, I examine the price effects of mergers for different types of commodities.

[21] Table A.4 shows the robustness check results by looking at change of prices following each railroad merger.

The argument is that the shipment of different types of commodities faces different levels of competition from other transportation modes. Therefore, if the price effects are driven by changes in other transportation modes, the price effects should be greater for commodities facing higher competition from other modes of transport. Table 4 summarizes the two commodities used in this analysis: the Commodity Flow Survey (CFS) of 2012 shows that coal is mainly shipped by railroads. Only 1.5% of coal is shipped by trucking, and 91.8% is shipped by rail. In comparison, food or kindred products are largely shipped by trucking. 62.37% of food or kindred products is shipped by trucking, and only 17.63% is shipped by rail.

Table 4: Summary Statistics of Coal and Food Shipment

	Coal (STCC 11)	Food or kindred products (STCC 20)
Total Ton-Miles in 2012 (Truck)	1.5%	62.37%
Total Ton-Miles in 2012 (Rail)	91.8%	17.63%

Source: U.S. Census Bureau, Commodity Flow Survey

Table 5 shows the estimation results of price effect of mergers for coal and food or kindred products respectively. The results show that railroad mergers have a significantly negative price effect for both coal and food or kindred products. Moreover, the price effect of mergers is greater for coal. This is contrary to the prediction of the hypothesis that the price effect is driven by changes in other transport modes.

The estimated price effect is comparable to other analysis of freight railroad mergers. In the Surface Transportation Board analysis of the Union Pacific and Southern Pacific merger, the shipment price of coal was found to decrease by 11%, and that of other commodities by 6% after the merger. The price effect of mergers found in the U.S. freight railroad industry is larger than the price effect of mergers found in some other industries. For example, Ashenfelter et al. (2015) find that the estimated price reduction caused by merger efficiency is 2%. In comparison, I find a 9.4% overall shipment price reduction, and a 17.9% average price reduction for coal shipment, which suggests that cost efficiency following mergers is very important in this industry.

Table 5: Effect of Merger on Price Change (by Commodities)

	(1) Log Price (Coal)	(2) Log Price (Food or Kindred Products)
Indicator of Merger	-0.179***	-0.052***
	(0.028)	(0.014)
Log Billed Weight	-0.030	-0.212***
	(0.020)	(0.010)
Ownership of Railcar (Private)	-0.096***	-0.132***
	(0.027)	(0.008)
Ownership of Railcar (Trailer Train)	-0.021	-0.144***
	(0.071)	(0.016)
N	1,002,552	882,066
Firm FE	Y	Y
Year FE	Y	Y
O-D Route FE	Y	Y
O-D Route Cluster	Y	Y

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Source: Surface Transportation Board, Carload Waybill Sample

As a robustness check of the price effect of mergers, I run the price regression for each type of commodity, and the results show that price reduction following railroad mergers is consistent across different types of commodities. If we look particularly at commodities that are largely shipped by rail, such as coal, chemicals, and construction materials (clay, concrete, etc.), there is a large and significant price reduction following railroad mergers.[22]

4.2 Evidence from Aggregate Operational Statistics

To better understand the sources of price changes, and provide evidence for efficiency gain after mergers, I further examine four metrics of efficiency and how they change before and after mergers. I first look at the Class I Railroad Annual Report R-1 data, and examine the change of average length of haulage and total switching hours after mergers. The ratio of switching hours to road service hours measures proportion of train hours spent in sorting and

[22] Results are in Appendix A.5 and Table A.5.

switching in railyards. The less time a train spends switching in yards, the more efficient the operation is. Length of haul is another metric of efficiency, because it is more fuel efficient for a train to run a longer distance.

I run two types of regressions to evaluate the effect of mergers on aggregate operational statistics:

$$y_{it} = \gamma_i + \lambda_t + \delta_0 \cdot D_{i,t} + \epsilon_{it}$$
$$y_{it} = \gamma_i + \lambda_t + \sum_{k=-3}^{T=2} \delta_k \cdot \Delta_{i,t+k} + \epsilon_{it}$$

where: y_{it} : ratio of switching hours to road service hours of firm i at time t, or average length of haulage of firm i at time t

γ_i : firm fixed effect, λ_t : year fixed effect

$D_{i,t}$: indicator of if a merger has happened to firm i before or equal to time t

$\Delta_{i,t}$: indicator of if a merger happens to firm i at time t

The lagged terms incorporated in the second specification are used to examine the pre-trend of changes before mergers.

Table 6 shows the results. In column 1, on average a merger results in an 11.5 percentage point decrease of the ratio of switching hours to road service hours. The median value of the ratio is 0.735, therefore, a 11.5 percentage point decrease of the ratio is equivalent to a 15% decrease of switching to road service hours. Column 3 of Table 6 does not show a pre-trend of reduction in the ratio of switching hours to road service hours before the mergers. As a robustness check, I examine the merger effect for each merger case. The results in column 2 of Table A.1 show that in general mergers still generate a significant reduction of the ratio of switching hours to road service hours. However, the estimated effect varies among mergers, because the potential to reduce switching hours depends on the network size and network structure of each merging railroad. For some merger, the ability to re-optimize network operation and reduce switching hours is limited. In section 5, I will jointly consider the pricing decision and operation decision in a railroad network, and use the detailed Waybill data to uncover the exact relation between network structure and efficiency gain.

Column 2 of Table 6 shows the effect of mergers on the average length of haulage. The results indicate that on average a merger results in a 5% increase in haul length. Column 4 of Table 6 indicates that there is no pre-trend of increase in the average length of haulage before mergers. The merger effect is significantly positive but small right after the merger and becomes larger one year later, which may be because it takes time for different railroad companies to integrate their networks after the merger. As a robustness check, I also look at the merger effect case-by-case. The robustness check confirms that in general there is an increase of average length of haulage after mergers, and shows that small companies have a substantial increase in average length of haulage after being acquired by a large company.[23]

Table 6: Effect of Merger on Metrics of Efficiency

	(1) Ratio of Switching Hrs to Road Service Hrs	(2) Log Average Length of Hauling	(3) Pre-Post Ratio of Switching Hrs to Road Service Hrs	(4) Pre-Post Log Average Length of Hauling
Indicator of Merger	-0.115**	0.052**	-0.068**	0.053*
	(0.051)	(0.023)	(0.024)	(0.026)
1 Year After Merger			-0.065*	0.147***
			(0.032)	(0.040)
2 Years After Merger			-0.027	0.060**
			(0.032)	(0.028)
1 Year Prior Merger			0.049*	0.045
			(0.026)	(0.028)
2 Year Prior Merger			0.021	0.040
			(0.022)	(0.028)
3 Years Prior Merger			0.055*	0.027
			(0.030)	(0.026)
Observations	208	208	208	206
Year FE	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y
Firm Cluter	Y	Y	Y	Y

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: AAR, Analysis of Class I Railroads Annual Issues

In brief, analysis of aggregate operational statistics suggests that on average railroad mergers result in a 15% decrease in the ratio of switching to road service hours, and a 5% increase in the average length of haulage. However, there are certain limitations to studying the efficiency gain by looking only at firm-level aggregate statistics. The firm-level statistics cannot not reveal the details of efficiency gain of route operations. Especially in the case of a large railroad company acquiring a small railroad company, there may be efficiency gain in

[23] Results of robustness check are in Appendix A.5.

a portion of the network, but the outcome might not be revealed in the firm-level statistics because the acquired company is small. To solve these problems, I use the Confidential Waybill data to study the change of shipment attributes at finer scale.

4.3 Evidence from Shipment Data

Here I use detailed waybill data to examine number of interchanges and use of unit trains. A unit train is a train in which all railcars carry the same commodity and are shipped from the same origin to the same destination, without being split up or stored en route. The use of unit trains saves time and money by avoiding the complexities and delays that are involved with assembling and disassembling trains at railyards.

Former Southern Pacific Railroad president Krebs (2018) states "Every time you interchange with another railroad, you add to the cost and delay." Following this statement, combined with other descriptive evidence provided in Section 2, I propose that the more interchanges there are on a route, the higher the operational cost will be in carrying a shipment. Hence, reducing the number of interchanges will be a clear sign of efficiency gain from a merger. Table 7 shows the change in the number of waybills containing interchanges by comparing the numbers two years before and two years after each merger. The result shows a clear reduction in the number of waybills with interchanges following railroad mergers. For example, the percentage of waybills with interchanges decreases from 27.2% to 18.5% following the merger of the Burlington Northern and the Santa Fe railways, and the percentage of waybills with interchanges decreases from 50.7% to 30.3% following the merger of the Southern Pacific and Union Pacific railroads. The only exception is the merger of the Illinois Central with the Canadian National, where the percentage of waybills with interchanges increases from 44.4% to 51.5%. One explanation is that because the Canadian National is a Canadian Class I freight railway, a large fraction of the Canadian National's business in the United States involves interchanging with other large U.S. railroads, such as the Burlington Northern Santa Fe, Union Pacific, CSX Transportation, and Norfolk Southern.

Table 7: Comparing Number of Interchanges Before and After Mergers

	Number of Waybill with Interchange			Percentage of Waybill with Interchange		
	t-2	t+2	Difference	t-2	t+2	Difference
SBD	35,588	29,152	-6,436	50%	39%	-11%
BNSF	23,511	21,456	-2,055	27%	18%	-9%
LA	4,478	4,530	52	82%	67%	-14%
MSRC	3,614	3,875	261	74%	71%	-4%
IC	19124	11678	-7,446	44%	51%	7%
CNW	18,273	15,123	-3,150	51%	28%	-23%
MKT	8,072	7,807	-265	52%	48%	-4%
DRGW	8,543	8,848	305	86%	84%	-2%
SP	57,053	41,665	-15,388	51%	30%	-20%
SSW	14,803	19,565	4,762	85%	81%	-4%
WC	4,534	3,750	-784	50%	44%	-6%

Source: Surface Transportation Board, Carload Waybill Sample

Another efficiency measure is use of unit trains in carrying shipment. Table 8 shows the number of waybills with unit trains before and after each merger. I focus on coal shipments because unit trains are widely used only for such bulk commodities as coal, agricultural products, and petroleum, and because coal is the single largest commodity per revenue share of railroads.[24] Table 8 suggests that following most of the mergers, the number of waybills using unit trains increases. There is some heterogeneity in the change of number of unit trains because coal shipments occur only in certain geographic markets. Railroad companies conduct business in diverse geographic markets, and the flexibility of switching to unit trains varies among companies and markets. For example, Louisiana and Arkansas Railway (LA), Wisconsin Central Railway (WC), and MidSouth Rail Corporation (MSRC) have very few coal shipments, so there is no large increase of unit trains for those mergers. Moreover, the use of unit trains depends on geographic conditions, and therefore the total number of unit trains may not increase proportionally with respect to total shipments.

[24]For more on commodity share, see Appendix A.2.

Table 8: Comparing Usage of Unit Trains Before and After Mergers (Coal Shipment)

	Number of Waybill with Unit Train			Percentage of Waybill with Unit Train		
	t-2	t+2	Difference	t-2	t+2	Difference
SBD	2,562	4,404	1,842	19.4%	48.0%	28.6%
BNSF	7,079	8,195	1,116	86.1%	89.3%	3.3%
LA	384	333	-51	95.0%	96.8%	1.8%
MSRC	0	0	0	0.0%	0.0%	0.0%
IC	1,449	1,496	47	73.3%	98.6%	25.4%
CNW	3,371	5,045	1,674	94.2%	92.7%	-1.5%
MKT	1,248	1,518	270	95.9%	94.6%	-1.3%
DRGW	307	571	264	65.3%	79.2%	13.9%
SP	5,001	6,709	1,708	91.5%	90.8%	-0.6%
SSW	131	313	182	90.3%	89.2%	-1.2%
WC	236	66	-170	75.2%	46.2%	-29.0%

Source: Surface Transportation Board, Carload Waybill Sample

In this section, I show that prices decrease after mergers, and the price effect is greater for inter-connecting routes. To understand the sources of price changes, I examine four metrics of efficiency and the results show efficiency gain after mergers.

Examining individual routes only is insufficient for understanding mergers in this industry, however, because origin-destination railroad markets are interdependent. Furthermore, in this networked industry it is hard to find a clean control group for performing a difference-in-differences analysis. Efficiency changes in one part of the network will affect the routing and optimization problem of the whole network, thereby affecting the efficiency in another part of the network. To examine the mechanism of cost efficiency following railroad mergers, I therefore build a structural model to capture firms' endogenous decisions of routing, pricing, and investment in track maintenance and locomotives.

5 Model

In the model, I define a market as an origin-destination pair. Firms provide either single-line service or joint-line service to serve a market. Single-line service means that the shipment is carried by only one railroad firm, and joint-line service means that the shipment is carried by two railroad firms and an interchange is involved. Each firm owns a network, and each firm makes three decisions. First, firms choose prices for the markets that they serve, conditional on their perceived cost of operating there. For interconnecting routes, I assume that the firm that serves the joint-line from the origin will make the pricing decision, incur the interchange cost, and compensate the other firm based on its transportation cost. Second, firms decide how to allocate infrastructure investment in their network. Third, firms make routing decisions for the transportation service demanded in each market. Firms make these three decisions simultaneously and compete in price. On the demand side, I assume a fixed amount of commodities needs to be shipped in each market. Consumers choose between railroad firms based on shipment price and firm characteristics. Consumers also face an outside option, which is shipping by trucks. In the subsections below, I will explain how I model demand and firm's problem in details.

5.1 Definition of Network

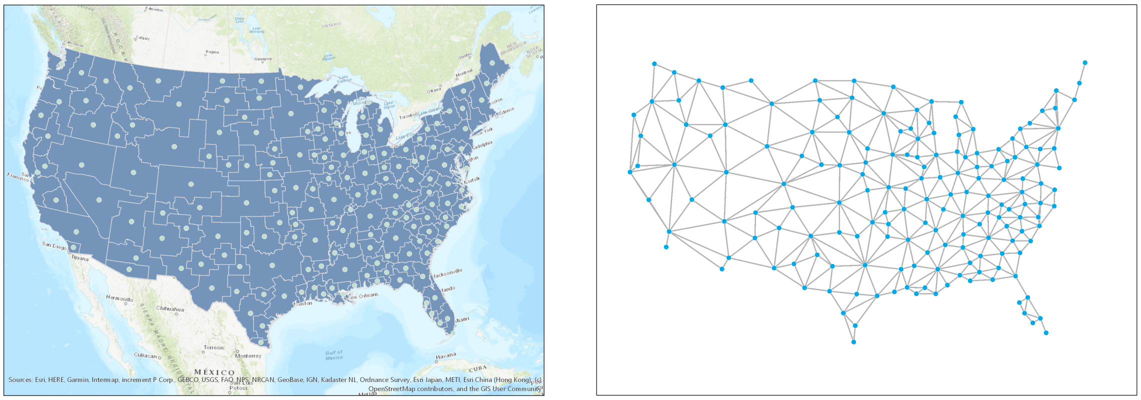
Following Galichon (2016), we define a network $\mathcal{N}$ as a directed graph $(\mathcal{Z}, \mathcal{A})$, where $\mathcal{Z}$ is a set of nodes and $\mathcal{A}$ is a set of arcs $\mathcal{A} \subseteq \mathcal{Z}^2$ which are pairs (x, y) where $x, y \in \mathcal{Z}$. In the model I define nodes as centroids of BEA regions[25] and arcs as rail lines that connect each BEA economic area.

In order to project origin-destination shipment data to traffic in a rail network, I geocode the rail network and label the rail lines with affiliated railroad companies. I obtain detailed geographic information for each rail line and information about the ancestry of rail lines from the Federal Transit Administration. The geographic coordinates and historical information allow me to reconstruct the rail network back in time. For example, Burlington Northern (BN) merged with the Atchison, Topeka and Santa Fe (ATSF) Railway in December 1996. We can reconstruct the network of the BN and ATSF, respectively, in 1996. Figure 6 depicts the geocoded map of the current U.S. rail network.

It shows all the BEA economic areas in the mainland U.S. and how they are converted into nodes and arcs in the virtual network for modeling.

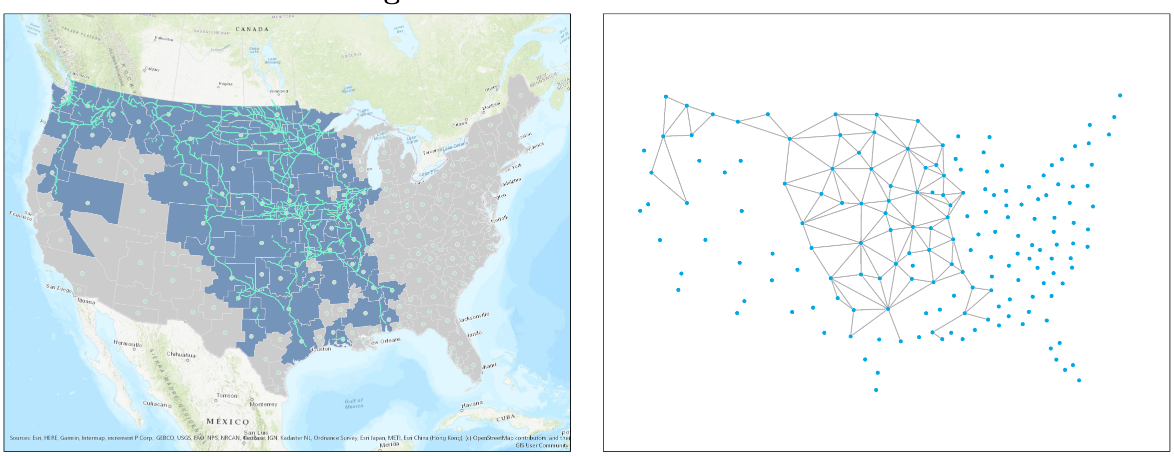
[25]BEA Economic Areas are used by the STB to conduct economic analysis.

Figure 6: U.S. Rail Network



Given the definition of arcs and nodes, I obtain network information for each firm. The left panel of Figure 7 shows the actual rail network of BN in 1994, and the right panel shows how the network is converted into nodes and arcs in the virtual network for analysis.

Figure 7: The Rail Network of BN



5.2 Demand

I follow the airline and the railroad literature (Coublucq (2013), Jourquin (2018), Peters (2006)) in modeling the demand of railroad shipment using a nested logit model (Berry (1994)). Demand is defined at firm-service-origin-destination level. For example, consumer i chooses railroad j and a single-line service to ship from origin o to destination d. A real world example would be that consumer i chooses the Union Pacific railway and a single-line service to ship from Portland, Oregon, to Houston. If the service is a joint-line service, a real example would be consumer i chooses the Santa Fe railway and a joint-line service to ship from Los Angeles to Memphis, in which the Santa Fe railway carries the commodities from Los Angles to Avard, Oklahoma, interchange with the Burlington Northern railway in Avard, and Burlington Northern railway carries the commodities from Avard, Oklahoma to Memphis. The set of railroad firms and services that are available to choose from in each market is assumed to be exogenous in my model, and the information is obtained from the data.

I allow the railroad firms to be more substitutable among themselves, versus outside option which is trucking. The utility of consumer i depends on three components. The price of using the railroad firm j to provide the freight service from o to d, the logarithm of total miles of tracks in the origin and destination regions, and the unobservable efficiency $\xi_{j,od}$ of railroad firm j providing freight service from o to d at time t.

The utility function is specified as:

$$u_{ij,od} = \alpha \cdot \log p_{j,od} + \beta_F \log FirmPresence_{j,od} + \xi_{j,od} + (1-\sigma)\epsilon_{ij,od}$$

where $\epsilon_{ij,od}$ is the consumer-specific deviation from the mean utility. As σ approaches one, the within-group correlation of utility levels goes to one, and as σ approaches zero, the within-group correlation goes to zero.[26]

$$\xi_{j,od} = \alpha_j \cdot \text{Firm}_j + \alpha_t \cdot \text{Time}_t + \alpha_{od} \cdot \text{Mkt}_{od} + v_{j,od}$$

Given that the distribution of $\epsilon_{ij,od}$ is an identically and independently distributed extreme value, the probability of choosing railroad j of freight service from o to d is as below, and it also gives a market share of:

$$s_{j,od} = \frac{e^{d_{j,od}/(1-\sigma)}}{\sum_{j' \in rail_{od}} e^{d_{j',od}/(1-\sigma)} + \left(\sum_{j' \in rail_{od}} e^{d_{j',od}/(1-\sigma)}\right)^{\sigma}}$$

where $d_{j,od}$ is the mean utility of choosing railroad j of freight service from o to d at time t and $d_{j,od} = \alpha \cdot \log p_{j,od} + \beta_F \log FirmPresence_{j,od} + \xi_{j,od}$. $rail_{od}$ is the set of railroads that provide freight service from o to d. Also, the total quantity of freight that railroad j ships

[26] This specification allows for the situation that two firms use joint-line service to ship from origin o to destination d. In that case, I assume that the firm that serves the joint-line from the origin will make the pricing decision, incur the interchange cost, and compensate the other firm based on its transportation cost. The unobserved efficiency term $\xi_{j,od}$ is separated estimated for the joint-line service to capture the combined effect of both firms providing this service.

from o to d is denoted as:

$$Q_{j,od} = M_{od} \cdot \frac{e^{d_{j,od}/(1-\sigma)}}{\sum_{j' \in rail_{od}} e^{d_{j',od}/(1-\sigma)} + \left(\sum_{j' \in rail_{od}} e^{d_{j',od}/(1-\sigma)}\right)^{\sigma}}$$

where M_{od} is the total amount of shipment request from origin o to destination d.[27] Having set out the basic demand model, we can now derive the analytical expression for mean utility levels:

$$\ln(s_{j,od}) - \ln(s_{0,od}) = \alpha \cdot \log p_{j,od} + \beta_F \log FirmPresence_{j,od} + \sigma \ln(\bar{s}_{j,od/rail_{od}}) + \xi_{j,od}$$

where $\bar{s}_{j,od/rail_{od}}$ is the within-group share of railroads serving o to d.

Estimates of demand parameters α, β_F and σ will be obtained from a linear instrumental variables regression of difference in log market shares on firm presence, prices, and the log of the within-group share.

We can also derive the own-price-elasticity and cross-price-elasticity of demand which will be used in deriving the equilibrium conditions:

$$\frac{\partial Q_{j,od}}{\partial p_{j,od}} = M_{od} \frac{\alpha}{1-\sigma} s_{j,od} \left[1 - \sigma \bar{s}_{j,od/rail_{od}} - (1-\sigma) s_{j,od}\right]$$
$$\frac{\partial Q_{j,od}}{\partial p_{j',od}} = -M_{od} \frac{\alpha}{1-\sigma} s_{j,od} \left[\sigma \bar{s}_{j',od/rail_{od}} + (1-\sigma) s_{j',od}\right]$$

Given the utility of consumer i choosing railroad j for freight service from o to d, we recover the consumer surplus from o to d as the expected utility specified in the formula below:

$$\begin{aligned} G_{i,od} &= \left(\sum_{j \in rail_{od}} \exp(\frac{u_{ij,od}}{1-\sigma})\right)^{(1-\sigma)} + (exp(u_{i0,od})^{(1-\sigma)}) \\ &= \left(\sum_{j \in rail_{od}} \exp(\frac{u_{ij,od}}{1-\sigma})\right)^{(1-\sigma)} + 1 \quad \text{(normalize } exp(u_{i0,od}) = 0 \text{ here)} \end{aligned}$$

[27] In my model the total amount of shipment requests is exogenously determined. The rationale behind this assumption is that under certain scenarios shippers have limited flexibility in choosing where to import and export certain commodities. This is especially true for bulk commodities like coal and agricultural products. Those commodities can only be produced in certain geographic markets, which limits shippers' freedom in choosing where to import the commodities.

Therefore total consumer surplus across all markets equals to:[28]

$$\begin{aligned} CS &= \frac{1}{\alpha}\sum_{o,d}\ln(G_{i,od}) \\ &= \frac{1}{\alpha}\sum_{o,d}\ln\left[\left(\sum_{j\in rail_{od}}\exp(\frac{u_{ij,od}}{1-\sigma})\right)^{(1-\sigma)}+1\right] \end{aligned}$$

5.3 Firm's Problem

Each firm j owns a network $\mathcal{N}_j$ with corresponding nodes $\mathcal{Z}_j$ and arcs $\mathcal{A}_j$. Each firm j makes three decisions. First, firm j chooses prices $\boldsymbol{p_j}$ in the markets that it serves, conditional on their perceived cost of operating there. Second, firm j decides how to allocate investment $\boldsymbol{I_j}$ on each arc $(a,b)\in\mathcal{A}_j$. Third, firm j makes routing decisions $\boldsymbol{\mathcal{R}_j}$ for the transportation service demanded in each market. For each market, routing $\mathcal{R}_{j,od}\in\mathcal{A}_j$ is a subset of connected arcs that routes firm j from origin o to destination d. By choosing the optimal routing and resource allocation decision, firms minimize their total operating cost. In the case of inter-connecting route, I assume firms only take into account the cost incurred in their own network. In equilibrium, the perceived cost of operating at the pricing stage is consistent with the outcome from firms cost minimization problem.

Firms simultaneously choose these three variables and compete in prices. On an interconnecting route that goes from multiple firms, we assume that there is no issue with double marginalization in the pricing of the interconnecting route based on findings from Alexandrov et al. (2018), so firms will take the cost of the other firms' routes that they are going on and operate as the cost of the other route as other firms' marginal cost.[29]

In summary, each firm j makes three kinds of decisions to maximize profit:

[28]Actual consumer surplus equals to

$$CS = \frac{1}{\alpha}\sum_{o,d}(\ln(G_{i,od})+C)$$

where C is an unknown constant.

[29]I also assume that there is no strategic interaction of pricing between single-line service and joint-line service. For example, assume firm j_1 serves the market Houston-Portland by providing single-line freight service. Meanwhile, firm j_1 and firm j_2 provide joint-line service for Houston-Portland as well. I assume that the pricing decisions of these two services are independent. This is because if firm j_1 truly has bargaining power, it will charge ∞ for the joint-line service and will become the local monopoly for the Houston-Portland market by providing only the single-line service.

1. $p_{j,od}$ on each origin-destination pair that j serves

2. Routing $\mathcal{R}_{j,od} \subseteq \mathcal{A}_j$

3. Track maintenance and locomotives (resources $I_{j,ab}$) on each arc $(a,b) \in \mathcal{A}_j$

Given the decisions each firm j needs to make, the firm's optimization problem is denoted as:

$$\pi_j := \max_{\{\mathcal{R}_{j,od}\},\{p_{j,od}\},\{I_{j,ab}\}} \sum_{o,d\in\mathcal{Z}_j} [p_{j,od} - C_{j,od}(\boldsymbol{I_j}, \mathcal{R}_{j,od})] \cdot Q_{j,od}(p_{j,od}, p_{-j,od})$$

such that:

(i) Constraint of capital allocation:

$$\sum_{(a,b)\in\mathcal{A}_j} I_{j,ab} \leq K_j$$

(ii) Balanced-flow constraint (routing):

$$\forall m \in \mathcal{Z}_j, \quad D_{j,m} + \sum_{a\in\mathcal{Z}_j(m)} q_{j,am} \leq \sum_{b\in\mathcal{Z}_j(m)} q_{j,mb}$$

where $q_{j,am} = \sum_{o,d\in\mathcal{N}_j} Q_{j,od} \cdot \mathbb{1}\{(a,m) \in \mathcal{R}_{j,od}\}$, and $D_{j,m} = \begin{cases} Q_{j,od} & \text{if } m = o \\ -Q_{j,od} & \text{if } m = d \\ 0 & \text{otherwise} \end{cases}$

The marginal cost of transportation depends on firm j's allocation of investment resources $\boldsymbol{I_j}$ and its routing decisions. More specifically:

$$\begin{aligned} C_{j,od} &= \sum_{(a,b)\in\mathcal{R}_{j,od}} c_{j,ab} + \mathbb{1}_{interchange} \cdot \eta \\ &= \sum_{(a,b)\in\mathcal{R}_{j,od}} \left[\frac{\delta_0 Dist_{j,ab}}{(1+I_{j,ab})^\gamma}\right] + \mathbb{1}_{interchange} \cdot \eta \end{aligned}$$

where $c_{j,ab}$ is the arc-level transportation cost, and $\mathcal{R}_{j,od}$ is the set of connected arcs that routes firm j from o to d. In English, $C_{j,od}$ is the summation of arc-level costs that firm j routes from o to j. I follow Galichon (2016) and Fajgelbaum and Schaal (2017) in defining the per-unit cost of transportation at arc level. For any arc (a,b), if $(a,b) \notin \mathcal{A}_j$, the per-unit cost of transportation $c_{j,ab} = \infty$. If $(a,b) \in \mathcal{A}_j$, $c_{j,ab}$ is defined as:

$$c_{j,ab} = \frac{\delta_0 Dist_{j,ab}}{(1 + I_{j,ab})^{\gamma}}$$

The arc-level cost $c_{j,ab}$ depends on the investment decision $I_{j,ab}$, and the more track maintenance investment and locomotives allocated to arc (a,b), the lower the cost of going through arc (a,b) is. The parameter γ captures the efficiency of resources and δ_0 captures average shipment cost per mile.[30]

Firms make three kinds of decisions simultaneously. Each firm j solves the routing problem by solving a linear programming problem and obtains a closed-form solution for investment decisions based on the first-order condition derived from the optimization problem.

To provide more intuition on how firm j solves the optimization problem, I look at each problem individually.

Given price vectors and firm investment decisions, firm j's routing problem can be written

[30] It is easy to enrich the model by adding geographic characteristics to the cost function such as in Fajgelbaum and Schaal (2017); δ_0 in my model can be further parameterized as:

$$\begin{aligned} & \delta_0 = \delta_1 \left(1 + |\Delta \text{Elevation}|_{ab}\right)^{\delta_2} \\ \text{or} \quad & \delta_0 = \delta_1 \left(1 + |\Delta \text{Elevation}|_{ab}\right)^{\delta_2} \delta_3^{\text{CrossingRiver}_{ab}} \delta_4^{\text{AlongRiver}_{ab}} \end{aligned}$$

What's more, we can add congestion in the cost function by modifying c_{ab} as a function of q_{ab}. However, this will add computational complexity because the routing problem is no longer a linear programming problem if c_{ab} depends on q_{ab}

as:[31]

$$D_{j,od}(Q_{j,od}) \equiv \min_{\mathcal{R}_{j,od}} \sum_{(a,b)\in\mathcal{R}_{j,od}} c_{j,ab} \cdot q_{ab}$$
$$\text{s.t. } \forall m \in \mathcal{Z}_j, \quad D_{j,m} + \sum_{a\in\mathcal{Z}_j(m)} q_{j,am} \leq \sum_{b\in\mathcal{Z}_j(m)} q_{j,mb}$$

where $q_{j,ab}$ is interpreted as the total traffic that goes through arc (a, b) and $D_{j,m}$ is the net demand of firm j at node m.[32] Conditional on the arc-level cost $c_{j,ab}$, we can solve the optimization of routing for each origin-destination market by using linear programming algorithms.

Given the functional form of arc-level cost $c_{j,ab}$ (transport technology), the optimal investment decision of track maintenance and locomotives arising from the firm's optimization problem is

$$\begin{aligned} I^*_{j,ab} &= \left[\frac{\gamma}{\lambda_j} \sum_{o,d\in\mathcal{N}_j} (\delta_0 Dist_{j,ab} \cdot Q_{j,od} \cdot \mathbb{1}\{(a,m) \in \mathcal{R}_{j,od}\})\right]^{\frac{1}{1+\gamma}} - 1 \\ &= \left[\frac{\gamma}{\lambda_j} \cdot \delta_0 Dist_{j,ab} \cdot q_{j,ab}\right]^{\frac{1}{1+\gamma}} - 1 \end{aligned}$$

where λ_j is the Lagrangian multiplier of capital constraint. Because the investment of track maintenance and locomotives cannot be negative, the optimal level of investment would be

$$I_{j,ab} = \max\{I^*_{j,ab}, 0\}$$

[31]The balanced-flow constraint could also be written in vectors:

$$\nabla \boldsymbol{q} = \boldsymbol{Q_j}, \text{ where } \boldsymbol{Q_j} = \begin{bmatrix} \cdots \\ -Q_{j,od} \\ 0 \\ 0 \\ Q_{j,od} \\ 0 \\ 0 \\ \cdots \end{bmatrix}$$

[32]$q_{j,ab} = \sum_{o,d\in\mathcal{N}_j} Q_{j,od} \cdot \mathbb{1}\{(a, b) \in \mathcal{R}_{j,od}\}$, and $D_{j,m} = \begin{cases} Q_{j,od} & \text{if } m = o \\ -Q_{j,od} & \text{if } m = d \\ 0 & \text{otherwise} \end{cases}$.

Last, if we look at the pricing decision of firm j, we can derive the first-order condition of price $p_{j,od}$ as (say something about inter-connecting route and rearrange the order)

$$\begin{aligned}\frac{\partial \pi_j}{\partial p_{j,od}} &:= Q_{j,od} + (p_{j,od} - C_{j,od}) \cdot \frac{\partial Q_{j,od}}{\partial p_{j,od}} \\ &= Q_{j,od} + (p_{j,od} - C_{j,od}) \cdot Q_{j,od} \cdot \left[1 - \sigma \bar{s}_{j,od/rail_{od}} - (1-\sigma) s_{j,od}\right],\end{aligned}$$

where $\bar{s}_{j,od/rail_{od}}$ is the within-group share of railroads serving o to d.

To sum up, after looking at the details of each problem, in equilibrium firms simultaneously choose these three variables and compete in prices.

6 Estimation

6.1 Demand Estimation

As a reminder, the utility function is specified as:

$$u_{ij,od} = \alpha \cdot \log p_{j,od} + \beta_F \log FirmPresence_{j,od} + \xi_{j,od} + (1-\sigma)\epsilon_{ij,od}$$

Parameters that need to be estimated are price coefficient α, coefficient on firm presence β_F, and within-group correlation parameter σ.

Estimates of demand parameters α, β_F and σ are obtained from a linear instrumental variables regression of difference in log market shares on firm presence, prices, and the log of the within-group share.[33]

$$\ln(s_{j,od}) - \ln(s_{0,od}) = \alpha \cdot \log p_{j,od} + \beta_F \log FirmPresence_{j,od} + \sigma \ln(\bar{s}_{j,od/rail_{od}}) + \xi_{j,od}$$

I obtain the share of rail mode versus the share of truck mode from one region to another from the Commodity Flow Survey, which shows what the substitution to the outside option looks like.

Then to conduct the estimation, I need to identify reasonable instruments to account for

[33] Using the GMM estimator is more efficient if I estimate demand parameters and cost parameters simultaneously. Given the level of complexity of the firm's problem in my model, however, I choose to estimate demand parameters using IV regression first.

any potential correlation between the observed and unobserved characteristics. The basic identifying assumption I use to construct a set of instruments is that although ownership of the network changes following a railroad merger, the physical layout of rail in the United States is stable and unchanged in time period under study. Therefore, the physical layout of the overall network structure is exogenous. That is, the set of possible routes served by each railroad is assumed to be independent of the unobserved component of utility ξ. This allows firms to choose markets in which to provide freight service. Firms can consolidate traffic and freely allocate investment of track maintenance and locomotives, and they do not necessarily need to serve markets where they own physical tracks. Therefore, the assumption is that the set of possible routes across markets is exogenous, but the set of actual chosen routes across markets and over time is endogenous.[34] The intuition behind the expected correlation between the selected instruments and price is that, absent perfectly collusive conduct, price will tend to fall with an increase in the number of alternative products. The number of alternative products is positively correlated with whether or not a firm has physical tracks in a region[35].

Firm presence is measured by miles of road operated in origin and destination regions for each firm, and the data are obtained from the Department of Transportation. Within-group market share $\bar{s}_{j,od/rail_{od}}$ is instrumented by other firms' characteristics, measured by miles of road operated in origin and destination regions by other firms. The premise here is that a railroad will tend to operate more trains in regions where firms have longer miles of tracks, and shippers are more likely to choose a railroad if that railroad has longer tracks in their region,because the tracks will be closer to the shipper's facilities and easier to reach.

Table 9 reports the estimated parameters from the demand model.

[34] The standard assumption in the literature on discrete-choice demand estimation (for example, Berry et al. (1995), Peters (2006)) is that variation in the set of available products across markets and over time is exogenous. Here given that routing decisions and investment decision of how to allocation track maintenance and locomotives depend on ownership of network, we relax this assumption by allow available products across markets to be endogenous.

[35] Another instrument for price is crude oil first purchase prices by area, which is used in Coublucq (2013), but I am worried there is not enough variation of this instrument across geographic markets.

Table 9: Demand Estimation Results

	(1) Difference of Log Shares
Log Price	-2.041***
	(0.328)
σ	0.700***
	(0.060)
β_f	0.592***
	(0.093)
Observations	109,011
Number of marketID	7,562
Year FE	Y
Firm FE	Y
O-D Route FE	Y

First, all parameters are highly significant with the expected sign, and within-group σ is significantly different from 0, which indicates the importance of allowing for closer substitution between railroads compared to other transportation modes. One way to check whether the estimated prameter is reasonable is to consider the implied aggregate demand elasticity. A convenient feature of the nested logit model is that the aggregate elasticity in any origin-destination market is simple to compute: in our case, aggregate demand elasticity equals -1.3.

Given the estimated parameters, I can write the total demand for each origin-destination pair as a function of firm prices:

$$Q_{j,od}(p_{j,od}, p_{-j,od}) = M_{od} \cdot \frac{e^{d_{j,od}(p_{j,od})/(1-\sigma)}}{\sum_{j' \in rail_{od}} e^{d_{j',od}(p_{j',od})/(1-\sigma)} + \left(\sum_{j' \in rail_{od}} e^{d_{j',od}(p_{j',od})/(1-\sigma)}\right)^{\sigma}}$$

where $d_{j,od}(p_{j,od}) = \alpha \cdot \log p_{j,od} + \beta_F \log FirmPresence_{j,od} + \xi_{j,od}$. Then the demand function $Q_{j,od}(p_{j,od}, p_{-j,od})$ is used in solving the firm's optimization problem.

6.2 Estimation of Cost Parameters

The marginal cost of transportation of firm j serving origin-destination pair o to d is specified as

$$C_{j,od} = \sum_{(a,b)\in\mathcal{R}_{j,od}} \left[\frac{\delta_0 Dist_{j,ab}}{(1+I_{j,ab})^{\gamma}}\right] + \mathbb{1}_{interchange} \cdot \eta$$

There are three parameters that I need to estimate, δ_0, γ, and η, and each parameter is interpreted as follows: if γ equals 0, δ_0 is interpreted as the transportation cost per unit-mile. If γ does not equal 0, intuitively δ_0 captures the effect of per-mile travel distance on transportation cost. γ captures the effectiveness of investment on track maintenance and locomotives. When the value of γ increases, investment on track maintenance and locomotives has a larger effect in reducing transportation cost. η captures the cost of interchanging between two railroad firms. The larger the value of η, the larger the interchange cost.

I use the Generalized Method of Moments to estimate the value of δ_0, γ, and η. I target four data moments in estimating the parameters:[36]

Table 10: Targeted Data Moments

	Data Moments
Average shipping expense per car-mile	\$0.87
Change of average shipping expense per car-mile on total travel distance (per 100 miles)	\$-0.11
Percentage of non-minimum-distance routing	18.3%
Average difference of shipping expense between interconnecting route and non-interconnecting route	\$310

The rationale for choosing the four data moments to estimate the cost parameters is as follows: for non-interconnecting routes, if γ equals 0, δ_0 measures average shipping expense per

[36] I obtain shipping expense from the data as follows: in the data we can observe the shipment price for each waybill. Given the estimated demand parameters and information on market competition in each origin-destination pair, we can thus derive the shipping expense as

$$Q_{j,od} + (p_{j,od} - C_{j,od}) \cdot \frac{\partial Q_{j,od}}{\partial p_{j,od}} = 0$$
$$\Rightarrow C_{j,od} = p_{j,od} + \delta^{-1} Q_{j,od}$$

car-mile. If γ does not equal 0, conditional on investment of track maintenance and locomotives and fixed routing decisions, the average shipping expense per car-mile is monotonically increasing with respect to the value of δ_0. Therefore, average shipping expense per car-mile helps identify the value of δ_0. Average shipping expense per car-mile in the data is \$0.87. As a benchmark, according to the Analysis of Class I Railroads published by AAR, in 2007 the average loaded car-mile expense is \$1.2, which is comparable to the number we observe from the data. The second data moment I target is the change in average shipping expense per car-mile. The idea is that firms have more routing options when the distance between origin and destination is longer. Therefore, average shipping expense per car-mile conditional on minimum travel distance will be lower when total travel distance increases. The magnitude of this change depends on the value of both δ_0 and γ. The third data moment is the percentage of non-minimum-distance routing. If γ equals 0, for each origin-destination pair firms will always choose the routing with the minimum travel distance. However, when γ does not equal 0, firms will trade travel distance with the efficiency of the route. When the value of γ increases, firms have more incentive to choose routing that deviates from minimum-distance routing. The last data moment is the average difference of shipping expense between an interconnecting route and a non-interconnecting route. This moment captures the effect of η, where interchange cost increases if the value of η increases. The average difference of shipping expense between an interconnecting route and a non-interconnecting route in the data is \$310 per loaded car. As a benchmark, in the data the average shipment price is \$1,500 per loaded car, which means that the interchange cost is equivalent to 20% of average shipment price.

Table 11 shows the estimated results:[37]

Table 11: Estimation Result of Cost Parameters

	Point Estimate
δ_0	0.9
γ	0.85
η	310

Given the value of estimated parameters, we can compare the simulated moments with data moments and check fitness of the model:

[37]In the current version I calibrate the value of η and estimate δ_0 and γ. I am currently estimating η and will update the results soon. The confidence interval of the estimated parameters will come in future versions.

Table 12: Compare Simulated Moments with Data Moments

	Data Moments	Simulated Moments
Average shipping expense per car-mile	\$0.87	\$1.44
Change of average shipping expense per car-mile on total travel distance (per 100 miles)	\$-0.11	\$-0.12
Percentage of non-minimum-distance routing	18.3%	16.23%
Average difference of shipping expense between interconnecting route and non-interconnecting route	\$310	\$310

First, the model does well in matching the change in average shipping expense per car-mile on total travel distance, and the simulated moment approximates quite well the percentage of non-minimum-distance routing that we observe in the data. However, the simulated moment deviates from average shipping expense per car-mile in the data. Given that the model simulates pricing and routing decisions for tens of thousands of markets and I have only three parameters to match the moments, I lack the degree of freedom to match every moment perfectly. Even though the simulated average shipping expense per car-mile deviates from the expense I observe in the data, it does not deviate too much from the industry estimate of \$1.20 per loaded car.

6.3 Cross-Validation (Specification Test)

Before performing merger simulations using the estimated parameters, I perform specification tests by comparing simulated moments with non-targeted data moments. First, I look at the average price reduction following mergers. In the data the average price reduces by 9.4% following mergers. The simulated price change following merger in my model is 10.51%, which is comparable to the data moment. One reason that my simulated moment is larger than the price change in the data is because my model does not capture the increase in service quality. Moreover, firms conduct a Bertrand competition in my model and there is no space for collusion. Next, my model predicts which origin-destination pairs will have the largest price reduction following mergers. In the data I also observe which origin-destination markets have the largest price reductions after mergers. I compare the set of routes in my model with the set of routes in the data and examine whether my model correctly predicts which routes have the largest price reductions. For the top 10% markets with price reductions, my model has an accuracy of 62.7% of making the prediction.

Table 13: Compare Simulated Moments with Non-Targeted Data Moments

Moments	Data	Model
Average Price Reduction after Merger	-9.4%	-10.51%

If we look at the accuracy of prediction for each merger case, we find:

Table 14: Accuracy of Predicting the Top 10% Markets of Price Reduction

Merger ID	Number of O-D Markets	Accuracy of Predicting top 10% Price Reductions
1	597	54%
2	854	79%
3	1163	75%
4	1442	39%
5	1161	62%
6	11	100%
7	52	100%
8	192	100%
9	180	100%
10	40	50%
11	57	0%

The model does well in predicting the top 10% markets of price reduction. For large mergers that involve more than 500 origin-destination markets, the accuracy of prediction is above 50%. The only exception is the merger of the Southern Pacific and Union Pacific railways, which has an accuracy of prediction of only 39%. This might be because these railroads encountered well-documented hurdles when integrating their networks after their merger. This may cause the price change in the data to deviate from the predicted price change in the model.

For some mergers the accuracy of prediction is 100%. This may be because those mergers involve only a small amount of origin-destination markets, and it is easier to predict price changes when the number of markets is small. One exception, However, is the Kansas City Southern Railway mergers, for which the accuracy of prediction is 50% and 0%. This may be because the main business of Kansas City Southern originates and ends in Mexico, which is not captured in my model. My model estimates demand only within the United States because the CFS covers the United States only.

Next, I conduct merger simulations by simulating the pricing decision, routing decision, and investment decision of track maintenance and locomotives following each railroad merger and examine the efficiency gain from each source along with welfare changes in each geographic market.

7 Results

7.1 Sources of Cost Efficiency

First, I conduct counterfactual simulations based on my model to decompose sources of cost efficiency and examine the importance of each source in determining efficiency gain following railroad mergers. In general there are three sources of efficiency gain: the elimination of interchange cost, the reallocation of resources, and the consolidation of traffic and reoptimization of routing. First, the merger simulation that allows for all three types of changes results in a total cost change of $\Delta C_{tot,od}$ for each origin-destination market. I then conduct a counterfactual by fixing the pricing as the new equilibrium pricing while holding routing decisions the same as pre-merger routing decisions,[38] denoting the cost changes of each origin-destination market as $\Delta C_{invest,od}$. Then, under the new equilibrium pricing, I calculate the change in cost following the elimination of interchanges by calculating the cost changes for interconnecting routes as $\Delta C_{interchange,od}$. Last, the rest of the change in cost is attributed to the reoptimization of routing.

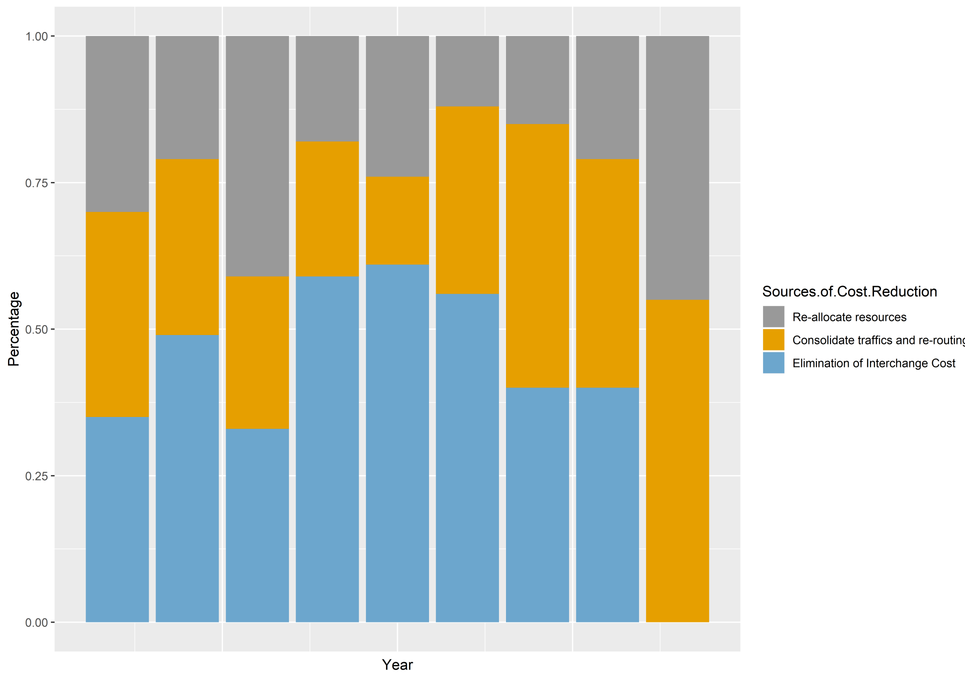
The counterfactual result shows that the reduction of interchange cost on average accounts for 41% of the cost reduction. The freedom to allocate resources on average accounts for 26% of the cost reduction, and the consolidation of traffic and reoptimization of routing on average accounts for 33% of the cost reduction. The result suggests, first, that the elimination of interchange costs play an important role in gaining efficiency following railroad mergers. Looking only at an individual market is not enough to understand mergers in this industry, however, because the reoptimization of routing and reallocation of resources also play key roles in cost reduction following railroad mergers.

I also look at how the decomposition changes across different mergers. We can see that it varies across mergers depending on the number of interconnecting lines involved in each

[38] For competing routes, after-merger routing is set to be the one with lower shipment cost. For example, say both Union Pacific and Southern Pacific has a route from Houston to Los Angeles, I choose the one with lower shipment cost as the after-merger routing.

merger and on the network structure of the firms. In general, the elimination of interchange costs is the most important source of efficiency gain, but the reoptimization of routing and reallocation of investment decisions also play important roles in obtaining cost efficiency.

Figure 8: Sources of Efficiency Gain Across Mergers

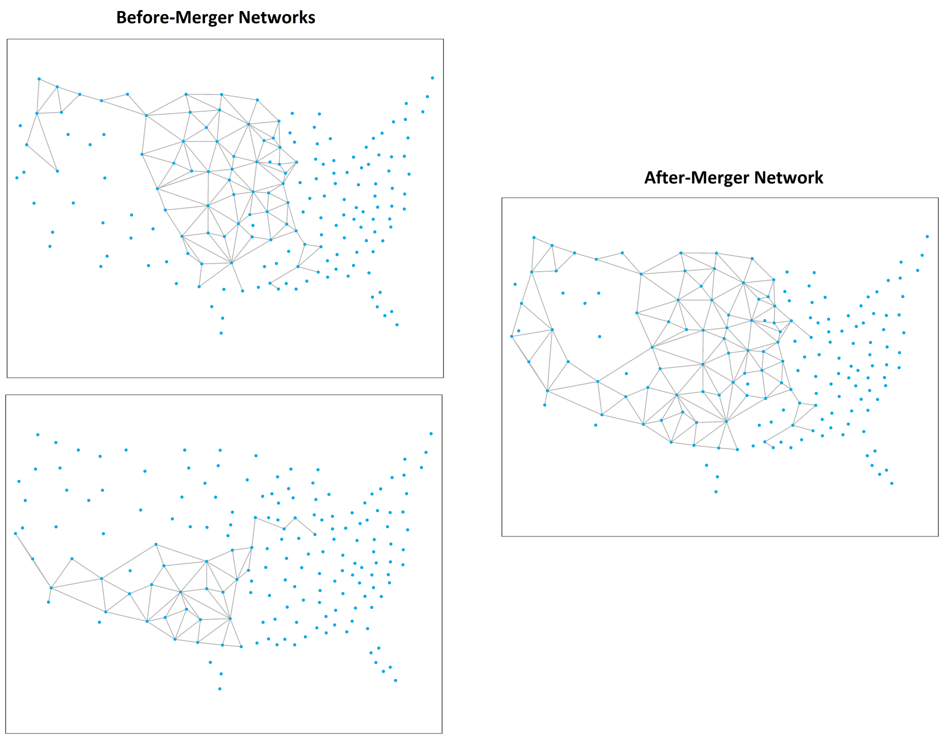


7.2 Heterogeneity of Welfare Changes

Given the sources of cost efficiency and how they change with features of the merger like ownership of network, next I analyze the trade-off of increased market power versus efficiency gain, and examine the magnitude of welfare changes in different geographic markets. To provide intuition on how topography of network affects the trade-off between increased market power and efficiency gain, here I look specifically at the merger of the Burlington Northern and Santa Fe railways.

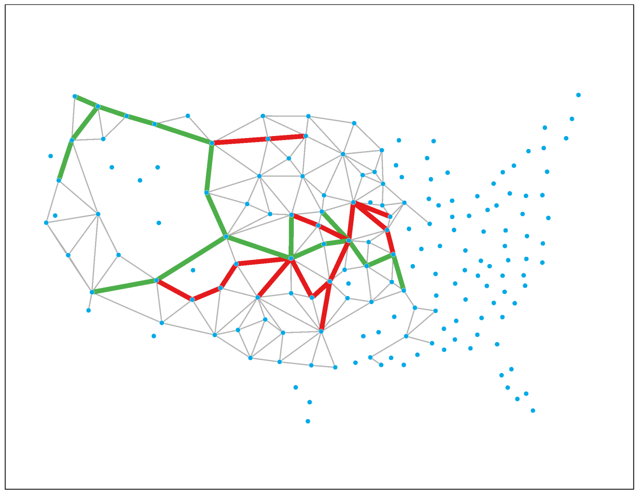
Figure 9 illustrates the network of the Burlington Northern and the Santa Fe before and after their merger. The left panel shows the networks owned by the Burlington Northern (top) and the Santa Fe (bottom). The right panel shows merged network. Note that the network of the Burlington Northern and the Santa Fe overlaps in the central United States, including Colorado, Kansas, Oklahoma, and north Texas.

Figure 9: Rail Networks of Burlington Northern and Santa Fe



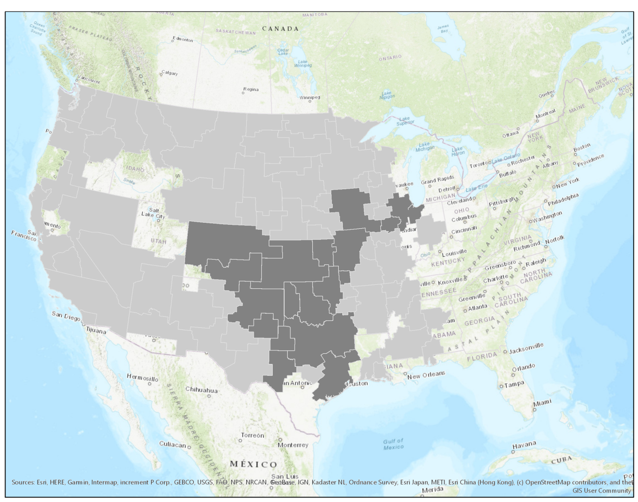
I first examine the efficiency gain following this merger. The merger simulation displays the firm's decision on routing and investment of track maintenance and locomotives in the new equilibrium. By comparing the investment decision before and after the merger, I show how the allocation of resources changes after the merger. The green lines in Figure 10 highlight regions where resources are consolidated. The red lines highlight regions where resources are lessened. The exact efficiency gain of each origin-destination market depends on its choice of routing, but a rule of thumb is that regions closer to the green lines are more likely to have an efficiency gain after the merger. Meanwhile, regions closer to the red lines are less likely to have an efficiency gain following the merger. One observation is that firms tend to enhance the connection of their networks after the merger. For example, more resources are allocated to regions where the network of the former Burlington Northern and Santa Fe railways connect, such as the central United States and West Coast.

Figure 10: Change of Investment Before and After Merger



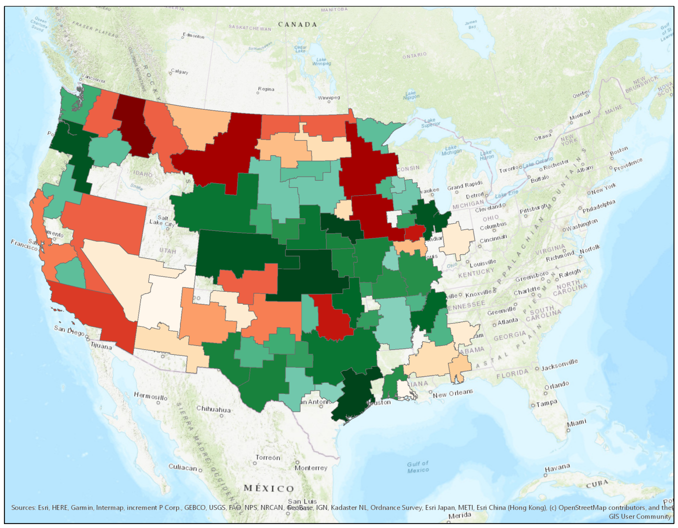
Next, I examine the change of market power in different geographic markets following the merger of the Burlington Northern and the Santa Fe. The gray areas in Figure 11 depict all regions affected by this merger. Light gray areas are regions where only one of the two companies provides freight service before the merger. Dark gray areas are regions where both firms provide freight service before the merger. Following the merger, therefore, the number of firms providing freight service remains the same in the light gray areas, whereas it decreases in the dark gray areas.

Figure 11: Change of Market Power Before and After Merger



The combined forces of change of market power versus cost efficiency results in a large degree of heterogeneity in welfare changes. For each BEA region, I calculate the change of consumer welfare by aggregating all the inbound and outbound traffic of that region. Figure 12 illustrates the change in consumer welfare after the merger in different regions. The green areas are places where consumer welfare increases following the merger, while the red areas are places where consumer welfare decreases after the merger. There is a large variation regarding the value of change in consumer welfare, ranging from -15% to 15%. The result suggests that in the merger of the Burlington Northern and the Santa Fe, the consumer welfare of regions in the periphery of the two networks is likely to decrease, while the consumer welfare of regions in the core of the merged network is likely to increase.

Figure 12: Change of Consumer Welfare Before and After Merger



8 Conclusion

I document evidence of improved cost efficiency following the wave of mergers in the U.S. railroad industry from 1980 to 2010. By conducting a reduced-form analysis with detailed route-level shipment data, I find that following the mergers, the ratio of switching hours to road-service hours decreases by 11% and the average haul length increases by 5%. Moreover, on average the number of interchanges decreases and use of unit trains increases following railroad mergers. Shipment prices decrease by 9.4% on average after the mergers, and interconnecting routes have the largest price reduction, 11%, of all the route types.

Using the reduced-form evidence and descriptive evidence from interviews and merger documents, I argue that looking solely at the effect of individual routes is not sufficient to understand efficiency gain in this industry. This is because each origin-destination market in the network is interdependent. To capture this important feature and examine how it affects consumer welfare following mergers, I propose an optimal transport network model by endogenizing firm pricing, routing, and investment decisions. The simulation results show there is a large degree of heterogeneity of welfare changes in different geographic markets following railroad mergers, and it depends on the ownership of networks and the location of each market within the network. Moreover, the decomposition of sources of cost efficiency shows that reduction of interchange cost on average accounts for 41% of cost reduction. The freedom to allocate resources on average accounts for 26% of cost reduction, and the consolidation of traffic and reoptimization of routing on average accounts for 33% of cost reduction. The structure model can be further used in conducting various counterfactual results such as policy simulations and evaluation of future mergers. The result of how cost efficiency and price incentives vary with respect to different topographic that a network has, may also help us understand the tradeoff between efficiency gain and market concentration in other network industries, such as telecommunications and electricity, airline, and railroad industries.

Certain limitations of this paper suggest areas for further exploration. First, the total amount of investment is fixed. One could look further at how the free capital market affects the predicted results by relaxing this assumption. Second, the fixed cost of a merger is larger if the network size of the merging party increases. For example, when the Union Pacific acquires the Southern Pacific and when Conrail splits and merges with the Norfork Southern and CSX Transportation, integration of their networks is difficult and has a large negative impact on local economy in the short run. Moreover, when the number of firms decreases, firms may find it easier to collude. In the railroad industry we observe more lawsuits alleging collusion by railroad companies after 2004, when the main mergers are finished. These features are not captured in my model but are worth exploration.

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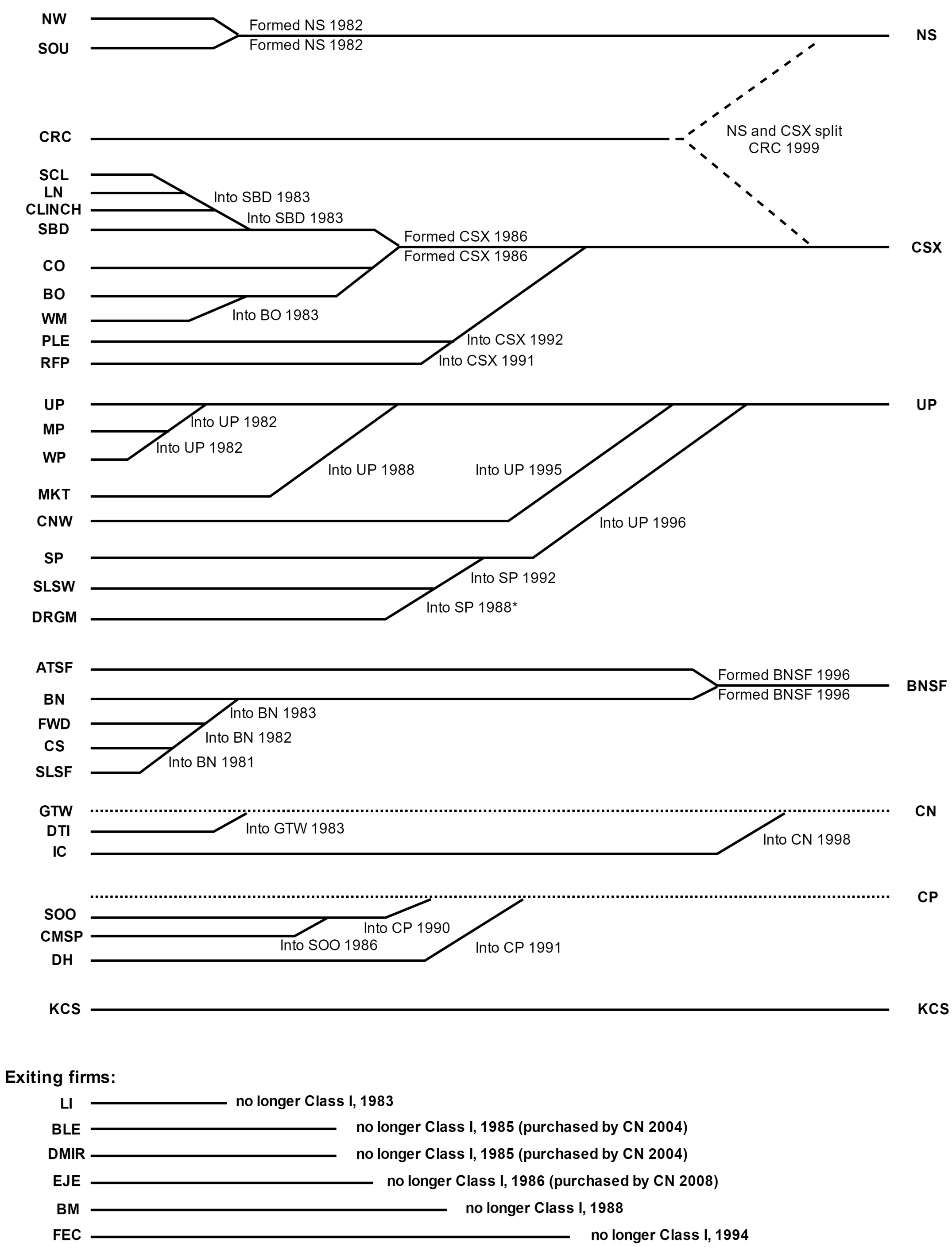
A Appendices

A.1 Merger History

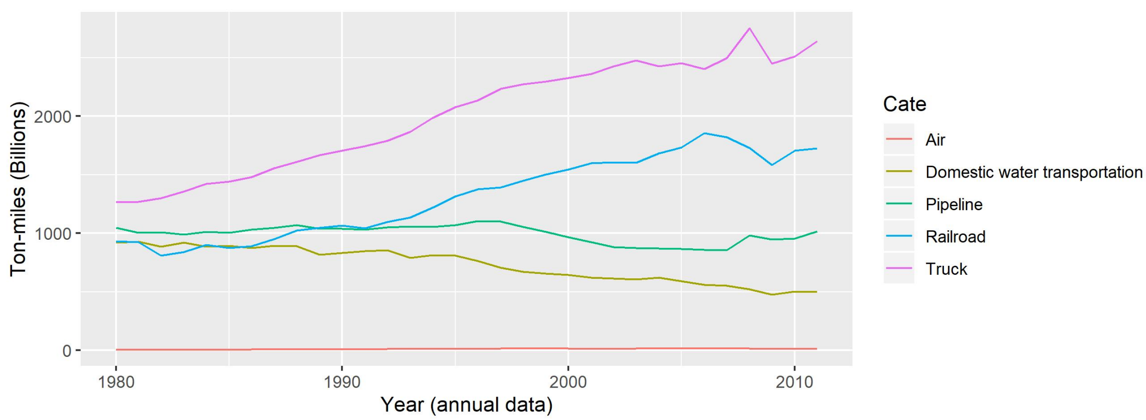
Figure A.1: Merger History of Railroads



A.2 Details of U.S. Railroad Industry

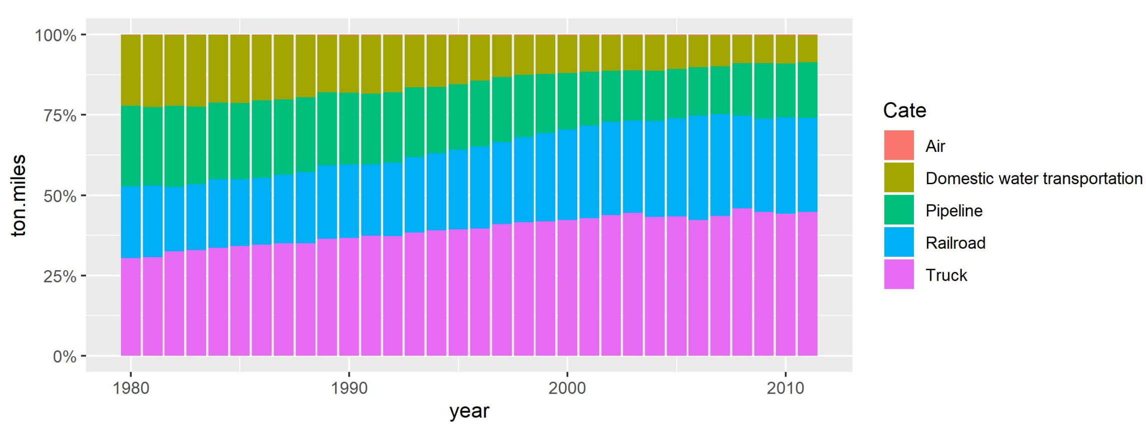
Figure A.2 and A.3 plots the total ton-miles of freight carried by mode, from 1980 to 2011 Importance of railroad industry among all the transportation mode. We can see that the U.S. railroad industry only accounts fo a small proportion of total ton-miles of freight (around 20%), and even accounts for a smaller proportion than pipelines at the start of 1980s. But it keeps increasing after the deregulation of 1980 and reaches 33% before the financial crisis. According to American Association of Railroads, if we only look at the intercity ton-miles, the railroad industry accounts for about 40 percent of the total shipping, more than any other transportation mode.

Figure A.2: U.S. total ton-miles of freight by mode



Source: U.S. Department of Transportation, Bureau of Transportation Statistics

Figure A.3: U.S. total ton-miles of freight by mode (percentage)



Source: U.S. Department of Transportation, Bureau of Transportation Statistics

A majority of the freight revenues in the U.S. freight railroad industry is generated by Class I railroads (see figure A.4, Class I railroads generate around 95% of the total freight revenues).

Figure A.4: U.S. Freight Railroad Industry 2012

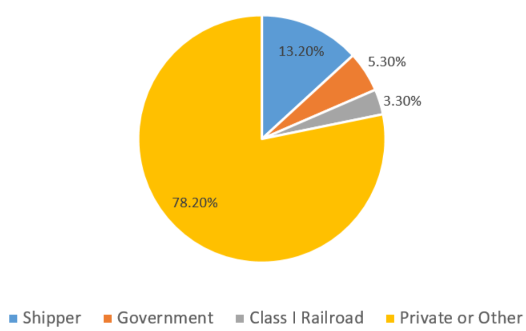
U.S. Freight Railroad Industry 2012

Railroad	Number	Miles	Employees	Revenue ($ bil)
Class I	7	95,264	163,464	$67.6
Regional	21	10,355	5,507	1.4
Local	546	32,858	12,293	2.6
Total U.S.	574	138,477	181,264	$71.6
Canadian	1	47		
Grand Total	575	138,524		

Source: Association of American Railroads, Analysis of Class I Railroads Annual Issues and Railroad Ten-Year Trends

Generally, the regional and local rails serve following purposes: first, shipping commodities from the main rails to end-users: for example, shipping coals from main rails to power plants; Second, serve as parking lot of railcars. A large proportion of regional and short lines are owned by leasing companies (Figure A.4) and serve this purpose; Third, used as interchanging places for different railroad companies to interchange the shippings.

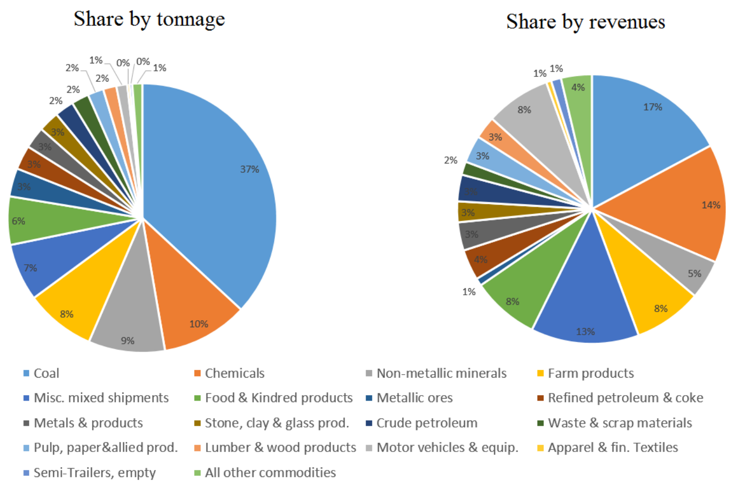
Figure A.5: Ownership of Regional and Short Lines



Source: American Short Line and Regional Railroad Association

The U.S. railroad industry ships various types of commodities, but the majority of carloads are generated by coal, chemical, and farm products. Although, the revenues generated by shipping coal are decreasing and the carloads of intermodal shippings (Misc. mixed shipments) are increasing nowadays.

Figure A.6: Carloads originated by commodity



Source: Association of American Railroads, Analysis of Class I Railroads Annual Issues and Railroad Ten-Year Trends

A.3 Interviews and Other Descriptive Evidence

Documentation of interviews (under confidentiality review, details to be filled in later):

1. Interview with Terminal Superintendent at Conrail, about how interchange works and why it is costly

2. Interview with Train & Terminal Operations Manager at Lake State Railway Company, about why interchange is costly and the incentive problem in exchanging equipment with another railroad

3. Interview with Manager in marketing department at Canadian National, about how firms make pricing decision in reality, how interchange contract is negotiated, story about network planning and how it is adjusted dynamically if anything happens (weather, congestion, accidents etc.)

Documentation of importance of routing and network planning:

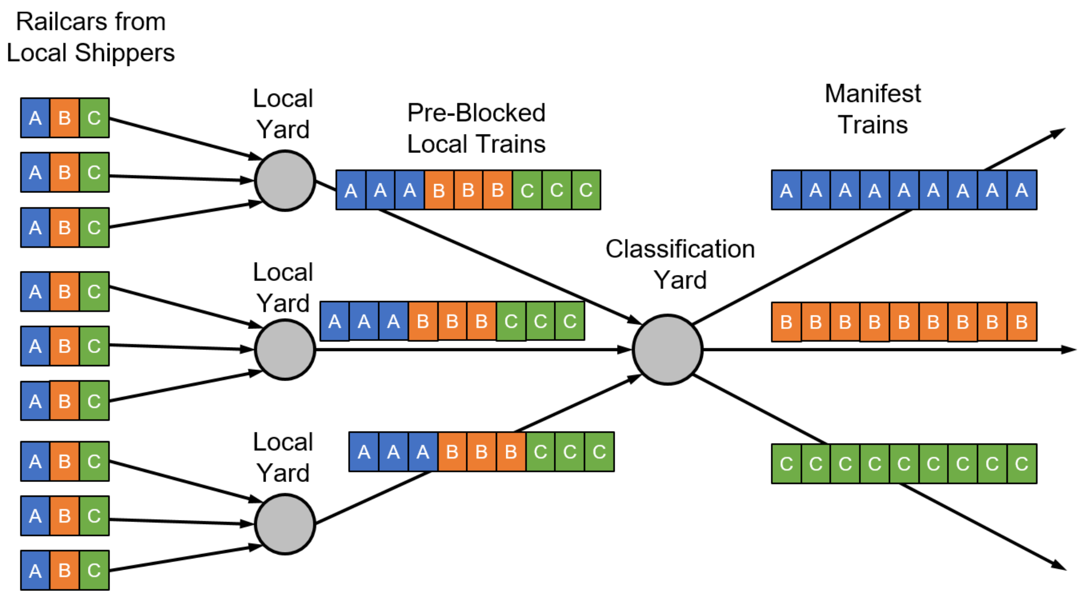
1. From former president of Southern Pacific and former CEO of Burlinton Northen Santa Fe, Robert Krebs, *Riding the Rails*

2. From former CEO of Canadian National and former CEO of CSX Transportation, E. Hunter Harrison, *How We Work and Why*

3. From Chief Operating Officer of CSX Transportation, Cindy Sanborn, *Reciprocal Switching, Opening Comments of CSX Transportation, INC.*

Figure A.7 illustrates how traffics are consolidated in a classification yard.

Figure A.7: Illustration of Consolidating Traffics



Picture from C. Tyler Dick, P.E., RailTEC

A.4 Regulation Changes in the U.S. Railroad Industry

History: 1887 - 1980

- 1887, the Interstate Commerce Act: create ICC value of service pricing (VOS pricing)
- 1973, The Regional Rail Reorganization Act ("3R" act): Establishment of US Railway Association, abandoning designated portions of the Northeast system
- 1976, Railroad Revitalization and Regulatory Reform Act ("4R" act): Creation of Conrail, permitting a railroad to adjust its rates up or down within a "zone of reasonableness", which is initially within 8 percent of the existing ICC tariff and widened over time. Accelerate the legal procedure dealing with abandoning unprofitable lines and expedite processing of merger
- 1980, The Staggers Act: The most important change is the removal of inefficient commodity rate regulation Enhanced the ability of abandoning lines and merge with others

Most recent: 1980 - current

- After the deregulation of 1980, ICC/STB no longer sets fixed prices for the railroad industry. Instead, it implements a constrained market pricing strategy, in which railroads are not allowed to set rates that are "too high". The STB does not have jurisdiction over the reasonableness of a rate for rail transportation unless the rail carrier providing the service has "market dominance". By statue, a necessary but not sufficient condition for a railroad to be considered to have market dominance is that the revenue produced by the rate is greater than 180% of its variable cost of providing the service as determined under the STB's Uniform Rail Costing System. When the rate goes beyond this 180% threshold, shippers are able to request STB to evaluate whether the service has "market dominance". There are three methods that STB allow shippers to use to evaluate market dominance of rail carriers: Stand-alone cost constraint (the most frequently used tools in law suits, invented in 1985), the three-benchmark procedure (invented in 1996), and the simplified-SAC (invented in 2007).
- 1985, ICC's Coal Rate Guidelines: ICC implements the requirement of constrained market pricing, in which the rate set by rail carriers needs to satisfy three constraints:
  - Revenue adequacy constraint: intended to ensure that railroads earn enough revenue to make normal profits, but not more (3 rate law cases invoked this principle since 1980 but all settled between shipper and railroad company)

  - Management efficiency constraint: prevent the shippers from paying avoidable costs that result from the inefficiency of the railroad (0 cases invoked this principle since 1980)
  - Stand-alone cost constraint (SAC): Simulate the competitive rate that would exist in a contestable market by assuming a new highly efficient competitor railroad. The shipper must demonstrate that the "new" competitor would fully cover its costs, including a reasonable return on investment (full-SAC) (the most frequently used principle in rate cases. 50 rate cases invoked this principle after 1996, according to STB data base)

- 1995, ICC Termination Act

- 1996, The Three-benchmark procedure (only applies to cases where the total revenue of service is under $1 million over five years)

  - Revenue shortfall allocation method, the uniform mark-up above variable cost that would be needed from every shipper in the captive group ($R/VC > 180$) to cover the URCS fixed cost
  - R/VC for comparative traffic
  - $R/VC_{>180}$ average captive price: calculate the average price of all the "captive" shippers

  Only 3 rate cases use three-benchmark from 1996 - 2007, while 25 rate cases use full-SAC in the same period.

- 2007, Simplified SAC (only applies to cases where the total revenue of service is under $5 million over five years): this allows shippers to use the existing infrastructure that serves the traffic, instead of coming up with a hypothetical stand-alone railroad to prove the market dominance of current service provider. Only 2 rate cases use simplified-SAC from 2007, while 20 cases use full-SAC in the same period

- 2013, Rate Regulations Reforms: remove limit of simplified-SAC, raise limit of three-benchmark to $4 million (we see 6 rate cases after 2016, but all are using full-SAC method)

A.5 Robustness Check of Reduced-form Analysis

Study effect of merger on ratio of switching hours to road service hours case-by-case:

Table A.1: Effect of Merger on Ratio of Switching Hours to Road Service Hours

	(1) Ratio of Switching Hrs to Road Service Hrs	(2) (case-by-case)
Indicator of Merger	-0.115**	
	(-2.26)	
BNSF merger		-0.103
		(-1.12)
IC merger		-0.401
		(-1.60)
DRGW merger		0.171
		(1.65)
SP merger		-0.348
		(-1.70)
CNW merger		-0.570***
		(-7.81)
MKT merger		-0.316**
		(-2.79)
CRNS merger		-0.484***
		(-3.41)
CRCSX merger		-0.516***
		(-3.64)
_cons	0.782***	0.495***
	(13.34)	(4.71)
N	208	208
Firm FE	Y	Y
Year FE	Y	Y

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Study effect of merger on average length of haulage case-by-case:

Table A.2: Effect of Merger on Average Length of Haulage

	(1) Log average length of hauling	(2) (case-by-case)
Indicator of Merger	0.0525**	
	(2.24)	
BNSF merger		-0.0574
		(-0.56)
IC merger		0.0784
		(1.70)
DRGW merger		-0.0238
		(-0.85)
SP merger		0.261
		(1.49)
CNW merger		0.589***
		(6.15)
MKT merger		0.628***
		(6.81)
CRNS merger		0.468***
		(5.16)
CRCSX merger		0.578***
		(6.37)
_cons	6.075***	6.404***
	(102.28)	(62.36)
N	208	208
Firm FE	Y	Y
Year FE	Y	Y

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

A complete summary statistics of commodities shipped by rail from waybill data:

Table A.3: Descriptive Statistics of Commodity Types and Car Ownership Category

	Number of Waybills	Percentage
Commodities		
Field Crops	466,584	3.85%
Forest Products	5,361	0.04%
Marine Products	2,138	0.02%
Metallic Ores	93,371	0.77%
Coal	1,002,580	8.28%
Crude Petroleum	2,855	0.02%
Nonmetallic Minerals	371,109	3.06%
Ordnance or Accessories	1,838	0.02%
Food or Kindred Products	882,352	7.28%
Tobacco Products	1,222	0.01%
Textile Mill Products	9,533	0.08%
Apparel or Other Textile Products	46,414	0.38%
Lumber or Wood Products	487,386	4.02%
Furniture or Fixtures	34,101	0.28%
Pulp, Paper or Allied Products	483,980	4.00%
Newspapers and Books	15,933	0.13%
Chemicals	635,119	5.24%
Petroleum or Coal Products	158,794	1.31%
Rubber or Miscellaneous Plastics Products	62,202	0.51%
Leather Products	2,484	0.02%
Clay, Concrete, Glass or Stone Products	323,923	2.67%
Primary Metal Products	354,360	2.93%
Fabricated Metal Exc.	24,387	0.20%
Machinery Exc.	23,351	0.19%
Electrical Machinery	70,893	0.59%
Transportation Equipment	1,098,439	9.07%
Instruments, Optical Goods	3,192	0.03%
Miscellaneous Products	21,965	0.18%
Waste or Scrap Materials	342,374	2.83%
Miscellaneous Freight Shipments	60,474	0.50%
Containers	660,513	5.45%
Mail	43,970	0.36%
Freight Forwarder	3,689	0.03%
Shipper Association	48,529	0.40%
Miscellaneous Mixed Shipments	3,434,269	28.35%
Small Packaged Freight Shipments	62,495	0.52%
Waste Hazardous	7,329	0.06%
Other	762,855	6.30%
Car Ownership Category		
Privately Owned	5,349,791	44%
Railroad Owned	3,621,221	30%
Trailer Train	2,202,838	18%
Non-Categorized	939,731	8%
Waybills (Carrier-Origin-Destination-Date)	12,113,581	

Source: STB, Carload Waybill Sample

Study effect of merger on price changes case-by-case. Table A.4 shows the estimation result of shipment price changes. The result suggests that on average a railroad merger reduces the shipment price by 9.4%. If we look at the merger effect case by case, we find that most of the large mergers result in a price reduction of more than 10%, such as the merger of the Burlington Northern and Santa Fe, the merger of the Southern Pacific and Union Pacific, and the merger of the Chicago and North Western Railway (CNW) and Union Pacific. The only exception is the merger of the Seaboard System Railroad (SBD), Chesapeake and Ohio Railway (CO), and Baltimore and Ohio Railroad (BO) which occurred in 1986. Mergers involving smaller railroad firms have an insignificant impact on shipment price, likely because these mergers affect only a small fraction of routes.

Table A.4: Effect of Merger on Price Change

	(1)	(2)
	Log Price	Log Price
Indicator of Merger	-0.094***	
	(0.014)	
SBD		0.106***
		(0.021)
BNSF		-0.114***
		(0.023)
LA		-0.043
		(0.058)
MSRC		0.052
		(0.059)
IC		-0.025
		(0.041)
CNW		-0.162***
		(0.039)
MKT		0.009
		(0.044)
DRGW		0.018
		(0.043)
SP		-0.119***
		(0.021)
SSW		-0.227***
		(0.040)
WC		0.006
		(0.058)
Log Weight	-0.259***	-0.260***
	(0.015)	(0.015)
Private Railcars	-0.112***	-0.110***
	(0.009)	(0.009)
Trailer Train Railcars	-0.052***	-0.053***
	(0.009)	(0.009)
Observations	12,110,107	12,110,107
Number of marketID	22,510	22,510
Adjusted R-squared	0.361	0.363
Year FE	Y	Y
Firm FE	Y	Y
Commodity FE	Y	Y
O-D Route FE	Y	Y

Standard errors in parentheses, clustered at O-D route level

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Source: Surface Transportation Board, Carload Waybill Sample

As a robustness check, I run the price regression for each type of commodity (defined in STCC):

Table A.5: Effect of Merger on Price Change (by Commodities)

	(1) Field Crops	(2) Metallic Ores	(3) Coal	(4) Nonmetallic Minerals	(5) Food or Kindred Products	(6) Apparel or Textile Products	(7) Lumber or Wood Products	(8) Furniture or Fixtures	(9) Pulp, Paper	(10) Newspapers
Indicator of Merger	-0.009	0.048	-0.179***	-0.036	-0.052***	0.049	0.016	-0.023	-0.013	-0.057
	(0.014)	(0.062)	(0.028)	(0.029)	(0.014)	(0.047)	(0.013)	(0.036)	(0.015)	(0.042)
Observations	466,222	93,316	1,002,552	371,035	882,066	46,409	487,275	34,095	483,952	15,933
Number of marketID	6,982	1,086	1,360	3,697	10,766	1,210	8,145	1,694	8,441	780
Adjusted R-squared	0.178	0.144	0.251	0.234	0.266	0.767	0.274	0.829	0.299	0.667
Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
O-D Route FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

	(11) Chemicals	(12) Petroleum	(13) Plastics Products	(14) Clay, Concrete, Stone Products	(15) Primary Metal Products	(16) Fabricated Metal Exc.	(17) Machinery	(18) Electrical Machinery	(19) Transportation Equipment	(20) Miscellaneous Products
Indicator of Merger	-0.114***	-0.115***	-0.056**	-0.045***	-0.112***	-0.104***	-0.035	-0.146***	-0.022	0.022
	(0.031)	(0.024)	(0.028)	(0.015)	(0.027)	(0.035)	(0.037)	(0.038)	(0.035)	(0.035)
Observations	634,684	158,774	62,197	323,910	354,322	24,385	23,343	70,889	1,097,641	21,963
Number of marketID	10,462	4,175	2,087	6,670	6,639	2,009	2,072	1,996	7,177	1,163
Adjusted R-squared	0.157	0.210	0.730	0.262	0.163	0.558	0.413	0.569	0.321	0.765
Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
O-D Route FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

	(21) Waste or Scrap Materials	(22) Miscellaneous Freight Shipment	(23) Containers	(24) Mail	(25) Shipper Association	(26) Miscellaneous Mixed	(27) Small Packaged	(28) 49
Indicator of Merger	-0.000	-0.103*	0.049	0.036*	-0.179***	-0.170***	0.019	-0.072***
	(0.022)	(0.055)	(0.052)	(0.019)	(0.035)	(0.034)	(0.041)	(0.018)
Observations	341,973	60,443	660,061	43,965	48,523	3,434,108	62,487	762,745
Number of marketID	7,843	2,775	2,747	903	1,245	5,821	633	9,562
Adjusted R-squared	0.195	0.412	0.426	0.611	0.468	0.569	0.670	0.224
Year FE	Y	Y	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y
O-D Route FE	Y	Y	Y	Y	Y	Y	Y	Y
O-D Route Cluter	Y	Y	Y	Y	Y	Y	Y	Y