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

Yanyou Chen †

PRELIMINARY. DO NOT CITE.

This Version: *August 30, 2020*

Abstract

Increased efficiency is generally cited as the primary benefit of mergers to both consumers and industry. However, there is little evidence on the mechanism of cost efficiency following mergers and whether this cost efficiency offsets incentives to raise prices. This paper uncovers the sources of cost efficiencies following freight railroad mergers. Using detailed shipment data on 12 million waybills, I show that the average shipment price decreases by 9% following a merger. The price decreases by 11% where railcars must formerly be switched between two companies. To evaluate cost efficiencies, I estimate an optimal transport network model that features firms' pricing, routing, and investment decisions in multiple origin-destination markets. I use the model to decompose the sources of cost efficiencies and find that consumer welfare either increases or decreases depending on the topology of the network and location of the markets. Counterfactual simulations show that shipment cost decreases on average by 32% after mergers, implying a predicted price decrease of 10%.

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

*I am indebted to my committee members, Allan Collard-Wexler, Daniel Yi Xu, James W. Roberts, and Christopher D. Timmins, for valuable comments and encouragement throughout this research project. I also thank participants in the Railway Management Certificate Program for their valuable insights on the industry. Any remaining errors are mine alone. Disclaimer: Any opinions and conclusions expressed herein are those of the author and do not necessarily represent the views of the U.S. Surface Transportation Board. All results have been reviewed to ensure that no confidential information is disclosed.

†Department of Economics, University of Toronto, yanyou.chen@duke.edu.

1 Introduction

In the past thirty years, a small number of firms have gained a very large share of the market in the United States, following mergers and consolidations. Autor et al. (2017) document an upward trend over time that industries have become more concentrated on average. There is a large strand of literature documenting and analyzing mergers in multiple industries.[1] However, an open question is that are the efficiency gains of mergers small, large, or absent? In theory, on the one hand a merger gives the combined firm greater market power hence incentive to increase prices. On the other hand, a merger may generate efficiencies, reduce marginal costs, and give the combined firm an incentive to lower prices. Economists are aware of this trade-off since Williamson (1968), yet there is very little direct empirical evidence showing efficiency gain of mergers, and if it offsets the incentive to raise prices. This is largely because it is difficult to measure and quantify if mergers lower the marginal cost of production of the combined firm. The objective of this paper is to study the mechanism of cost efficiency after mergers in U.S. railroads, and evaluate if the efficiency gain offsets the incentive to raise prices. Moreover, I contribute to the merger analysis by proposing a novel way to study efficiency gain at a network industry where origin-destination markets are interdependent.

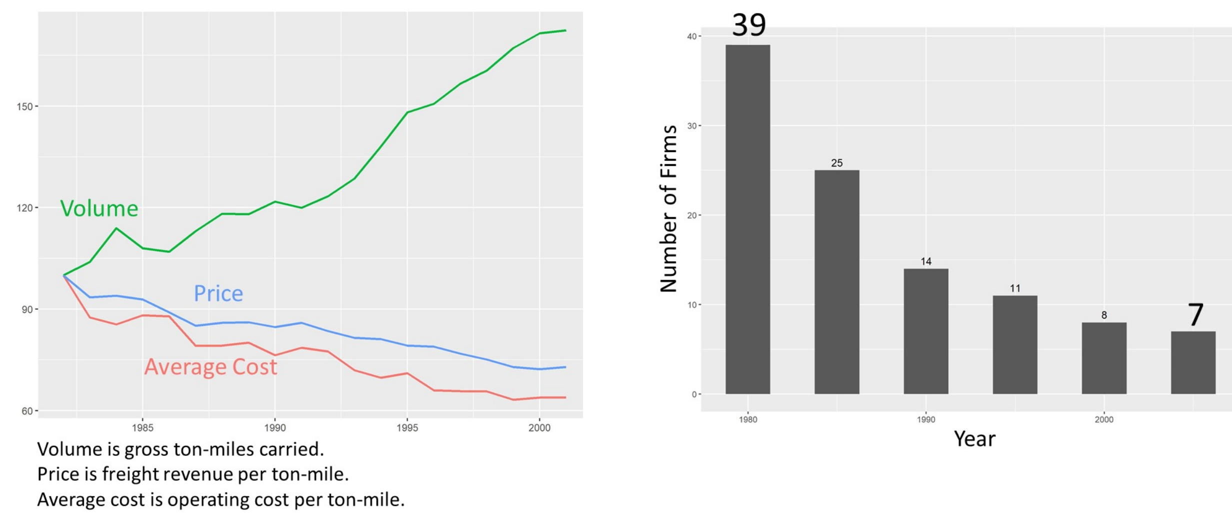
I do this by looking at the U.S. freight railroad industry. First, there was a series of merger from 1980 to 2005. The number of Class I railroads[2] dropped from 39 to 7, and market share of the top four firms increased from 66% to 94%. Although concentration has gone up in this industry, prices have decreased steadily. As illustrated in the left panel in Figure 1, from 1980 to 2005, prices per shipment have decreased by 20%, while the total volume of shipment has doubled. Given there is limited technological change in the studied period, the price reduction indicates that there might be efficiency gains following these railroad mergers. According to the Department of Transportation, in 2017, railroads are the second largest transport mode in providing freight service in the United States, 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

[1] In the airline industry, a wave of consolidation happened during a short period of time in the late 1980s (Peters, 2006); in the telecommunication industry, over 6,000 acquisitions occurred between 1996 and 2006 (Leeper, 1999; Jeziorski, 2014); a dozen global hard-disk manufacturers consolidated into only three in the last 20 years from 1996 to 2015 (Igami, 2017; Igami and Uetake, 2016); 190 hospital mergers occurred between 1989 and 1996 (Dafny, 2009; Bazzoli et al., 2002; Dranove and Lindrooth, 2003), and in the dialysis industry, more than 1,200 acquisitions occurred between 1998 and 2010 (Eliason et al., 2018).

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

40% of intercity ton-miles, more than any other mode of transportation.[3] Unlike many other industries, metrics of efficiency can be directly observed in railroad transport. At individual route level, the combined firm can abandon the redundant rail lines that serve the same origin and destination market. Also, the combined firm can eliminate the interchange cost where railcars need to be switched between two railroad companies before the merger. At network level, the combined firm can consolidate traffics and choose shorter efficiency-weighted routes that are not available before the merger.[4]

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



Source: AAR, Analysis of Class I Railroads Annual Issues

I use detailed shipment data on 12 million waybills to quantify the efficiency gain of mergers at both individual route level and network level. Railroad companies conduct point-on-point pricing, and the waybill data contains price information at firm-origin-destination level. The waybill data also contain detailed shipment information on such attributes as commodities carried, total billed weight, participating railroads, and origin, destination locations of each load. I begin my analysis by examining the price effect of mergers. By conducting reduced-form analysis at individual route level for each origin-destination market, I study

[3]One evidence that shows limited technological change in the studied time period is that 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.

[4]According to Kwoka and White (1997), efficiency gain of mergers include alleviation of capacity constraints, integration of track networks, reduction of mileage along major routes, and improved utilization of locomotives and railcars.

how prices change before and after mergers. After controlling for observable characteristics and a rich set of fixed effects, I find that on average shipment prices have decreased by 9% after mergers. Then I open up the merger cases and examine the price effects for different route types. For route where railroad companies exchange railcars before the merger, the price effect of merger is 11%. For other types of route, the price effect of merger is only 6%. The results suggest that efficiency gain of mergers vary by route types, and elimination of interchange cost where railroad firms exchange railcars is an important source of cost efficiency. One concern regarding these price effects is that such price effects might be driven by competition from other transportation modes, instead of mergers. I address this concern by showing that 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. The results suggest that the price effects are not driven by competition from other transportation modes.

I then provide motivating evidence to show that there is efficiency gain of mergers. I do this by examining changes of aggregate operational statistics at firm level, and also examine changes of operations at individual route level for each origin-destination market. At firm level, after controlling for observable characteristics, the reduced-form results show that on average the ratio of switching hours to road service hours has decreased by 11.5%, and length of haul has increased by 5.3% after railroad mergers. The results indicate that there is efficiency gain of mergers because the less time a train spends switching in yards the more efficient the operation is, and it is more fuel efficient for a train to run a longer distance. Results at individual route level also show that there is efficiency gain of mergers. By comparing the changes before and after mergers, I show that the number of interchanges has decreased following railroad mergers. Moreover, firms utilize more unit trains after mergers. 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. The use of unit trains saves time and money. The combined firm can reoptimize routing and consolidate traffics to initiate more unit trains after the merger.

One challenge in quantifying merger effects in the freight railroad industry, however, is that origin-destination markets in a railroad network are interdependent. The shipment cost from one origin to destination depends on the routing and investment decision, which depends on the location and demand of other markets in the railroad network. Therefore, looking only at changes at individual route level is insufficient for understanding mergers in this industry. To overcome this problem, I estimate a structural model that features firms pricing, routing, and investment decisions in multiple origin-destination markets based on the framework of Galichon (2016) and Fajgelbaum and Schaal (2017).

With the empirical evidence in mind, I propose an optimal transport network model that allows firms to choose pricing, routing, and investment for thousands of origin-destination markets. In the model, firms choose prices for the markets they serve, conditional on their perceived cost of operating there and the prices of competitors. Given the prices, the transportation service demanded for each firm in each origin-destination market is determined. Then firms jointly decide how to allocate infrastructure investment and make routing decisions in their network by minimizing the operational cost. Intuitively, firms allocate more resources to routes that carry larger volume of traffic, and choose the shortest efficiency-weighted routing to serve each origin-destination market. I model demand of transportation service using a nested logit model. Shippers choose between different railroad companies and an outside option which is trucking. Firms compete in prices, and in equilibrium, the perceived cost of operating at the pricing stage is consistent with the outcome from firms cost minimization problem. I consider the interdependence of markets in modeling routing and investment. Railroad firms can consolidate infrastructure investment into a small number of corridors, and then route traffic from multiple origins and destinations over these efficient corridors to reduce shipment cost. This allows operational cost to be dependent on topology of the network. For example, if origins and destinations locate near hubs, firms can consolidate traffics into a small number of routes through these hubs. If origins and destination locate in disperse regions, it is difficult to consolidate traffics from different origins and destinations into few efficient routes. I estimate the model using generalized method of moments, and the data moments are obtained from the detailed shipment data.

I then use the estimated parameters to conduct counterfactual simulations. Results of counterfactual simulations show that shipment cost decreases by 32% after mergers, which leads to a model predicted price decreases of 10%. The counterfactual simulations also decompose sources of cost efficiency into elimination of interchange cost, reallocation of resources for investment, and re-optimization of routing. The results suggest that elimination of interchange cost is the predominant source, which accounts for 44% of the cost reduction. Network efficiency that comes from routing accounts for 36% of the cost reduction. In general, the level of cost efficiency from a merger depends on the number of interconnecting services provided by the two merging parties, and it also depends on how traffic can be consolidated between the two merging parties. Last, I use the model to examine the trade-off between efficiency gains and increased market concentration, and study the implied welfare changes in different geographic markets. On the one hand, the degree of overlap between the two networks determine the incremental of market power, because the number of firms providing freight service decreases in the overlapped regions. On the other hand, the topology of the network and distribution of demand 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.

Contributions to the Literature. This paper adds to the literature on the effects of horizontal mergers by providing evidence of efficiency gain after mergers and uncovering the sources. 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.[5] 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.

This paper also contributes to the literature that studies the freight railroad industry. 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, McCullough and Angulo (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

[5]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.

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 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.

In this paper, I jointly model firms 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, Kalouptsidi and Papageorgiou (2017).[6] In both Buchholz (2015) and Brancaccio, Kalouptsidi and Papageorgiou (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 the interdependencies in routing in railroads.

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.

[6] 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, Kalouptsidi and Papageorgiou (2017) use detailed data on vessel movements and shipping contracts to study world trade costs and trade flows.

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 in the 1960s, many freight rail carriers faced liquidation.[7] 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.[8]

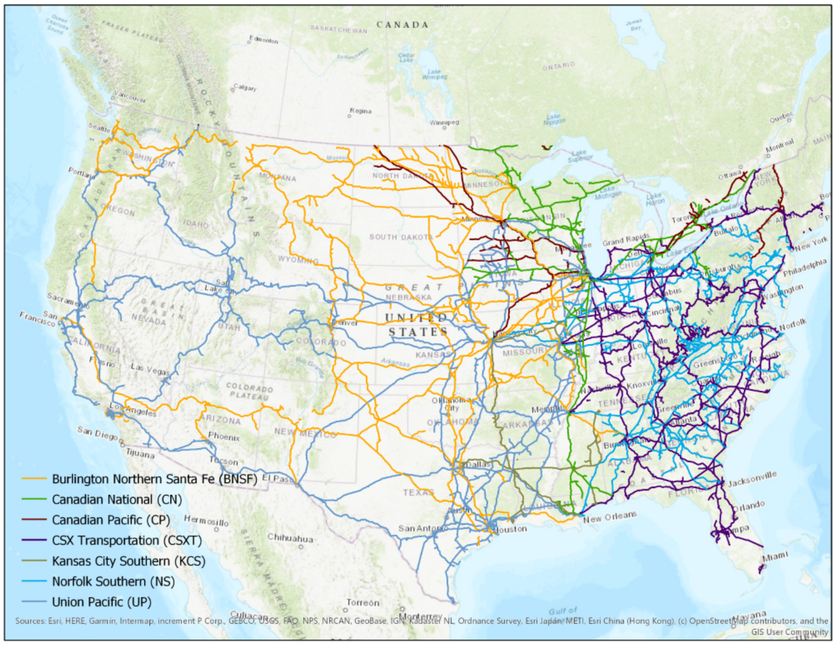
In response, a series of laws to deregulate the industry followed in the years 1973–1980.[9] Among them, the 1980 Staggers Act formally deregulated the industry, by offering railroad companies much greater pricing and operating freedom. The deregulation sparks a wave of mergers of railroad companies: 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 the Kansas City Southern railway (KCS) locates in the south and connects freight shipment between Mexico and the United States.

[7] 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.

[8] Figure B.1 and B.2 plots the total ton-miles of freight carried by different mode of transport and how it changed from 1980 to 2011.

[9] Appendix D provides details of regulation changes, and appendix A shows a complete history of railroad mergers.

Figure 2: U.S. Class I Railroads



Since the mergers, the U.S. freight railroad industry has enjoyed a renaissance, becoming not only self-sustaining but one of the most efficient freight 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.[10] 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.[11] 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

[10]The Surface Transportation Board defines a Class I railroad as "having annual carrier operating revenues of $250 million or more in 1991 dollars", which is equivalent to $464 million in 2017 dollars.

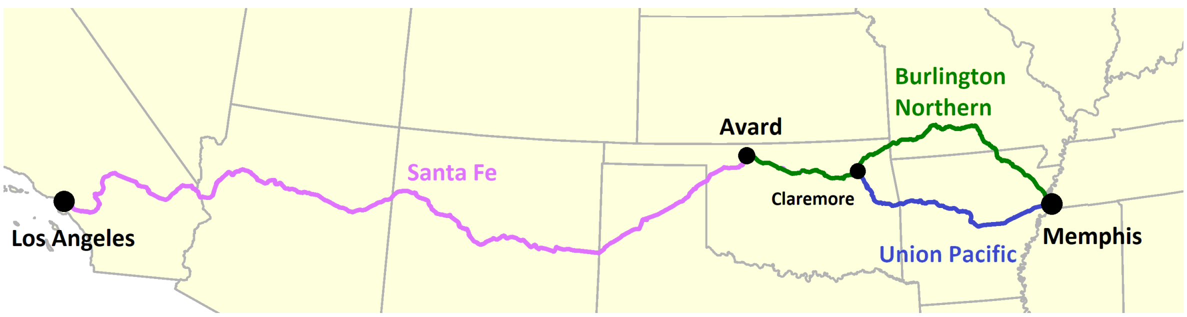
[11]The rest of the revenues are generated by regional and short lines. Check Appendix B for more details on regional and short lines.

by shipping coal are decreasing. Instead, the carloads of intermodal shipping[12] (Misc. mixed shipments such as containers) are increasing nowadays, and intermodal shipment accounts for 13% of total freight revenues in 2012.[13]

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.[14]

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."*

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

[13] Check Appendix B for more details on carloads originated by different types of commodities.

[14] 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.

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 investment decisions regarding track maintenance and locomotives. 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 is essential for railroad operation.[15] Regular track maintenance is costly,[16] and railroad companies decide on the frequencies of track evaluation in each region. In the example of train 9-698-21, if the railroad companies invest more in the route from Los Angeles to Memphis by allocating more locomotives and conducting more frequent track maintenance, 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. Efficiency gain of mergers at individual route level is achieved by eliminating interchange cost and combining resources of the two merging firms in each individual market. Efficiency gain of mergers at network level is achieved by re-optimization of routing and consolidating traffics across markets. Network efficiency depends on the topology of network and location of each

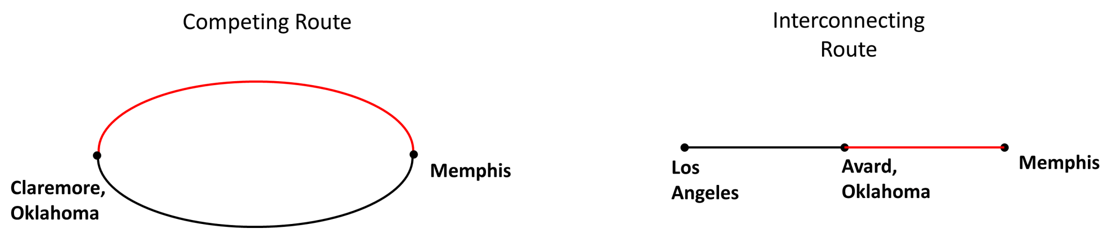
[15] To perform regular maintenance, railroad companies need to operate track evaluation cars to evaluate track geometry, performance based track geometry, rail wear etc and other things. Then the track evaluation cars will report the data for capital and maintenance planning.

[16] According to a Bloomberg report, 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. https://www.bloomberg.com/news/articles/2018-10-18/how-nj-transit-s-lifesaving-rail-task-dragged-while-cost-doubled

market.

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

Figure 4: Route Efficiency



In the case of competing routes, both merging parties provide freight service serving the same market before the merger. After the merger, firms can consolidate resources to one of the parallel lines and abandon the other to achieve greater cost efficiency.[17] In other words, firm can get rid of redundant rail lines by combining resources of the two merging firms. Based on the story of train 9-698-21 in Section 2, interchange is costly. Besides the evidence provided in that story, interviews with Terminal Superintendent of Conrail and Terminal Operations manager of Lake State Railway Company confirm that interchange usually means more delays and higher operational cost.[18] In the case of interconnecting route, the combined firm eliminates interchange costs following the merger.

Network Efficiency. Firms can achieve greater cost efficiency by optimizing over routing and consolidating traffic after mergers. More specifically, railroad firms can consolidate infrastructure investment into a small number of routes, and then consolidate traffics from multiple origins and destinations over these efficient routes to reduce shipment cost. The Chief Operating Officer, Cindy Sanborn of CSXT states that "An essential feature of the operating plan is to consolidate traffic over a smaller number of efficient, high-volume routes."[19] 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).

To elaborate how does topology of network affect efficiency gain of mergers, Figure 5 depicts two networks, network A and network B. Each network consists of three individual

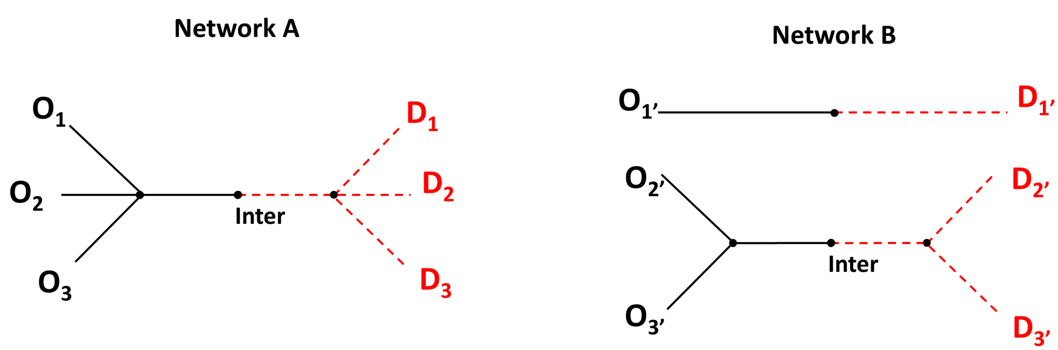
[17]In my model firms cannot physically abandon rail lines, but they can choose where to allocate the resources. Firms are allowed to allocate 0 resources to a rail line.

[18]More details of the interviews can be found in appendix C.

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

routes. There are two firms within each network, firm 1 owns all the black and solid lines, and firm 2 owns all the red and dashed lines. 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 the total mass of demand of market $O_{1'}$ to $D_{1'}$ in network B. Therefore, the only difference between these two networks are the topology of the network.

Figure 5: Network Efficiency



If merger effects only occur at individual route level, we should expect route O_1 to D_1 in network A and route $O_{1'}$ to $D_{1'}$ in network B 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 topology 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 topology of the network, 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 sample of carload waybills for all U.S. rail traffic submitted to the Surface Transportation Board (STB) by those rail carriers terminating 4,500 or more revenue carloads annually.[20] 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.[21]

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 materials such as concrete and clay.[22] 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.

[20]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. More details about Carload Waybill Sample can be found at `https://www.stb.gov/stb/industry/econ_waybill.html`.

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

[22]For full information of commodities shipped by rail, check Table E.3.

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.

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.[23] 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

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

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. 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)	(2)
	Log Price (Coal)	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.[24]

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 switching in railyards. The less time a train spends switching in yards, the more efficient the

[24]Results are in Appendix E and Table E.5.

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 E.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.[25]

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 Cluster	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 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.

[25] Results of robustness check are in Appendix E.

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.[26] 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.

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

To sum up, 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.

The Need for a Model. 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

[26] For more on commodity share, see Appendix B.

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 simultaneously choose prices, conditional on their perceived cost of themselves and their rivals. For interconnecting routes, I assume that the firms participating in the joint-line service jointly determines the price of the joint-line service. 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[27] and arcs as rail lines that connect each BEA economic area.

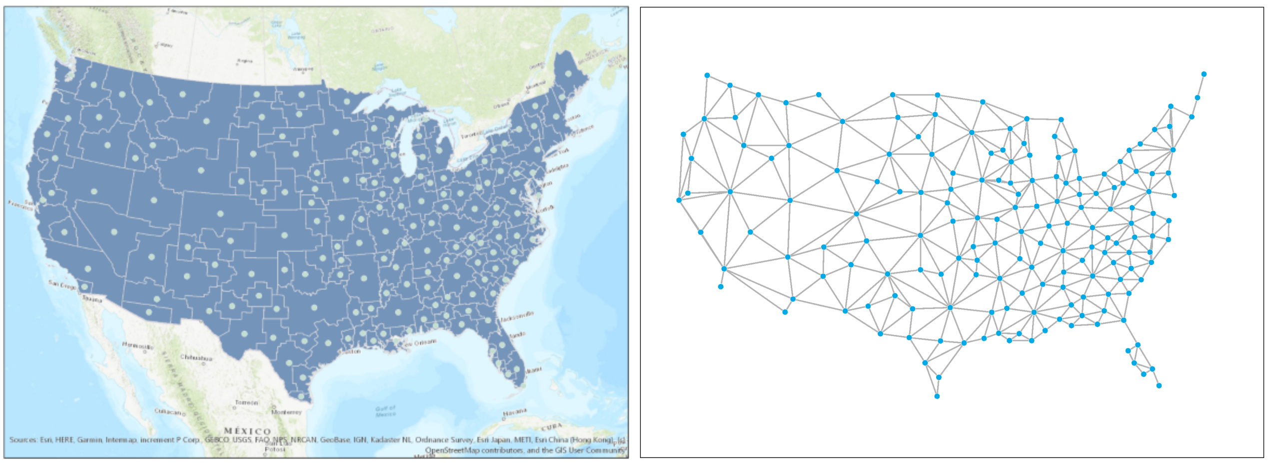
In order to project origin-destination shipment data to traffic in a rail network, I geocode the rail network and label the rail lines with affiliated railroad companies. I obtain detailed geographic information for each rail line and information about the ancestry of rail lines from the Federal Transit 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

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

the geocoded map of the current U.S. rail network.

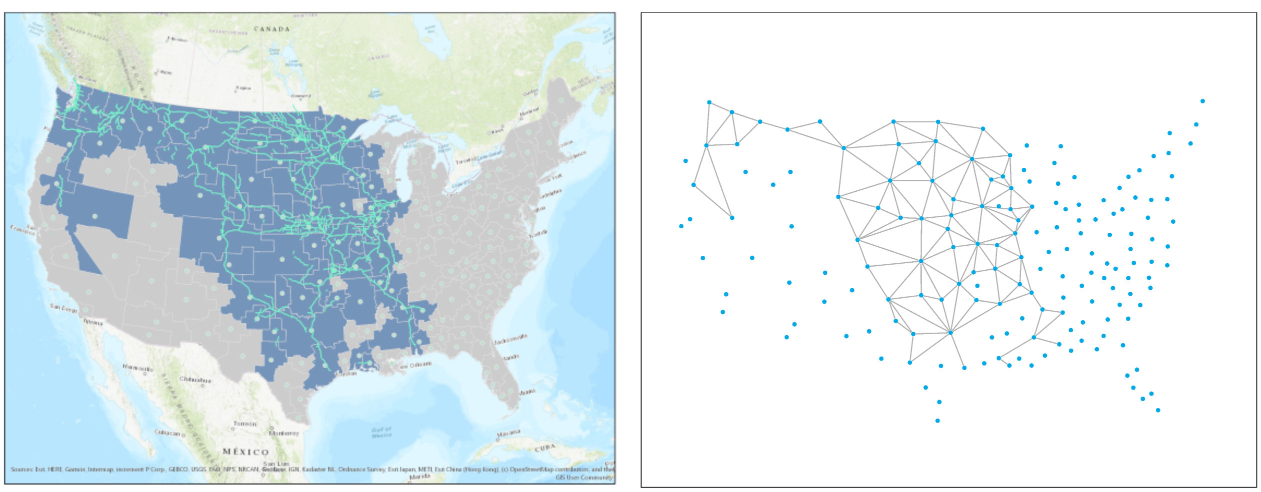
It shows all the BEA economic areas in the mainland U.S. and how they are converted into nodes and arcs in the virtual network for modeling.

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

Changed to logit model, need to change the estimation.

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 service-origin-destination level. For example, consumer i chooses service s to ship from origin o to destination d. A service s is either a single-line service or a joint-line service. Single-line service means that shipment from origin o to destination d is only carried by one railroad firm. Joint-line service means that the shipment is carried by more than one railroad firm and interchanges are incurred. Information of services in each market and firms providing these services are obtained from the data and assumed to be exogenous.

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 service s to ship from o to d, distance to customer's facility, which is measured by the logarithm of total miles of tracks of railroads, and the unobservable efficiency $\xi_{s,od}$.

The utility function is specified as:

$$u_{is,od} = \alpha \cdot \log p_{s,od} + \beta \cdot \log DistToFacility_{s,od} + \xi_{s,od} + (1-\sigma)\epsilon_{is,od}$$

where $\epsilon_{is,od}$ 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. To control for unobservable efficiency that are constant within significant subsets of the data, I include fixed effects of services, time periods, and markets.[28] Mathematically,

$$\xi_{s,od} = \alpha_s \cdot \text{Service}_s + \alpha_t \cdot \text{Time}_t + \alpha_{od} \cdot \text{Mkt}_{od} + \upsilon_{s,od}$$

Given the probability of choosing service s among all the rail services, multiply it by the probability of choosing railroad over other transportation modes, I obtain the probability of choosing service s in the market from o to d. Given that the distribution of $\epsilon_{is,od}$ is an identically and independently distributed extreme value, the probability of choosing service s in market from o to d is derived as

$$\Pr(\text{choose service } s \text{ in market } od) = \frac{e^{\mathrm{u}_{s,od}/(1-\sigma)}}{\sum_{s'\in rail_{od}} e^{\mathrm{u}_{s',od}/(1-\sigma)}} \cdot \frac{\left[\sum_{s'\in rail_{od}} e^{\mathrm{u}_{s',od}/(1-\sigma)}\right]^{(1-\sigma)}}{\left[\sum_{s'\in rail_{od}} e^{\mathrm{u}_{s',od}/(1-\sigma)}\right]^{(1-\sigma)} + \left[e^{\mathrm{u}_{0,od}/(1-\sigma)}\right]^{(1-\sigma)}}$$

[28] I estimate demand parameters and cost parameters separately in section 6. In the demand estimation, I use the whole sample that ranges from 1984-2000. So, I control for time fixed effects in the demand estimation. However, because my model is static, to be consistent with other parts of the model, I do not put a subscript t in defining $u_{is,od}$ and $\xi_{s,od}$.

it also gives a market share of:

$$shr_{s,od} = \frac{e^{\mathfrak{u}_{s,od}/(1-\sigma)}}{\sum_{s' \in rail_{od}} e^{\mathfrak{u}_{s',od}/(1-\sigma)} + \left(\sum_{s' \in rail_{od}} e^{\mathfrak{u}_{s',od}/(1-\sigma)}\right)^{\sigma}}$$

where $\mathfrak{u}_{0,od}$ is the mean utility of choosing the outside option, and the value is normalized to 0. $\mathfrak{u}_{s,od}$ is the mean utility of choosing service s from o to d at time t and

$$\mathfrak{u}_{s,od} = \alpha \log p_{s,od} + \beta \log DistToFacility_{s,od} + \xi_{s,od}$$

$rail_{od}$ is the set of railroad services from o to d. Also, the total quantity of freight that railroad service s ships from o to d is denoted as:

$$Q_{s,od} = M_{od} \cdot \frac{e^{\mathfrak{u}_{s,od}/(1-\sigma)}}{\sum_{s' \in rail_{od}} e^{\mathfrak{u}_{s',od}/(1-\sigma)} + \left(\sum_{s' \in rail_{od}} e^{\mathfrak{u}_{s',od}/(1-\sigma)}\right)^{\sigma}} \tag{1}$$

M_{od} is the total population of shipment from origin o to destination d.[29] Having set out the basic demand model, we can now derive the analytical expression for mean utility levels:

$$\ln(shr_{s,od}) - \ln(shr_{0,od}) = \alpha \log p_{s,od} + \beta \log DistToFacility_{s,od} + \sigma \ln(s\bar{h}r_{s,od/rail_{od}}) + \xi_{s,od}$$

where $s\bar{h}r_{s,od/rail_{od}}$ is the within-group market share of service s among all railroad services that serve market from o to d.

Estimates of demand parameters α, β 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:

$$\begin{aligned}
\frac{\partial Q_{s,od}}{\partial p_{s,od}} &= M_{od} \frac{\alpha}{1-\sigma} shr_{s,od} \left[1 - \sigma s\bar{h}r_{s,od/rail_{od}} - (1-\sigma) shr_{s,od}\right] \\
\frac{\partial Q_{s,od}}{\partial p_{s',od}} &= -M_{od} \frac{\alpha}{1-\sigma} shr_{s,od} \left[\sigma s\bar{h}r_{s',od/rail_{od}} + (1-\sigma) shr_{s',od}\right]
\end{aligned}$$

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

[29]In my model the total population of shipment of each market 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.

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

Therefore total consumer surplus across all markets equals to:[30]

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

5.3 Firm's Problem

Each firm j owns a network $\mathcal{N}_j$ with corresponding nodes $\mathcal{Z}_j$ and arcs $\mathcal{A}_j$. Firms make three types of decisions: pricing decision, routing decision, and allocation decision of investment. Firms choose prices $p_{s,od}$ for each service s, conditional on their perceived cost of themselves and their rivals. For interconnecting routes, I assume that firms participating in the joint-line service jointly determine the price of the joint-line service.[31] I also assume that firms do not consider the cannibalization between their own single-line service and joint-line service that they participate in for a given o-d market.[32] Then firms make routing and allocation decisions in their own network to minimize operation cost. Each firm j decides how to allocate investment $I_{j,ab}$ on each arc $(a,b) \in \mathcal{A}_j$. Each firm j also makes routing decisions $\mathcal{R}_{j,od_j(s)}$ for the transportation service demanded in each market. For a single-line service, firm j makes routing decision $\mathcal{R}_{j,od}$ from origin o to destination d. For a joint-line service, firm j makes routing decision $\mathcal{R}_{j,om}$ from origin o to interchange stations m if the firm serves the origin, or firm j makes routing decision $\mathcal{R}_{j,md}$ from interchange station m to destination d if the firm serves the destination. Routing $\mathcal{R}_{j,od_j(s)} \in \mathcal{A}_j$ is a subset of connected arcs that

[30] Actual consumer surplus equals to

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

where C is an unknown constant.

[31] I assume that there is no issue with double marginalization in the pricing of the interconnecting route based on findings from Alexandrov et al. (2018).

[32] This assumption has little impact on the empirical results because in the data a firm rarely provides both single-line service and joint-line service in the same market.

routes firm j from origin o_j to destination d_j. For interconnecting routes, I assume that the locations of interchange stations $m(s)$ and the firms participate in the joint-line service $J(s)$ are exogenous. By choosing the optimal routing and investment allocation decision, firms minimize their total operating cost. Firms make all decisions simultaneously and compete in prices. In equilibrium, the perceived cost of operating at the pricing stage is consistent with the outcome from firms cost minimization problem.

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

1. Price of service s from origin o to destination d, $p_{s,od}$

2. Routing decisions, $\mathcal{R}_{j,od_j(s)} \subseteq \mathcal{A}_j$

   - Single-line service: from origin o to destination d, $\mathcal{R}_{j,od} \subseteq \mathcal{A}_j$

   - Joint-line service: (WLOG) from origin o to interchange station m, $\mathcal{R}_{j,om} \subseteq \mathcal{A}_j$

3. Amount of resources to allocate to each arc (a, b), $I_{j,ab}$, $(a, b) \in \mathcal{A}_j$

Pricing Firms choose price of each service s, conditional on their perceived cost of themselves and their rivals. For interconnecting routes, I assume that the firms participating in the joint-line service determine the price jointly. [33]

The optimization problem of pricing of each service s is denoted as:

$$\tilde{\pi}_s := \max_{p_{s,od}} \left[p_{s,od} - \tilde{C}_{s,od}\right] \cdot Q_{s,od}(p_{s,od}, p_{-s,od})$$

where $\tilde{C}_{s,od}$ is the perceived cost of providing service s to ship from origin o to destination d.[34] Firms compete in prices and the transportation service demanded in each market $Q_{s,od}$ is derived in equation 1. Then the first-order condition of price $p_{s,od}$ is calculated as

$$\begin{aligned} \frac{\partial \tilde{\pi}_s}{\partial p_{s,od}} &:= Q_{s,od} + (p_{s,od} - \tilde{C}_{s,od}) \cdot \frac{\partial Q_{s,od}}{\partial p_{s,od}} \\ &= Q_{s,od} + (p_{s,od} - \tilde{C}_{s,od}) \cdot Q_{s,od} \cdot \frac{\alpha}{1-\sigma} \cdot \left[1 - \sigma s\bar{h}r_{s,od/rail_{od}} - (1-\sigma) shr_{j,od}\right] \end{aligned} \tag{2}$$

[33] In practice, the pricing department gets an estimate of operational cost from the operations department about how much money it costs to serve each origin-destination market. Then based on these cost estimates, the pricing department maximizes profits by charging a reasonable price margin that is allowed by the market. Check interview with business development manager of Canadian National in Appendix C for more details.

[34] In equilibrium, the perceived cost of operating at the pricing stage is consistent with the outcome from firms cost minimization problem.

where $s\bar{h}r_{j,od/rail_{od}}$ is the within-group share of railroad services serving market from o to d. Conditional on firms perceived cost of operating in each market, and combine equation 1 with equation 2, I can get the equilibrium prices $\{\tilde{p}_{s,od}, \tilde{p}_{-s,od}\}$ that firms charge in each market. Plug these prices back into equation 1, I get the transportation service demanded $Q_{s,od}(\tilde{p}_{s,od}, \tilde{p}_{-s,od})$ for each service s in each market from o to d.

Transport Cost The per-unit transportation cost of a service $C_{s,od}$ depends on the routing decision $\mathcal{R}_{\cdot,od}$ and investment allocation decision $\boldsymbol{I}$. For single-line service, $C_{s,od}$ is specified as: (Reduced number of parameters, no δ_1 now. Need to clarify this in write-up and code.)

$$C_{s,od}(\boldsymbol{I_j}, \mathcal{R}_{j,od}) = \sum_{(a,b)\in\mathcal{R}_{j,od}} c_{j,ab}(\boldsymbol{I_j})$$

where firm j is the firm that provides this single-line service from origin o to d, and $c_{j,ab}$ is the arc-level cost of firm j. The per-unit transportation cost $C_{s,od}$ is the summation of arc-level costs that firm j routes from o to d, and it depends on the routing decision $\mathcal{R}_{j,od}$, and investment allocation decision $\boldsymbol{I_j}$.

The per-unit transportation cost of joint-line service is specified as:

$$C_{s,od} = \sum_{(a,b)\in\mathcal{R}_{j,om}} c_{j,ab} + \sum_{(a',b')\in\mathcal{R}_{j',md}} c_{j',a'b'} + \eta$$

where η is the interchange cost, and m is the interchange station. Firm j carries the shipment from origin o to interchange station m, and firm j' carries the shipment from interchange station m' to destination d. The per-unit transportation cost of joint-line service $C_{s,od}$ is the summation of cost of firm j from o to m, and the cost of firm j' from m to d plus the interchange cost η.

I follow Galichon (2016) and Fajgelbaum and Schaal (2017) in defining the per-unit cost of transportation at arc level. The arc-level transportation cost of firm j at arc (a, b) is parameterized as:

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

The arc-level transportation cost $c_{j,ab}$ depends on the distance between a and b, and depends on the route efficiency $I_{j,ab}$. If firm j allocates more resources to arc (a, b), the route efficiency increases hence the arc-level transportation cost $c_{j,ab}$ decreases. For any arc (a', b') such that $(a', b') \notin \mathcal{A}_j$, the arc-level cost of transportation $c_{j,a'b'} = \infty$.[35]

[35]It is easy to enrich the model by adding geographic characteristics to the cost function such as in

Given the arc-level transportation cost, the general form of transportation cost of service s from origin o to destination d is written as:

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

where $J(s)$ is the set of firms that provides service s. For a single-line service provided by firm j, $J(s) = \{j\}$, and for a joint-line service provided by firm j and j', $J(s) = \{j, j'\}$. $\#_{interchanges}$ is the total number of interchanges incurred in providing service s.

Routing and Investment Allocation Given the prices, the transportation service demanded in each market is determined. Given the transportation service demanded in each market $Q_{j,od}(\tilde{p}_{j,od}, \tilde{p}_{-j,od})$, firms make routing and allocation decision to minimize operating cost. Firms choose routing $\{\mathcal{R}_{j,od_j(s)}\}$ and investment allocation decision $\{I_{j,ab}\}$ in their own railroad networks $(\mathcal{Z}_j, \mathcal{A}_j)$, by solving the cost minimization problem and satisfying the constraint of capital allocation and balanced-flow constraints. The cost minimization problem of firm j is written as:

$$\min_{\{\mathcal{R}_{j,od_j(s)}\},\{I_{j,ab}\}} \sum_{s: j \in J(s)} C_{s,od_j(s)}(\boldsymbol{I_j}, \mathcal{R}_{j,od_j(s)}) \cdot Q_{s,od}(\tilde{p}_{s,od}, \tilde{p}_{-s,od}) \tag{3}$$

such that

Constraint of capital allocation:

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

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, I can add congestion in the cost function by modifying c_{ab} as a function of total traffics q_{ab} that go through arc (a, b). I choose not to include congestion in my model because it does not provide new insights into my story here, but it adds computational complexity because the routing problem is no longer a linear programming problem if congestion is included.

Balanced-flow constraint, $\forall m' \in \mathcal{Z}_j$:

$$D_{j,m'} + \sum_{a \in \mathcal{Z}_j(m')} Q_{s,od} \cdot \mathbb{1}\{(a,m') \in \mathcal{R}_{j,od_j(s)}\} \leq \sum_{b \in \mathcal{Z}_j(m')} Q_{s,od} \cdot \mathbb{1}\{(m',b) \in \mathcal{R}_{j,od_j(s)}\}$$

The intuition of the capital allocation constraint is that each firm j has a fixed amount of capital K_j, that firm j can allocate to arcs in its network. The balanced-flow constraint means that for each node m', the total inflow of traffic plus the net demand equals to the total outflow of traffic. $Q_{s,od} \cdot \mathbb{1}\{(a,m') \in \mathcal{R}_{j,od_j(s)}\}$ measures the total traffic that run through arc (a,m') of firm j. Then the total inflow of traffic into node m' is the summation of traffic from all the arcs (a',m') of firm j, such that a' is in the neighborhood of node m, $a' \in \mathcal{Z}_j(m)$. $D_{j,m'}$ is the net demand at node m'.[36]

Let us first look at the routing problem. Given prices $\{\tilde{p}_{j,od}, \tilde{p}_{-j,od}\}$ and fix firms investment allocation decisions, firm j's routing problem from origin o_j to destination d_j is written as:

$$\min_{\mathcal{R}_{j,od_j(s)}} \sum_{(a,b) \in \mathcal{R}_{j,od_j(s)}} c_{j,ab} \cdot Q_{s,od} \tag{4}$$

s.t. $\forall m' \in \mathcal{Z}_j$, the balanced-flow constraint is satisfied:

$$D_{j,m'} + \sum_{a \in \mathcal{Z}_j(m')} Q_{s,od} \cdot \mathbb{1}\{(a,m') \in \mathcal{R}_{j,od_j(s)}\} \leq \sum_{b \in \mathcal{Z}_j(m')} Q_{s,od} \cdot \mathbb{1}\{(m',b) \in \mathcal{R}_{j,od_j(s)}\}$$

where $D_{j,m'}$ is the net demand of firm j at node m', and $\mathbb{1}\{\cdot\}$ is the indicator function that has value 1 if the condition is true and 0 otherwise. Solving equation 4 is equivalent to solving the minimization problem:

$$\min_{\mathcal{R}_{j,od_j(s)}} \sum_{(a,b) \in \mathcal{R}_{j,od_j(s)}} c_{j,ab}$$

$$\Rightarrow \min_{\mathcal{R}_{j,od_j(s)}} \sum_{(a,b) \in \mathcal{R}_{j,od_j(s)}} \frac{\delta_0 Dist_{j,ab}}{(1+I_{j,ab})^{\gamma}}$$

s.t. $\forall m' \in \mathcal{Z}_j$,

$$\mathbb{1}\{m' = o\} - \mathbb{1}\{m' = d\} + \sum_{a \in \mathcal{Z}_j(m')} \mathbb{1}\{(a,m') \in \mathcal{R}_{j,od_j(s)}\} \leq \sum_{b \in \mathcal{Z}_j(m')} \mathbb{1}\{(m',b) \in \mathcal{R}_{j,od_j(s)}\}$$

[36] $D_{j,m'} = \begin{cases} Q_{s,od} & \text{if } m' = o \\ -Q_{s,od} & \text{if } m' = d \\ 0 & \text{otherwise} \end{cases}$

The intuition of the routing problem is that firm j chooses the shortest efficiency-weighted route to travel from origin o_j to destination d_j in its own railroad network. Firm j obtains the optimal routing for each market from o_j to d_j by solving a linear programming problem.[37]

The optimal allocation decision is obtained by solving the cost minimization problem in equation 3. By taking the derivatives with respect to $I_{j,ab}$ for each firm j and arc $(a,b) \in \mathcal{A}_j$, the optimal investment allocation decision is solved as:

$$\begin{aligned} I_{j,ab} &= \left[\frac{\gamma}{\lambda_j} \sum_{s: j \in J(s)} \left(\delta_0 Dist_{j,ab} \cdot Q_{s,od} \cdot \mathbb{1}\{(a,b) \in \mathcal{R}_{j,od_j(s)}\} \right) \right]^{\frac{1}{1+\gamma}} - 1 \\ &= \left[\frac{\gamma}{\lambda_j} \cdot \delta_0 Dist_{j,ab} \cdot q_{j,ab} \right]^{\frac{1}{1+\gamma}} - 1 \end{aligned} \tag{5}$$

where $q_{j,ab}$ is the total amount of traffics that run through arc (a,b), and λ_j is the Lagrangian multiplier of the capital constraint of firm j.[38] Therefore, for any non-zero $I_{j,ab}$ and $I_{j,a'b'}$, from equation 5 we know that:

$$\frac{I_{j,ab} + 1}{I_{j,a'b'} + 1} = \left[\frac{Dist_{j,ab} \cdot q_{j,ab}}{Dist_{j,a'b'} \cdot q_{j,a'b'}} \right]^{\frac{1}{1+\gamma}} \tag{6}$$

The intuition of the allocation problem is that firms will allocate more resources to arcs that carry larger volume of traffic. Conditional on optimal routing, and combine equation 6 with the capital constraint of firm j such that $\sum_{(a,b) \in \mathcal{A}_j} I_{j,ab} = K_j$, I can obtain the solution of

[37] To represent a linear-programming problem, the routing problem from origin o to destination d can be written in vectors as:

$$\min_{\boldsymbol{q}} \boldsymbol{c} \times \boldsymbol{q}$$

$$\text{such that } \nabla \boldsymbol{q} = \boldsymbol{Q_s}, \text{ where } \boldsymbol{Q_s} = \begin{bmatrix} \cdots \\ -Q_{s,od} \\ 0 \\ 0 \\ Q_{s,od} \\ 0 \\ 0 \\ \cdots \end{bmatrix}$$

[38] Because the investment of track maintenance and locomotives cannot be negative, the optimal level of investment would be

$$I_{j,ab} = \max\{I_{j,ab}, 0\}$$

the optimal investment allocation problem.

To sum up, given the transportation service demanded of each service $Q_{s,od}(\tilde{p}_{s,od}, \tilde{p}_{-s,od})$, firms make routing and allocation decision by solving the cost minimization problem in equation 3. The optimal routing of firm j chooses the shortest efficiency-weighted route to travel from origin o_j to destination d_j by solving a linear programming problem, and the optimal allocation is solved by allocating more resources to arcs that carry larger volume of traffics.

In equilibrium, firms choose prices conditional on their perceived cost of themselves and their rivals. Given the prices, the transportation service demanded for each service is determined. Then, given the transportation service demanded in each market, firms make routing and allocation decision to minimize operating cost. Last, the outcome from firms cost minimization problem is consistent with the perceived cost of operating at the pricing stage.

6 Estimation

6.1 Demand Estimation

The utility function in my model is specified as:

$$u_{is,od} = \alpha \log p_{s,od} + \beta \log DistToFacility_{s,od} + \xi_{s,od} + (1-\sigma)\epsilon_{is,od}$$

where the utility of consumer i depends on three components. The price of service s to ship from o to d, distance to customer's facility, which is measured by the logarithm of total miles of tracks, and the unobservable efficiency $\xi_{s,od}$. $\epsilon_{is,od}$ is the consumer-specific deviation from the mean utility. I allow the railroad firms to be more substitutable among themselves, versus outside option which is trucking. Parameters that need to be estimated here are price coefficient α, coefficient on firm presence β, and within-group correlation parameter σ.

The demand estimation follows the procedure of Berry (1994), and estimates of α, β and σ are obtained from a linear instrumental variables regression.[39]

$$\ln(shr_{s,od}) - \ln(shr_{0,od}) = \alpha \log p_{s,od} + \beta \log DistToFacility_{s,od} + \sigma \ln(s\bar{h}r_{s,od/rail_{od}}) + \xi_{s,od}$$

$shr_{s,od}$ is the market share of service s in serving market from o to d, $shr_{0,od}$ is the market

[39] It is more efficient to estimate demand parameters and cost parameters together using GMM. Given the level of complexity of the firm's problem in my model, however, I choose to estimate demand parameters and cost parameters separately.

share of the outside option, which is trucking in serving market from o to d, and $s\bar{h}r_{s,od/rail_{od}}$ is the within-group market share of service s among all railroad services from o to d. 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.

In this application, shipment price $p_{s,od}$ and within-group market share $s\bar{h}r_{s,od/rail_{od}}$ are likely to be endogenous. I instrument price $p_{s,od}$ by the number of competing railroads that serve the same market from o to d, and I instrument within-group market share $s\bar{h}r_{s,od/rail_{od}}$ by characteristics of other railroads that serve the same market from o to d.

The intuition behind the expected correlation between the selected instruments and price $p_{s,od}$ is that, absent from perfectly collusive conduct, price will tend to fall with an increase in the number of competing railroads in the market from o to d. After controlling for market, firm, and time fixed effects of the unobservable efficiency $\xi_{s,od}$, I believe the instruments are uncorrelated with firms idiosyncratic efficiency shocks $v_{s,od}$. One concern is that market entry depends on firms idiosyncratic efficiency shocks $v_{s,od}$, therefore the instrument exogeneity assumption is violated. To address this concern, I define the number of competing railroads as number of railroads that have tracks connecting origin o to destination d. A firm that has tracks connecting origin o to destination d, may not necessarily choose to provide freight service in serving market from o to d.[40] The physical layout of rail in the United States was largely stable and unchanged in the time period under study. Therefore, the overall network structure is exogenous. Although firms endogenously choose which markets to serve, the number of railroad firms that have tracks connecting origin o to destination d in each market are assumed to be uncorrelated with firms idiosyncratic efficiency shocks $v_{s,od}$.

To instrument the within-group market share $s\bar{h}r_{s,od/rail_{od}}$, I use other firms characteristics in the origin o. The premise here is that shippers are more likely to choose a railroad to carry its shipment from the origin to the destination, if that railroad has longer tracks in the origin. This is because the longer miles of tracks a railroad has in a region, the more likely the railroad is closer to the shipper's facilities and easier to reach. The exogeneity assumption is satisfied because I assume the overall network structure is exogenous, hence the total miles of tracks of each firm in a region is fixed and orthogonal to firms idiosyncratic efficiency shocks $v_{s,od}$.

Table 9 reports the estimated parameters from the linear instrumental variables regression.

[40] Actively serving a market requires constant track maintenance, so firms may choose not to serve a market even if it has tracks connecting origin o to d.

Table 9: Demand Estimation Results

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

First, all parameters are highly significant with the expected sign. Shipment price is negatively correlated with market share, and firm presence is positively correlated with market share. The within-group correlation σ is significantly different from 0, which indicates that it is important to allow for closer substitution between railroads compared to other transportation modes. 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 price elasticity equals -1.3. The estimated aggregate elasticity is comparable to the estimates found by other research. For example, Ivaldi and McCullough (2005) found the price elasticity of bulk shipment in freight railroad is -1.52.

Given the estimated demand parameters, I can write the transportation service demanded in each market $Q_{s,od}(p_{s,od}, p_{-s,od})$ as a function of firms prices according to equation 1. Then, I can solve the firms optimization problem and estimate the cost parameters.

6.2 Estimation of Cost Parameters

In section 5, the arc-level transportation cost of firm j at arc (a, b) is parameterized as

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

The arc-level transportation cost $c_{j,ab}$ depends on the distance between a and b, and depends on the amount of investment $I_{j,ab}$. The per-unit transportation cost of service s is:

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

Therefore, the cost parameters to be estimated are δ_0, γ, and η. δ_0 captures the average shipment cost per efficient mile, γ captures the effectiveness of investment, and η captures interchange cost.Need to explain which parameter is pinned down by which moment.

I use simulated GMM to estimate δ_0, γ, and η. I target four data moments in estimating the parameters:[41]

Table 10: Targeted Data Moments

	Data Moments
Average shipping expense per actual mile	\$0.87
Change of average shipping expense per actual 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 identification argument is as follows: the first three moments jointly pin down the value of δ_0 and γ. The first and second moment measures the intercept and gradient of the effect that travel distance has on average shipping expense. Because δ_0 captures the average shipment cost per efficient mile, the larger the value of δ_0, the larger the value of average shipping expense per actual mile. γ captures the effectiveness of investment, and affects the conversion between shipping expense per efficient mile and shipping expense per actual mile. The value of δ_0 and γ jointly affects firms routing decisions, which in turn affects the

[41] 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

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

gradient of the effect that travel distance has on average shipping expense. The value of γ largely affects the value of the third moment, percentage of non-minimum-distance routing. Route efficiency depends on investment allocation decisions $I_{j,ab}$ and the value of γ. Firms will trade travel distance with the efficiency of the route when making routing decisions. When the value of γ increases, firms have more incentive to choose routing that deviates from minimum-distance routing. Therefore, the value of γ largely affects the percentage of routes that deviate from minimum-distance routing. To sum up, the first three moments jointly identify δ_0 and γ. Conditional on the value of δ_0 and γ, the last moment the average difference of shipping expense between an interconnecting route and a non-interconnecting route identifies the interchange cost η. When the value of interchange cost η increases, the average shipping expense of an interconnecting route increases, hence the difference between average shipping expense of an interconnecting route and average shipping expense of a non-interconnecting route increases.

Regarding the value of the data moments, average shipping expense per actual mile in the data is \$0.87. As a benchmark, according to AAR, in 2007 the average shipping expense per mile for a loaded car is \$1.2, which is comparable to the number I observe in my data here. In my data, if the total travel distance increases by 100 miles, the average shipping expense per mile decreases by \$0.11, which is equivalent to a 12% decrease of average shipping expense per mile. 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 around 20% of average shipment price.

I estimate the cost parameters by minimizing the weighted distance between data and simulated moments. Table 11 shows the estimated results:[42]

Table 11: Estimation Result of Cost Parameters

	Point Estimate
δ_0	0.9
γ	0.7
η	290

The estimated value of γ is less than 1. It indicates that the marginal return of investment is decreasing. Therefore, railroad companies are more likely to spread out investment of infrastructure into multiple arcs, rather than stacking investment of infrastructure in only

[42]The confidence intervals of the estimated parameters are obtained from bootstraps and coming in the future versions.

few arcs. Table 12 compares the data moments with simulated moments under the estimated cost parameters.

Table 12: Compare Simulated Moments with Data Moments

	Data Moments	Simulated Moments
Average shipping expense per car-mile	\$0.87	\$1.28
Change of average shipping expense per car-mile on total travel distance (per 100 miles)	\$-0.11	\$-0.10
Percentage of non-minimum-distance routing	18.3%	17.1%
Average difference of shipping expense between interconnecting route and non-interconnecting route	\$310	\$342

The model does well in matching the change in average shipping expense per car-mile on total travel distance, and the simulated moment approximates 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. This might be because conditional on routing, my model has a very restricted relation between travel distance and transportation cost. My model does not consider the topography such as elevation and ruggedness of the terrain. Therefore, the data moment might be different, because besides investment of infrastructure, other factors may also affect the average shipping expense per car-mile in the data. The simulated moment of average difference of shipping expense between interconnecting route and non-interconnecting route also deviates from the data moment. This might be because the simulated moment is capturing some of the systematic difference between interconnecting and non-interconnecting route. For example, interconnecting routes may have longer travel distance compared to non-interconnecting route, hence the average shipping expense captures the effect of longer travel distance.

6.3 Out-of-Sample Predictions

To validate the model, I perform out-of-sample predictions 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, I find:[43]

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 merger #4, 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 railway that is involved in merger #10 and merger #11, for which the accuracy of prediction is 50% and

[43]Due to confidentiality reasons, the names of the actual mergers are marked.

0%. This may be because the main business of that railway originates and ends in country outside the United States, 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 following each railroad merger and examine the efficiency gain from each source along with welfare changes in each geographic market.

7 Results

My model allows markets to be interdependent in the cost minimization stage, and the model has rich implications in understanding the change of transportation cost after mergers. I conduct counterfactual simulations of mergers and calculate the change of cost. Then I decompose the sources of cost efficiencies by fixing the pricing as the new equilibrium pricing after merger, and change the cost component one by one. Last, I evaluate the welfare changes at different geographic markets, and look at how topology of the network affects such changes.

7.1 Sources of Cost Efficiency

First, I conduct counterfactual simulations of mergers and calculate cost changes. For example, I observe the mass of demand, and I observe the network of each incumbent railroad firm including the Burlington Northern railway (BN) and the Santa Fe railway (SF) before the merger. Using the value of the estimated demand and cost parameters, I solve for each firm's pricing, routing, and investment decision, and derive the equilibrium price and shipment cost of each firm in each origin-destination market before the merger. Then I evaluate the merger between BN and SF. I fix the mass of demand and the network of railroad firms other than BN and SF as what they are before the merger. Then I combine the network of BN and the network of SF, and assume the merged firm BNSF makes pricing, routing, and investment decision in the newly combined network. Next I solve for the new equilibrium price and shipment cost of firms after the merger. By comparing the change of costs and prices before and after mergers, I find what the merger effect is. I repeat this kind of analysis and conduct merger simulations for all the mergers in my studied period. I find that on average shipment cost decreases by 32% after mergers. The model predicted price decrease from the merger simulations is 10.5%.

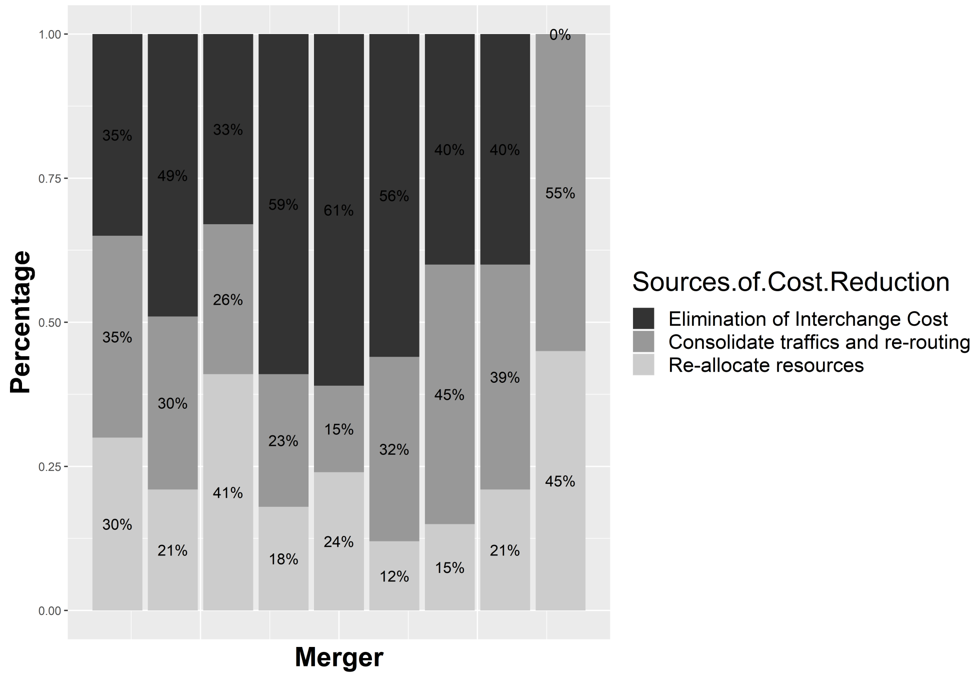
Second, I conduct other counterfactual simulations to decompose sources of cost efficiency, and I examine the importance of each source in determining efficiency gain following railroad mergers. In total there are three sources of efficiency gain: the elimination of interchange cost, the reallocation of resources for investment, and reoptimization of routing. First, I conduct a merger simulation by allowing for all three types of changes. The cost change after the merger is denoted as $\Delta C_{tot,od}$ for each origin-destination market. I then conduct a counterfactual by fixing the pricing as the new equilibrium pricing while holding routing and investment decisions the same as pre-merger routing and investment decisions. The cost changes under this counterfactual is denoted as $\Delta C_{inter,od}$. $\Delta C_{inter,od}$ measures the cost changes caused by elimination of interchange cost. Next, I conduct a counterfactual by fixing the pricing as the new equilibrium price, and holding the investment decisions the same as pre-merger investment decisions. The cost changes under this counterfactual is denoted as $\Delta C_{invest,od}$. The difference between $\Delta C_{invest,od}$ and $\Delta C_{inter,od}$ measures the cost changes caused by reallocation of resources for investment. Last, the rest of the change in cost (the difference between $\Delta C_{invest,od}$ and $\Delta C_{tot,od}$) is attributed to the reoptimization of routing.[44]

The counterfactual result shows that the reduction of interchange cost on average accounts for 44% of the cost reduction. The freedom to allocate resources on average accounts for 20% of the cost reduction, and the consolidation of traffic and reoptimization of routing on average accounts for 36% 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 by repeating this analysis for mergers in my studied period. Figure 8 shows that sources of efficiency gain vary across mergers. The variation depends on the number of interconnecting lines involved in each merger and on the network structure of the firms. In general, the elimination of interchange costs is the most important source of efficiency gain.

[44]The three sources of efficiency interact with each other. For example, the routing decision depends on if the interchange cost is eliminated or not. Therefore, the exact decomposition of cost changes depends on the sequence of how I conduct the counterfactuals.

Figure 8: Sources of Efficiency Gain Across Mergers

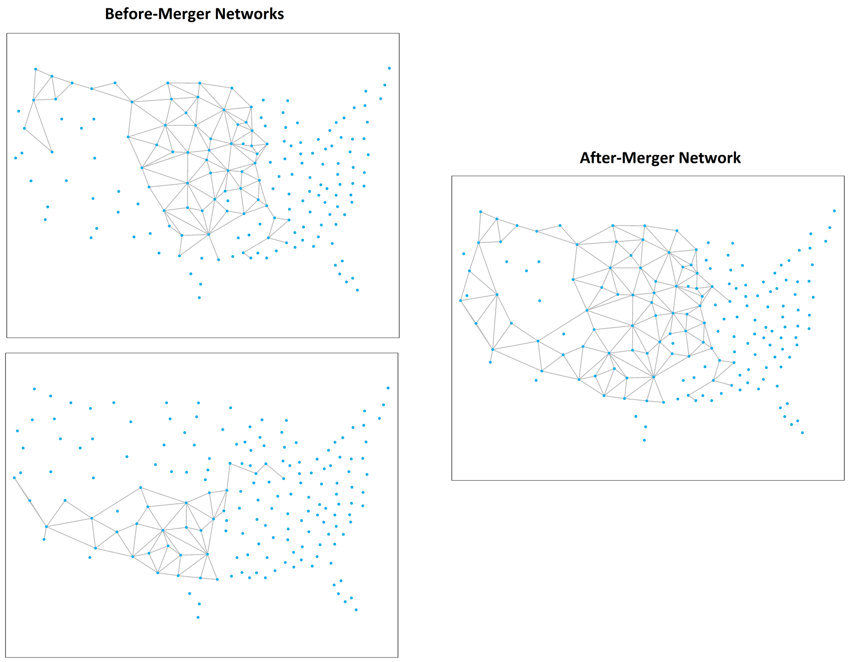


7.2 Heterogeneity of Welfare Changes

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 topology 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. Here I need more explanations, what happens before and after the merger. What is changed.

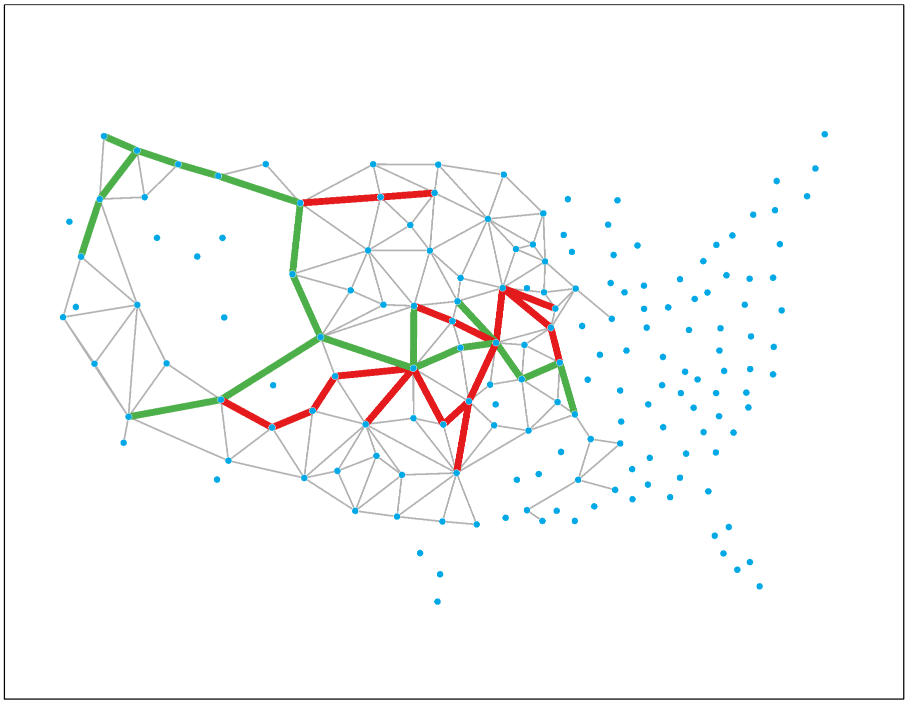
Figure 9 illustrates the network of the Burlington Northern and the Santa Fe before and after their merger. The left panel shows the networks owned by the Burlington Northern (top) and the Santa Fe (bottom). The right panel shows merged network. Note that the network of the Burlington Northern and the 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



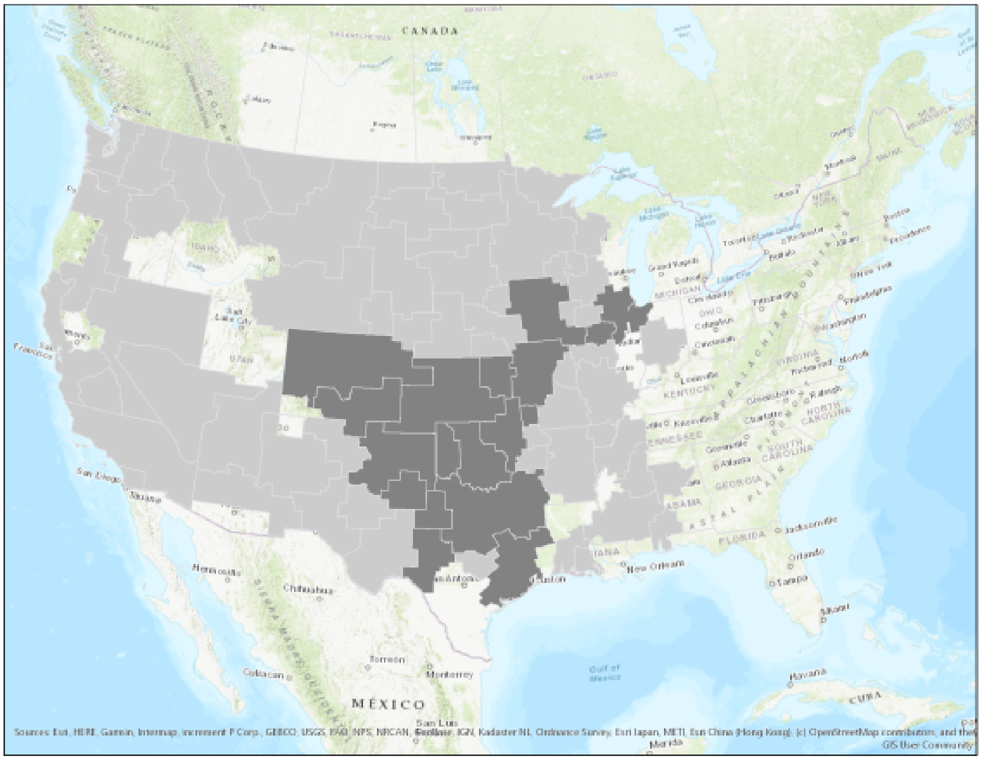
I first examine the efficiency gain following this merger. The merger simulation displays the firm's decision on routing and investment of track maintenance and locomotives in the new equilibrium. By comparing the investment decision before and after the merger, I show how the allocation of resources 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



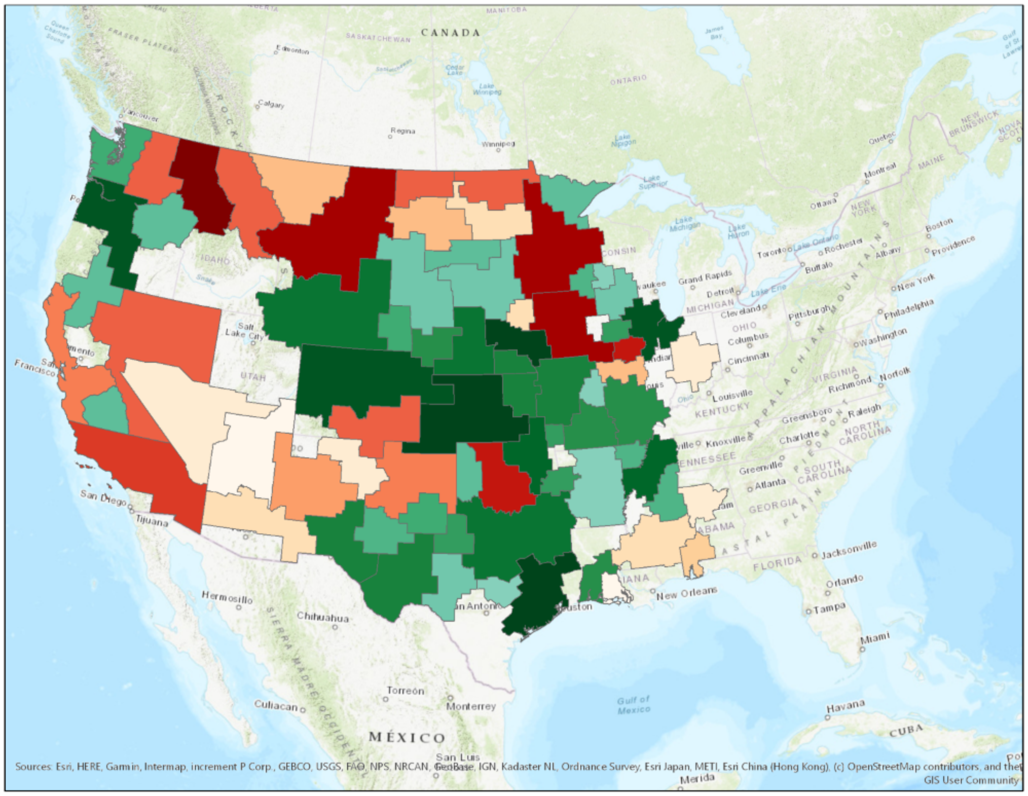
Next, I examine the change of market power in different geographic markets following the merger of the Burlington Northern and the Santa Fe. The gray areas in Figure 11 depict all regions affected by this merger. Light gray areas are regions where only one of the two companies provides freight service 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 44% of cost reduction. The freedom to allocate resources on average accounts for 20% of cost reduction, and the consolidation of traffic and reoptimization of routing on average accounts for 36% 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, it is difficult to integrate two large networks into one. For example, when the Union Pacific railway acquires the Southern Pacific railway, integration of their networks is difficult and has a large negative impact on freight transportation in the short run. The trade-off between short-term chaos and long-term efficiency gain is not considered in my model. Moreover, when the number of firms decreases, firms may find it easier to collude. In the U.S. freight railroad industry there are 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 exploring.

References

Alexandrov, Alexei, Russell W Pittman, and Olga Ukhaneva, "Pricing of Complements in the US freight railroads: Cournot versus Coase," *US Department of Justice, Antitrust Division, Economic Analysis Group Discussion Paper EAG*, 2018, pp. 18–1.

Armstrong, John H, *The Railroad: What it is, What it Does. The Introduction to Railroading*, Simmons Boardman Pub Co, 1990.

_ , "Track planning for realistic operation," 1998.

Ashenfelter, Orley C, Daniel S Hosken, and Matthew C Weinberg, "Efficiencies brewed: pricing and consolidation in the US beer industry," *The RAND Journal of Economics*, 2015, *46* (2), 328–361.

Autor, David, David Dorn, Lawrence F Katz, Christina Patterson, and John Van Reenen, "The fall of the labor share and the rise of superstar firms," 2017.

Bazzoli, Gloria J, Anthony LoSasso, Richard Arnould, and Madeleine Shalowitz, "Hospital reorganization and restructuring achieved through merger," *Health Care Management Review*, 2002, *27* (1), 7–20.

Berry, Steven, James Levinsohn, and Ariel Pakes, "Automobile prices in market equilibrium," *Econometrica: Journal of the Econometric Society*, 1995, pp. 841–890.

Berry, Steven T, "Estimating discrete-choice models of product differentiation," *The RAND Journal of Economics*, 1994, pp. 242–262.

Borenstein, Severin, "Airline mergers, airport dominance, and market power," *The American Economic Review*, 1990, *80* (2), 400–404.

Brancaccio, Giulia, Myrto Kalouptsidi, and Theodore Papageorgiou, "Geography, Search Frictions and Endogenous Trade Costs," Report, National Bureau of Economic Research 2017.

Buchholz, Nicholas, "Spatial equilibrium, search frictions and efficient regulation in the taxi industry," Report, Technical report, University of Texas at Austin 2015.

Casavant, Ken, Eric Jessup, Marvin E Prater, Bruce Blanton, Pierre Bahizi, Daniel Nibarger, Johnny Hill, and Isaac Weingram, "Rail rate and revenue changes since the Staggers Act," in "Journal of the Transportation Research Forum," Vol. 50 2012.

Chapin, Alison and Stephen Schmidt, "Do mergers improve efficiency? Evidence from deregulated rail freight," *Journal of Transport Economics and Policy*, 1999, pp. 147–162.

Cheaney, Douglas G., "How To Ship By Rail," 2009.

Cho, Soo-Haeng, "Horizontal mergers in multitier decentralized supply chains," *Management Science*, 2013, *60* (2), 356–379.

Ciliberto, Federico, Emily E Cook, and Jonathan W Williams, "Network Structure and Consolidation in the US Airline Industry, 1990–2015," *Review of Industrial Organization*, 2017, pp. 1–34.

Collier, Paul, Martina Kirchberger, and Måns Söderbom, "The cost of road infrastructure in low-and middle-income countries," *The World bank economic review*, 2015, *30* (3), 522–548.

Corsi, Thomas M, Ken Casavant, and Tim A Graciano, "A preliminary investigation of private railcars in north america," in "Journal of the Transportation Research Forum," Vol. 51.

Coublucq, Daniel, *Demand Estimation with Selection Bias: A Dynamic Game Approach with an Application to the US Railroad Industry* number 94, DICE Discussion Paper, 2013.

Dafny, Leemore, "Estimation and Identification of Merger Effects: An Application to Hospital Mergers," *Journal of Law and Economics*, 2009, *52.*

Davis, David E and Wesley W Wilson, "Deregulation, mergers, and employment in the railroad industry," *Journal of Regulatory Economics*, 1999, *15* (1), 5–22.

Design, Construction, "Railway Transportation Systems," 2016.

Donaldson, Dave, "Railroads of the Raj: Estimating the impact of transportation infrastructure," Report, National Bureau of Economic Research 2010.

Dranove, David and Richard Lindrooth, "Hospital consolidation and costs: another look at the evidence," *Journal of health economics*, 2003, *22* (6), 983–997.

Drury, George H, *The historical guide to North American railroads*, Kalmbach Publishing, Co., 2000.

Eliason, Paul J, Benjamin Heebsh, Ryan C McDevitt, and James W Roberts, "How ownership changes affect behavior and outcomes: Evidence from dialysis facility acquisitions," Technical Report, Working paper 2018.

Fajgelbaum, Pablo D and Edouard Schaal, "Optimal transport networks in spatial equilibrium," Report, National Bureau of Economic Research 2017.

Friebel, Guido, Gerard McCullough, and Laura Padilla Angulo, "Patterns of Restructuring The US Class 1 Railroads from 1984 to 2004," *Journal of Transport Economics and Policy (JTEP)*, 2014, *48* (1), 115–135.

Galichon, Alfred, *Optimal Transport Methods in Economics*, Princeton University Press, 2016.

Gallamore, Robert E and John Robert Meyer, *American Railroads*, Harvard University Press, 2014.

Gavazza, Alessandro, "Asset liquidity and financial contracts: Evidence from aircraft leases," *Journal of financial Economics*, 2010, *95* (1), 62–84.

_ , "Leasing and secondary markets: Theory and evidence from commercial aircraft," *Journal of Political Economy*, 2011, *119* (2), 325–377.

Grimm, Curtis and Clifford Winston, "Competition in the deregulated railroad industry: Sources, effects, and policy issues," *Deregulation of network industries: What's next*, 2000, pp. 41–71.

Harrison, E. Hunter, *How We Work and Why*, Canadian National Railway Company, 2005.

Hastings, Justine S, "Vertical relationships and competition in retail gasoline markets: Empirical evidence from contract changes in Southern California," *The American Economic Review*, 2004, *94* (1), 317–328.

Igami, Mitsuru, "Estimating the innovator's dilemma: Structural analysis of creative destruction in the hard disk drive industry, 1981–1998," *Journal of Political Economy*, 2017, *125* (3), 798–847.

_ **and Kosuke Uetake**, "Mergers, Innovation, and Entry-Exit Dynamics: Consolidation of the Hard Disk Drive Industry, 1996-2015," 2016.

Ivaldi, Marc and Gerard J McCullough, "Welfare trade-offs in US rail mergers," 2005.

Jeon, Jihye, "Learning and Investment under Demand Uncertainty in Container Shipping," 2016.

Jeziorski, Przemysław, "Estimation of cost efficiencies from mergers: Application to US radio," *The RAND Journal of Economics*, 2014, *45* (4), 816–846.

Jourquin, Bart, "Estimating elasticities for freight transport using a network model: an applied methodological framework," *Journal of Transportation Technologies*, 2018, *9* (01), 1.

Jr, Alfred D Chandler, "The Visible Hand: The Managerial Revolution in American Business (Cambridge, Mass., 1977)," *ChandlerThe visible hand: the managerial revolution in American business1977*, 1990.

Kalouptsidi, Myrto, "Time to build and fluctuations in bulk shipping," *The American Economic Review*, 2014, *104* (2), 564–608.

Kim, E Han and Vijay Singal, "Mergers and market power: Evidence from the airline industry," *The American Economic Review*, 1993, pp. 549–569.

Krebs, Robert D, *Riding the Rails: Inside the Business of America's Railroads*, Indiana University Press, 2018.

Kwoka, John E and Lawrence J White, "Manifest destiny? The union Pacific-Southern Pacific merger," 1997.

Leeper, Sarah Elizabeth, "The game of radiopoly: An antitrust perspective of consolidation in the radio industry," *Fed. Comm. LJ*, 1999, *52*, 473.

MacDonald, James M, "Competition and rail rates for the shipment of corn, soybeans, and wheat," *The RAND Journal of Economics*, 1987, pp. 151–163.

magazine Editors of Trains, "Great American Railroad Stories: 75 Years of Trains magazine," 2014.

McCullough, Gerard J, "US railroad efficiency: A brief economic overview," *Faculté d'économie appliquée, université du Minnesota, Minneapolis*, 2005.

McGuckin, Robert H and Sang V Nguyen, "On productivity and plant ownership change: New evidence from the longitudinal research database," *The RAND Journal of Economics*, 1995, pp. 257–276.

Peltzman, Sam and Clifford Winston, *Deregulation of network industries: what's next?*, Brookings Institution Press, 2000.

Pesendorfer, Martin, "Horizontal Mergers in the Paper Industry," *RAND Journal of Economics*, 2003, *34* (3), 495–515.

Peters, Craig, "Evaluating the performance of merger simulation: Evidence from the US airline industry," *The Journal of law and economics*, 2006, *49* (2), 627–649.

Pittman, Russell W, "Railroads and Competition: The Santa Fe/Southern Pacific Merger Proposal," *The Journal of Industrial Economics*, 1990, pp. 25–46.

_ , "Railway Mergers and Railway Alliances: Competition issues and lessons for other network industries," 2009.

Prater, Marvin E, Ken Casavant, Eric Jessup, Bruce Blanton, Pierre Bahizi, Daniel Nibarger, and Isaac Weingram, "Rail competition changes since the Staggers Act," in "Journal of the Transportation Research Forum," Vol. 49 2012.

STB, "Economics, Service, and Capacity in the Freight Railroad Industry," Technical Report, Hearing before the Subcommittee on Surface Transportation 2006.

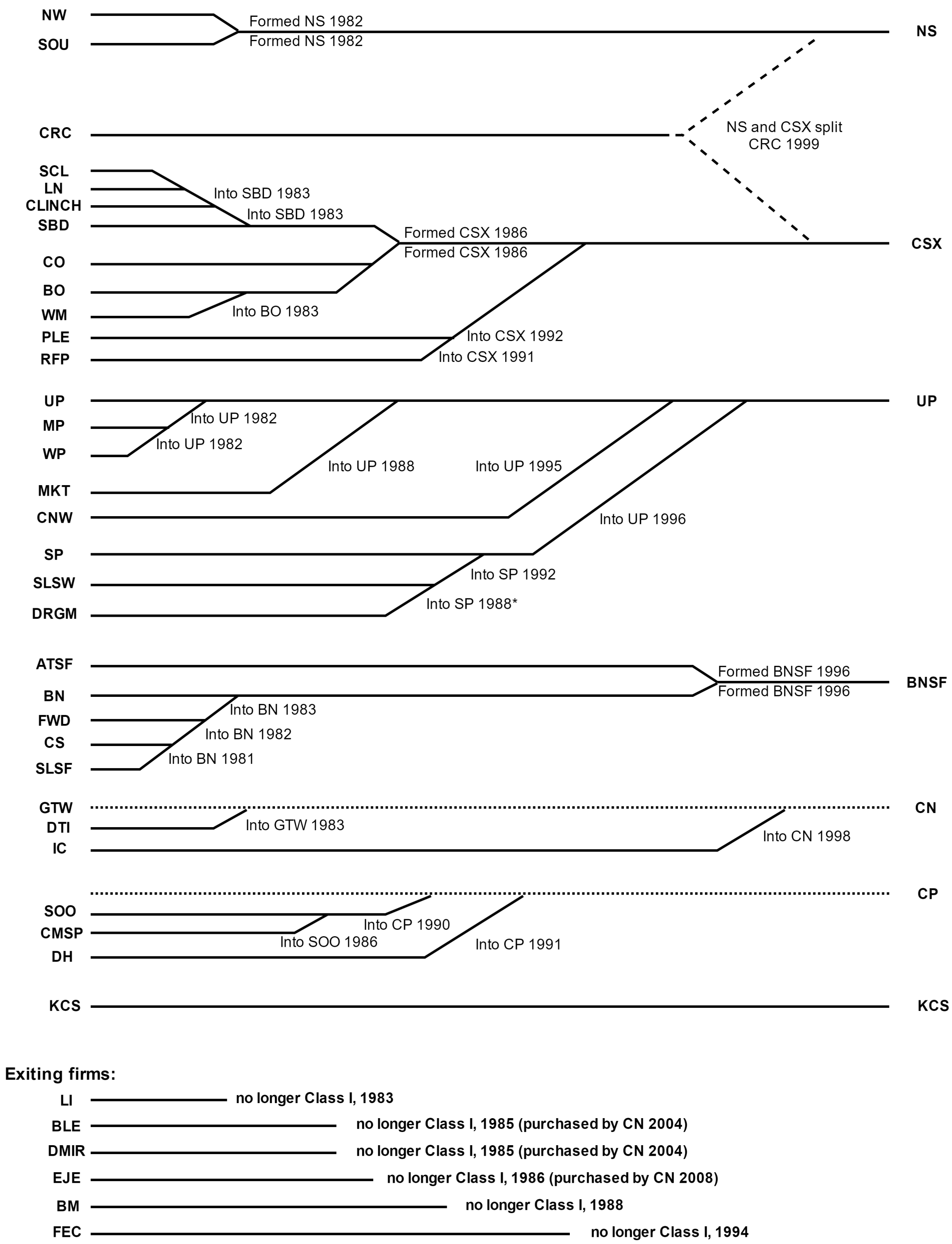
_ , "An Examination of the STB's Approach to Freight Rail Rate Regulation and Options for Simplification," Technical Report, Project FY14-STB-157 2016.

Williamson, Oliver E, "Economies as an antitrust defense: The welfare tradeoffs," *The American Economic Review*, 1968, *58* (1), 18–36.

Winston, Clifford, "US industry adjustment to economic deregulation," *The Journal of Economic Perspectives*, 1998, *12* (3), 89–110.

A Merger History

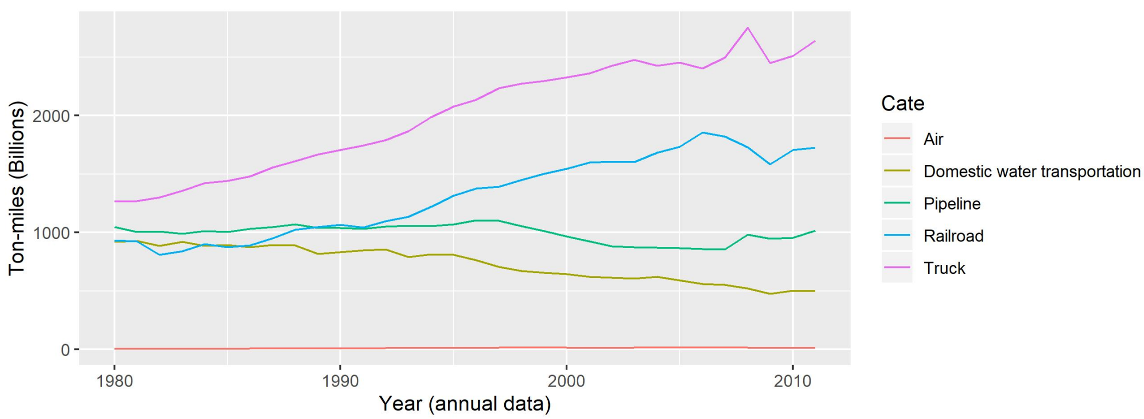
Figure A.1: Merger History of Railroads



B Details of U.S. Railroad Industry

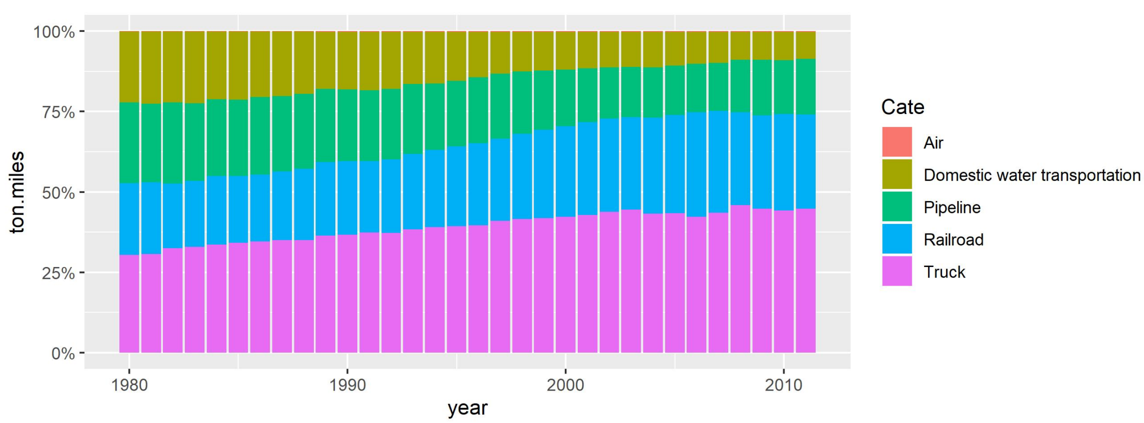
Figure B.1 and B.2 plots the total ton-miles of freight carried by mode, from 1980 to 2011 Importance of railroad industry among all the transportation mode. We can see that the U.S. railroad industry only accounts fo a small proportion of total ton-miles of freight (around 20%), and even accounts for 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 B.1: U.S. total ton-miles of freight by mode



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

Figure B.2: 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 B.3, Class I railroads generate around 95% of the total freight revenues).

Figure B.3: U.S. Freight Railroad Industry 2012

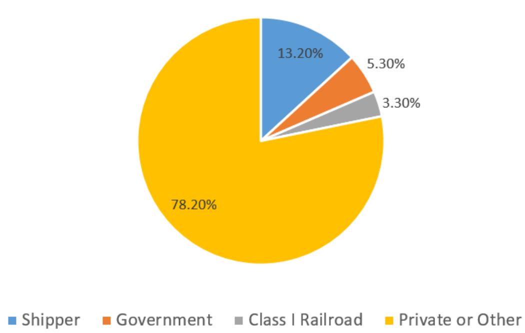
U.S. Freight Railroad Industry 2012

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 B.3) and serve this purpose; Third, used as interchanging places for different railroad companies to interchange the shippings.

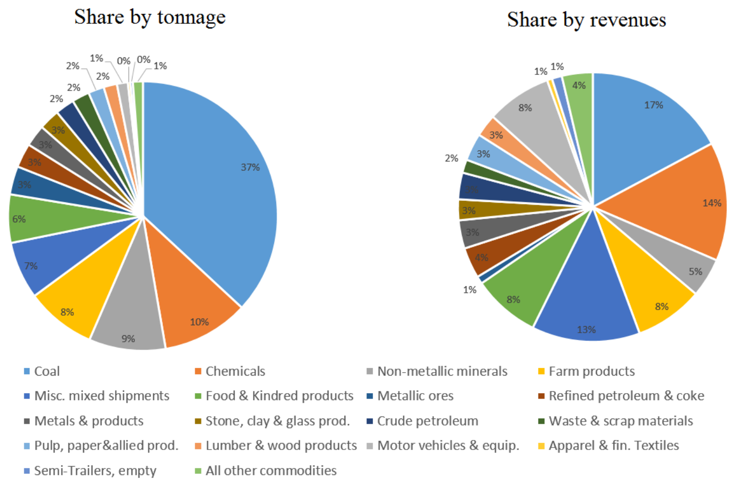
Figure B.4: Ownership of Regional and Short Lines



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 B.5: Carloads originated by commodity



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

C 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 business development manager of Canadian National:

   - How do firms make pricing decision?

     - The pricing department gets an estimate of operational cost from the Costing department about how much money it costs to serve each origin-destination market. Then based on these cost estimates, the pricing department maximizes profits by charging a reasonable price margin as much as the market allows.

     - (The downward spiral) The service of a particular origin-destination market will be reduced if the operational cost outweighs the generated profits. However, sometimes this happens only because the operational cost is mismeasured. For example, the actual miles run by the train may not necessarily be fully related to the service it is providing. As a consequence, once a service is reduced, the volume of shipment decreases thus the operational cost further increases on a per-car basis, and more services get reduced.

   - How is interchange contract negotiated?

     - Usually the origin railroad has the bargaining power, but it depends. For example, there was a time when CN needs to make some shipment from Vancouver to New York, and they ask for a quote from the connecting railroad on shipment from Buffalo to New York. However, the Marketing representative from the other railroad only agree to give quote from Chicago to New York, rather than from Buffalo to New York, in order to maximize their revenue. "The hot stuff of one person is not the hot stuff of the other."

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.*

D 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)

E Robustness Check of Reduced-form Analysis

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

Table E.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 E.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 E.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 E.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 E.4: Effect of Merger on Price Change

	(1) Log Price	(2) 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 E.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

F The Algorithm

Solve for convergence of price vectors:

Given a price vector (firm-origin-destination), say $\mathbf{P_0}$
Calculate demand vector (firm-origin-destination) ← *Where demand kicks in*

Solve for convergence of allocation of resources:

Given vector of allocation of resources (firm-arc), say $\mathbf{I_0}$ ← *Where ownership of network kicks in*
Calculate transportation cost (firm-arc)

Solve for routing for each firm-origin-destination pair, say q

Given new allocation of resources $\mathbf{I_1}$ and routings $\mathbf{q}$
Calculate vector of marginal cost of shipment (firm-origin-destination)

Given demand function and cost vectors
Calculate new equilibrium price vector $\mathbf{P_1}$ (firm-origin-destination) ← *Where competition kicks in*

When solving for new equilibrium price vector P_1, need to solve for NE price vectors of all the firms. So, there is another loop here in solving the NE.

G The Algorithm: Solving Optimal Infrastructure

The optimal allocation decision is obtained by solving the cost minimization problem in equation 3. By taking the derivatives with respect to $I_{j,ab}$ for each firm j and arc $(a,b) \in \mathcal{A}_j$, the optimal investment allocation decision is solved as:

$$\begin{aligned} I_{j,ab} &= \left[\frac{\gamma}{\lambda_j} \sum_{s:j\in J(s)} \left(\delta_0 Dist_{j,ab} \cdot Q_{s,od} \cdot \mathbb{1}\{(a,b) \in \mathcal{R}_{j,od_j(s)}\} \right) \right]^{\frac{1}{1+\gamma}} - 1 \\ &= \left[\frac{\gamma}{\lambda_j} \cdot \delta_0 Dist_{j,ab} \cdot q_{j,ab} \right]^{\frac{1}{1+\gamma}} - 1 \end{aligned} \tag{7}$$

where $q_{j,ab}$ is the total amount of traffics that run through arc (a,b), and λ_j is the Lagrangian multiplier of the capital constraint of firm j.[45] Therefore, for any non-zero $I_{j,ab}$ and $I_{j,a'b'}$, from equation 7 we know that:

$$\frac{I_{j,ab} + 1}{I_{j,a'b'} + 1} = \left[\frac{Dist_{j,ab} \cdot q_{j,ab}}{Dist_{j,a'b'} \cdot q_{j,a'b'}} \right]^{\frac{1}{1+\gamma}} \tag{8}$$

The intuition of the allocation problem is that firms will allocate more resources to arcs that carry larger volume of traffic. Conditional on optimal routing, and combine equation 8 with the capital constraint of firm j such that $\sum_{(a,b)\in\mathcal{A}_j} I_{j,ab} = K_j$, I can obtain the solution of the optimal investment allocation problem.

Here is how I solve it in the algorithm:

$$I_{j,ab} + 1 = \left[\frac{Dist_{j,ab} \cdot q_{j,ab}}{Dist_{j,a'b'} \cdot q_{j,a'b'}} \right]^{\frac{1}{1+\gamma}} \cdot (I_{j,a'b'} + 1)$$

Then I order $I_{j,ab}$ by $Dist_{j,ab} \cdot q_{j,ab}$, and denote I_j as the benchmark, where $I_j > 0$ and I_j has the smallest $Dist_{j,ab} \cdot q_{j,ab}$. Assume N_j is the number of arcs in firm j that has positive amount of allocation of resources.

[45] Because the investment of track maintenance and locomotives cannot be negative, the optimal level of investment would be

$$I_{j,ab} = \max\{I_{j,ab}, 0\}$$

We also have

$$\begin{aligned}
\sum_{(a,b)\in\mathcal{A}_j} I_{j,ab} = K_j &\Rightarrow I_j + \sum_{(a,b)\in\mathcal{A}_j} \left(\left[\frac{Dist_{j,ab} \cdot q_{j,ab}}{Dist_{j,a'b'} \cdot q_{j,a'b'}} \right]^{\frac{1}{1+\gamma}} \cdot (I_j + 1) - 1 \right) = K_j \\
&\Rightarrow I_j - (N_j - 1) + \sum_{(a,b)\in\mathcal{A}_j} (\cdot)(I_j) + \sum_{(a,b)\in\mathcal{A}_j} = K_j \\
&\Rightarrow I_j(1 + \sum_{(a,b)\in\mathcal{A}_j} (\cdot)) = K_j + N_j - 1 - \sum_{(a,b)\in\mathcal{A}_j} \\
&\Rightarrow I_j = \frac{K_j + N_j}{1 + \sum_{(a,b)\in\mathcal{A}_j} (\cdot)} - 1
\end{aligned}$$