Network Structure and Efficiency Gains from Mergers: Evidence from U.S. Freight Railroads *

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This Version: *August 23, 2021*

Abstract

Markets are interdependent in a network, hence the network structure (topology of the network) affects how much firms benefit from economy of scope. This paper studies the role of networks in the effect of mergers by examining mergers that took place from 1980 to 2005 in the U.S. freight railroad industry. I estimate an optimal transport network model that features firms' decisions about pricing, routing, and allocation in multiple origin–destination markets, and allows origin–destination markets to be interdependent in the cost minimization stage. Counterfactual results show that on average shipment cost decreased by 15.49%. Among the total cost reduction, 26% is due to misallocation of resources before merger, while 74% is due to network changes and re-optimization of routing. Counterfactual results studying the role of network structure show that averaging over all mergers, an increase degree centrality of 1 results in a 0.6 percentage-point extra reduction in cost and a 0.2 percentage-point extra increase in markup after merger.

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

*I am indebted to my committee members, Allan Collard-Wexler, Daniel Yi Xu, James W. Roberts, Christopher D. Timmins, and Bryan Bollinger for valuable comments and encouragement throughout this research project. I am also grateful to Victor Aguirregabiria, Yao Luo, Heski Bar-Isaac, Matthew Mitchell, and seminar participants at Minnesota, Wharton BEEP, Indiana Kelly, Tuck School of Business, Queen's, Western, Monash, Peking, Toronto, and IO Canada for helpful discussions and comments. I would like to 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.

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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 in industry concentration on average over time. There is a large strand of literature documenting and analyzing mergers in multiple industries.[1] However, an open question remains: 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 an incentive to increase prices. On the other hand, a merger may generate efficiencies, reduce marginal costs, and give the combined firm an opportunity to lower prices. Economists have been aware of this trade-off at least since Williamson (1968), yet there is very little direct empirical evidence for efficiency gains of mergers, and whether they offset the incentive to raise prices. This is largely because it is difficult to measure and quantify whether mergers lower the marginal cost of production of the combined firm. The objective of this paper is to study the mechanism of post-merger cost efficiency in U.S. railroad and to evaluate whether the efficiency gain offsets the incentive to raise prices. I propose a novel way to study efficiency gains in a network industry for which origin–destination markets are interdependent. In recent years, the U.S. government calls for greater scrutiny of mergers, and the freight railroad is one of the main target.[2] Meanwhile, in 2021 the Canadian Pacific railway and the Kansas City Southern railway proposed a multi-billion dollar merger. Given these backgrounds, it is important to understand whether the railroad mergers result in efficiency gains, and what are the key factors that impact merger effects.

In the freight railroad industry, there are two reasons why post-merger costs might be lower. First, there is misallocation of resources before merger. Between the two merging railroad firms, the marginal productivity of capital might be higher in one firm than the other. Therefore, after merger, resources can be reallocated from the less efficient firm to the more efficient one. I call this first effect "the effect of misallocation."[3] Second, network structure

[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] *Biden's Antitrust Team Signals a Big Swing at Corporate Titans*, `https://www.nytimes.com/2021/07/24/business/biden-antitrust-amazon-google.html`.

[3] This will not be true if there is a perfect capital market. There are several reasons why such perfect capital markets do not exist in this industry. First, for physical capital like locomotives, time-to-build must be taken into account. At peak times capital market is constrained. Second, railroad firms have different level of bargaining power or long-term relationship with the upstream suppliers, hence the price of the physical capital varies across firms. In my model, I abstract away from assuming any capital market, assuming

is important in this industry because of economy of scope. Traffic from different origin–destination pairs can utilize the same resources (such as physical tracks or locomotives) to make the shipment. For example, the railroad firm can make a main route very efficient by allocating large track maintenance spending to it, and all traffic that travels through this route will benefit. After merger, because of elimination of transaction cost between firms, the merged firm can re-optimize routing and benefit from greater economy of scope in the merged network. I call the second effect "the effect of change of network." Some have argued that the effect of misallocation is not merger-specific because misallocation of resources could be alleviated by having a more efficient capital market. Therefore, I build a structural model based on the framework of Galichon (2016) and Fajgelbaum and Schaal (2020) and conduct counterfactual analysis to distinguish between the two effects. I can then isolate changes in costs and markups caused by change of network after merger. In the structural model, I model firms' endogenous decisions on pricing, routing, and allocation of resources. Because efficiency changes in one part of the network will affect the routing and optimization problem for the whole network, they thereby affect the efficiency in another part of the network. To capture this effect, I allow different origin-destination markets to be interdependent in the cost minimization stage.

The U.S. freight railroad industry provides a good opportunity to study the merger efficiency in a network industry. From 1980 to 2005, a series of mergers took place in this industry. The number of Class I railroads[4] dropped from 39 to 7, and market share of the top four firms increased from 66% to 94%. Although concentration has increased 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 the 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, as of 2017 railroads were the second largest transport mode in providing freight service in the United States, carrying 1,675 billion ton-miles of freight and accounting for around 30% of total freight transportation. According to the Association of American Railroads (AAR), in 2016 the railroads transported about 40% of intercity ton-miles, more than any other mode of transportation.[5] Unlike many other in-

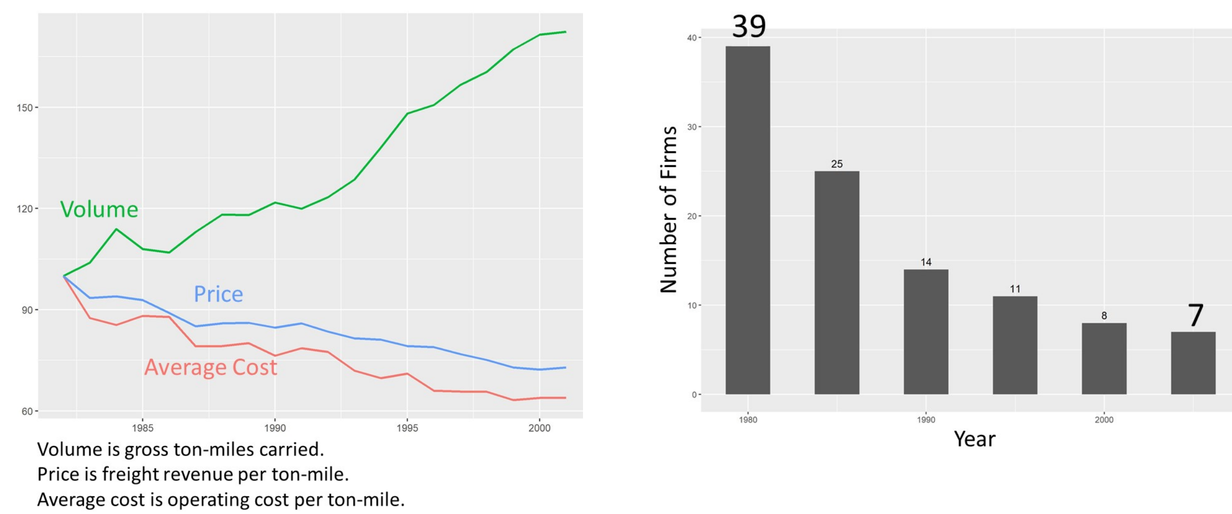
instead that in any given year each individual firm has a fixed amount of capital that can be allocated within its own network. A number of recent papers have tried to identify specific mechanisms to explain why productivity difference are not eliminated by market-based resource reallocation. See Restuccia and Rogerson (2008), Hsieh and Klenow (2009), Collard-Wexler (2011), Midrigan and Xu (2014), Moll (2014), and Asker, Collard-Wexler and De Loecker (2014) for recent work.

[4]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.

[5]One piece of evidence that shows limited technological change over the studied time period is that until

dustries, metrics of efficiency can be observed directly in railroad transport. At individual route level, the combined firm can abandon redundant rail lines that serve the same origin–destination market. Also, the combined firm can eliminate interchange costs where railcars would need to be switched between railroad companies prior to merger. At network level, the combined firm can consolidate traffic and choose shorter efficiency-weighted routes that were not previously available.[6]

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 gains of mergers at both individual route level and network level. Railroad companies apply point-on-point pricing, and the waybill data contain price information at firm–origin–destination level. After controlling for observable characteristics and a rich set of fixed effects, I find that on average shipment prices have decreased by 9% post-merger. I then open up the merger cases and examine the price effects for different route types. For routes where railroad companies exchange railcars before the merger, the price effect of mergers is 11%. For other types of route, the price effect is only 6%. The results suggest that efficiency gains of mergers

the late 1990s, the vast majority of rail lines in the U.S. still relied on the human crews for compliance with all safety rules. One accident that highlights this 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, killing 47 people and injuring 103. The accident happened partly because no technology had been implemented to monitor the real-time condition of tracks and train movements, and the Amtrak engineer was not notified of the collision in time. The Positive Train Control system, which monitors and controls train movements, was mandated by rail safety law in 2008, with full implementation in the fall of 2020.

[6] 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.

vary by route type, and elimination of railcar interchange costs is an important source of cost efficiency. One concern regarding these price effects is that they might be driven by competition from other transportation modes rather than 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 for commodities that are also significantly transported by other modes such as electrical machinery. The results suggest that price effects are not driven by competition from other transportation modes.

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 allocation 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 allocation decisions in multiple origin-destination markets. I model demand of transportation service using a logit model. Shippers choose between different railroad companies and an outside option which is trucking. In the model, railroad firms play a two-stage game. First, firms make routing and allocation decisions to minimize operational cost, conditional on the expected demand in each local market. Second, firms compete in local markets and choose prices simultaneously. In equilibrium, the expected demand in each local market is consistent with the outcome at the pricing stage. I consider the interdependence of markets in modeling routing and allocation. 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 traffic from different origins and destinations into few efficient routes.

I then use the estimated parameters to conduct counterfactual simulations. The counterfactual results show that averaged over all mergers, shipment cost decreased by 15.49%. As explained before, there are two reasons that why before-merger cost might be higher: the effect of misallocation, where after merger resources can be reallocated from the less efficient firm to the more efficient one, and the effect of change of network, where the merged firm can re-optimize routing and benefit from greater economy of scope. Regarding decomposition of the cost reduction, counterfactual results show that averaged across all mergers, misallocation of resources before merger accounts for 26% of total cost reduction. Network changes and re-optimization of routing account for 74% of total cost reduction after merger. I further investigate the mergers effects by looking at the change in costs and markups of individual origin–destination market. In the merger of the Burlington Northern railway (BN) and the Santa Fe railway (SF), among all the destinations, nodes in the areas around Omaha, NE and Lubbock, TX have the largest cost reduction (about 25%), while nodes in the before-merger overlapping region have a disproportionately large increase in markup compared to other nodes. This is because after the merger, the merged firm allocates more resources to enhance the connection of the two parts of the merged network after the merger. Most reallocation happens in or near the overlapping region of the two merging networks. In the west/east-bound direction, more resources are allocated to the arcs between Amarillo, TX and Omaha, NE. In the north/south-bound direction, more resources are allocated to the arcs between South Dakota and Kansas.[7]

In studying merger effects in the freight railroad industry, network structure or topology matters because it affects how much firms benefit from economy of scope. To better understand the role of network structure and how it affects effect of mergers, I further look at different centrality measures of a network, and how such measures are related to change of costs and change of markups after a merger. Within each merger, nodes with higher centrality measures have greater cost reductions and larger increases in markup post merger. Averaging over all mergers, an increase degree centrality of 1 results in a 0.6 percentage-point extra reduction in cost and a 0.2 percentage-point extra increase in markup after merger. This is because for nodes with higher centrality measure, there are more opportunities of routing to other origin–destination markets. Therefore, it is more likely that resources will be reallocated to such regions because more markets can benefit from economy of scope by routing through these nodes. When more resources are allocated to those regions post merger, the reduction in shipment cost will be larger. Across mergers, if the average degree centrality of the merged network increases by 1, the average change of markup will increase by 1 percentage point after merger. If the average betweenness centrality increases by 0.1, the average change of markup will decrease by 2.6 percentage points after merger. This is because when the average degree centrality of a network is larger, there are more routing choices in the network.[8] Therefore, the potential gains from re-optimization of routing are larger after the merger. By comparison, if the average betweenness centrality of a network is larger, the network is more "linear,"[9] hence there are fewer routing choices. Therefore, the potential gains from re-optimization of routing will be smaller after the merger.

Contributions to the Literature. This paper adds to the literature on the effects

[7] Figure 9 shows the model-implied changes in allocation of resources after ATSF–BN merger.

[8] See an illustration of networks with different level of average degree centrality in Figure C.1.

[9] Figures C.2 and C.3 show networks with different levels of average betweenness centrality.

of horizontal mergers by providing evidence of efficiency gains after mergers and uncovering their sources. The price effects of mergers are extensively studied in the literature. Borenstein (1990) and Kim and Singal (1993) analyze the effects of airline mergers, the latter finding that airfares increase by 9.44% on airline routes served by the merging firms. For comparison, my paper finds that on average price decreases by 9% after a railroad merger, and by 11% for interconnecting routes. By contrast, the literature on the cost efficiency of mergers is sparse. One valuable exception is Ashenfelter et al. (2015), in which the authors exploit panel scanner data and geographic variation in the U.S. beer industry, finding 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.[10] My paper contributes to the cost efficiency literature by not only providing reduced-form evidence on price reduction after mergers, but also uncovering through a structural model the key efficiency gain mechanisms and how these change with network features specific to the merger.

In this paper, I jointly model firms' pricing, routing, and allocation decisions by employing an optimal transport network method, based on the framework of Fajgelbaum and Schaal (2020). I differ from their paper by adding competition and routing choices for 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 (2018), and Brancaccio, Kalouptsidi and Papageorgiou (2017).[11] In Buchholz (2015), the network interdependence in taxicab service comes from the fact that once I drop somebody off, I find myself in the drop-off location for picking up future rides, which is more limiting than the interdependencies in routing in railroads.

My paper also contributes to the literature by showing how different network structure impacts effects of mergers. Empirically, Ciliberto et al. (2019) shows the effect of consolidation on airline network connectivity using different measures of centrality, and Holmes (2011) studies Wal-Mart's choice of locations and infers the magnitude of density economies. In theory, Hendricks et al. (1999) investigates the conditions under which hub-spoke networks are equilibria when two large carriers compete with each other. Aguirregabiria and

[10] Given the fact that direct metrics of efficiency are hard to define and measure, other research 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 has increased by $583.5 million as a result of the mergers.

[11] Buchholz (2015) analyzes the dynamic spatial equilibrium of taxicabs and shows how common taxi regulations lead to substantial inefficiencies; Donaldson (2018) uses archival data from colonial India to investigate the impact of India's vast railroad network; Fajgelbaum and Schaal (2020) 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.

Ho (2012) extends the static duopoly game of network competition to a dynamic framework by allowing local managers to decide whether or not to operate nonstop flights in their local markets. My paper connects these two parts by showing which geographic markets became more connected after merger (firms allocate more resources to those regions) hence benefited more from mergers. I show how routing was re-optimized in the merged network, and explicitly explain when economy of scope exists, why firms had incentives to re-optimize routing and allocation post merger.

Last, my paper contributes to the literature on the freight railroad industry. Most of the existing literature studies change in 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.[12] 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.

The remainder of the paper is organized as follows. Section 2 describes the industry background and uses a toy model to explain why network structure matters. Section 3 outlines the three datasets used in the paper. Section 4 defines what is a railroad network. Section 5 provides reduced-form evidence on how shipment prices change after railroad mergers. Section 6 constructs the structural model of firm pricing, routing and allocation decisions in a rail network. Section 7 shows the estimation results and assesses the validity of the model. Section 8 presents the counterfactual simulations that decompose the sources of cost efficiency, and explains the role of network structure in impacting within- and across-merger effects of mergers. Section 9 concludes.

[12]The existing literature 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 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 for 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.

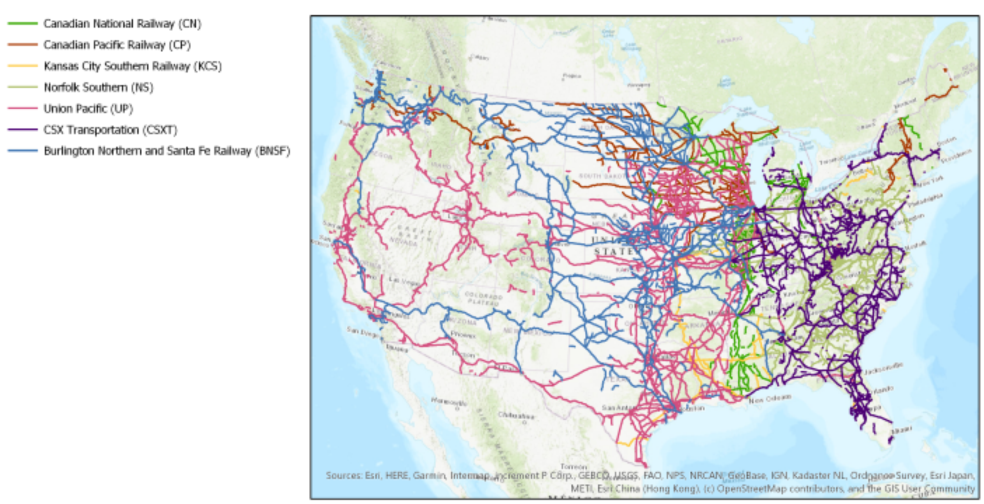
2 Industry Background

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.[13] At the start of the 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.[14]

In response, a series of laws to deregulate the industry were enacted in the years 1973–1980.[15] Among them, the 1980 Staggers Act formally deregulated the industry, by offering railroad companies much greater pricing and operating freedom. The deregulation sparked a wave of mergers of railroad companies: from 1980 to 2005, the number of Class I railroads decreased from 39 to 7. Figure 2 shows the network formed by the current seven Class I railroads: the Burlington Northern and Santa Fe railway (BNSF) competes with the Union Pacific railway (UP) in the west, while the CSX Transportation (CSXT) and the Norfolk Southern railway (NS) compete 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 the U.S., and the Kansas City Southern railway (KCS) locates in the south, connecting freight shipment between Mexico and the United States.

Figure 2: U.S. Class I Railroads



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

[14] Figures 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.

[15] Appendix A.1 details a complete history of railroad mergers, and Appendix A.2 provides details of regulation changes.

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. The proportion of total ton-miles of U.S. freight carried by rail increased after the deregulation of 1980. According to the Department of Transportation, in 2017 railroads were the second largest transport mode for 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.[16] According to the AAR, in 2012 the seven Class I railroads generated $67.6 billion in freight revenues, accounting for around 95% of the total freight revenues generated by railroad transport.[17] 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, chemicals, and farm products. According to the AAR, in 2012 the top four commodities measured by share of total tonnage were coal (37%), chemicals (10%), non-metallic minerals (9%), and farm products (8%). If we look at share of revenues, these four commodities account for 17% (coal), 14% (chemicals), 5% (non-metallic minerals), and 8% (farm products) of total freight revenues. "King Coal" has been the most important commodity in the freight railroad industry, but the revenues it generates are in decline. Instead, carloads of intermodal shipping[18] (misc. mixed shipments such as containers) are nowadays increasing, and intermodal shipment accounted for 13% of total freight revenues in 2012.[19]

2.2 The Story of Train 9-698-21

To better explain sources of cost efficiency and my model in the later sections, I now introduce three core railroading concepts: interchange cost, interconnecting route versus competing route, and allocation decisions regarding track maintenance and locomotives. I use the example of train 9-698-21 to explain these three concepts.[20]

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

[17] The rest of the revenues are generated by regional and short lines. Check Appendix B.1 for more details.

[18] Intermodal refers to the use of two modes of freight, such as truck and rail.

[19] Check Appendix B.1 for more details on carloads originated by different types of commodities.

[20] 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 coordination is a problem when two railroads are involved in a shipment.

Figure 3: The 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, beginning 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 were UPS and J.B. Hunt, and the train was an express freight train initiated to "reach downtown L.A. in time for UPS to deliver the next morning." The contract specified that Santa Fe be given haulage rights over BN to Memphis and Birmingham. These haulage rights meant that 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, nothing went right with 9-698-21:

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

First note that interconnecting and competing routes are both illustrated 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 UP or the BN line, an example of competing routes. Second, this example shows the micro-level foundation of interchange cost. When Train 9-698-21 arrived at Avard gateway in Oklahoma, it needed to exchange crews and rolling stock (rail-cars and locomotives) between the BN and Santa Fe railways. However, because BN and Santa Fe prioritized this train differently, the usual result was delays in completing this process. Moreover, to check the condition of railcars and exchange rolling stocks took time and effort, further adding to the interchange cost.

Last, I want to introduce the allocation decisions regarding track maintenance and locomotives. When more locomotives were available in the Avard gateway, the wait time for Train 9-698-21 to complete the interchange was shortened. Moreover, adequate and constant maintenance of tracks is essential for railroad operation.[21] Regular track maintenance is costly,[22] and railroad companies decide on the frequency of track evaluation in each region. In the example of Train 9-698-21, if the railroad companies had invested 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 would have increased.

2.3 Why Does Network Structure Matter?

The main reason network structure is important is economy of scope. Traffic from different origin–destination pairs can utilize the same resources (such as physical tracks or locomotives) to make the shipment. For example, the railroad firm can make a main route very efficient by allocating large track maintenance spending to it, and all traffic that travels through this route will benefit. I use a toy model below to elaborate why network structure (topology of the network) matters for economy of scope.

Figure 4 shows two networks A and B. There are two firms, I and II, in each network. Firm I owns nodes 1 through 4, while firm II owns nodes 5 through 8. There are six within-firm traffic routes, $1 \to 2$, $1 \to 3$, $1 \to 4$ within firm I, and $5 \to 6$, $5 \to 7$, $5 \to 8$ within firm II. There are also six across-firm traffic routes, $1 \to 6$, $1 \to 7$, $1 \to 8$, and $5 \to 2$, $5 \to 3$, $5 \to 4$. Each connected arc has a travel cost of 1, and across-firm traffic incurs an extra interchange cost η. So, the cost of traveling from $1 \to 2$ is 1, and the cost of traveling from $1 \to 5$ is $1 + \eta$ in Network A.

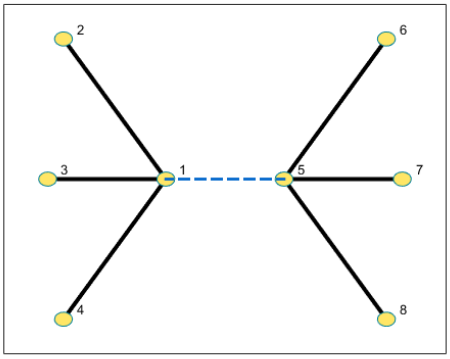
If there is no economy of scope, each traffic route will have exactly the same travel cost in network A and network B. The travel cost of the six enumerated within-firm traffic in both networks is 1, while the travel cost of the six enumerated across-firm traffic is $2 + \eta$. This is because when there is no economy of scope, each origin-destination market is independent and the travel cost only depends on the shortest travel distance from origin to destination.

If economy of scope exists, however, travel costs of the enumerated traffic will be different in the two networks. For simplicity, in the toy model I assume that the per-unit shipment

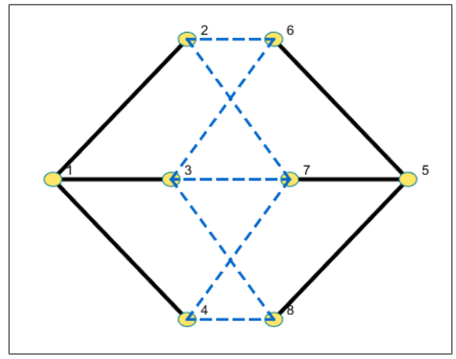
[21] To perform regular maintenance, railroad companies need to operate track evaluation cars to evaluate track geometry, performance-based track geometry, rail wear, etc. The track evaluation cars then report the data for capital and maintenance planning.

[22] According to a Bloomberg report, a New Jersey Transit safety project costs more than $320 million, yet 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

Figure 4: Toy Example (Why Network Structure Matters)



(a) Network A



(b) Network B

cost is proportional to the inverse of total traffic.[23] The example shows that the average costs of within-firm shipment for networks A and B are 0.11 and 0.16. The average costs of across-firm shipment for networks A and B are 0.24 and 0.35 respectively. So, on average, cost of shipment is smaller in network A when there is economy of scope. This is because the ability to consolidate traffic is stronger in network A than in network B. In network A, all across-firm traffic goes though arc $(1,5)$. However, in network B only two across-firm traffic routes go through arc $(3,7)$: $1 \rightarrow 7$ and $5 \rightarrow 3$. In network A, both within-firm traffic $1 \rightarrow 2$ and across-firm traffic $5 \rightarrow 2$ will go through arc $(1,2)$, but in network B, only within-firm traffic $1 \rightarrow 2$ will go through arc $(1,2)$. Therefore, network A has lower average shipment cost because traffic can be better consolidated than in network B.[24] This example shows that network structure or topology matters when there is economy of scope, because it affects how much firms benefit from economy of scope.[25]

The natural question is: can freight railroad firms achieve economy of scope by consolidating traffic in reality? The answer is yes. Cindy Sanborn, Chief Operating Officer of CSXT, states that "An essential feature of the operating plan is to consolidate traffic over a smaller

[23] This assumption is different from what I use in the full model. In the full model, I assume that each firm has a fixed amount of capital that it can allocate within its network. The shipment cost to go through arc (a,b) depends on the amount of resources allocated to that arc. The more resources allocated, the lower the shipment cost.

[24] This does not mean that the shipment cost of every origin–destination pair is smaller in network A than in network B. For example, the shipment cost of all within-firm traffic is 0.11 in network A, but the shipment cost of within-firm traffic in network B, comprising $1 \rightarrow 2$, $1 \rightarrow 4$, $5 \rightarrow 6$, $5 \rightarrow 8$, is 0.2192, which is larger than 0.11, but the cost of $1 \rightarrow 3$ and $5 \rightarrow 7$ is 0.0563, smaller than 0.11.

[25] Figure 7 shows how traffic volume changes in each network when the value of interchange costs changes.

number of efficient, high-volume routes."[26] The idea of achieving greater cost efficiency by consolidating traffic 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).

In reality, in a much more complicated network, a firm's pricing and routing decisions will significantly affect the degree of economy of scope that they achieve before and after mergers. This is what I will capture in my full model, by considering firm's pricing, routing, and allocation decisions based on their networks.

3 Data

I use three main datasets to document the changes in cost efficiency following railroad mergers: the confidential Carload Waybill Sample from the Surface Transportation Board (STB), the Class I Railroad Annual Report, and the Commodity Flow Survey. 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 the Commodity Flow Survey has information on shipment volumes for different transportation modes. I also make use of geographic information obtained from the Department of Transportation on all U.S. rail lines and their associated railroad companies. Based on the ancestry of each rail line, I trace back through time to reconstruct the rail network of each railroad firm between 1985 and 2005.

The Carload Waybill Sample is taken from carload waybills for all U.S. freight rail traffic submitted to the STB by those rail carriers completing 4,500 or more revenue carloads annually.[27] 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 for each load. The locations are recorded by BEA Economic Area, of which there are 173 in total (170 in the mainland, Figure 5). The waybill sample is about 2% of total waybills. The confidential Carload Waybill Sample to which I had access ranges from 1984 to 2010. Table 1 shows the summary statistics of key variables of the waybill data.

[26] Ex Parte No. 711 (Sub-No.1) Reciprocal Switching, Opening Comments, CSX Transportation Inc.

[27] The STB is an independent adjudicatory and economic-regulatory agency charged by Congress with resolving railroad rate and service disputes and reviewing proposed railroad mergers. It was created on January 1, 1996 by the ICC Termination Act of 1995, and is the successor to the old Interstate Commerce Commission. More details about the Carload Waybill Sample can be found at https://www.stb.gov/stb/industry/econ_waybill.html.

Table 1: Summary Statistics of Variables

	Mean	Std. Dev.	25th Percentile	Median	75th Percentile
Price per Railcar ($)	1,034	1,399	384	703	1,266
Shipment Weight per Railcar (Tons)	54	46	16	26	102
Travel Distance (Miles)	1,045	773	404	854	1,647
Number of Waybills (Carrier-Origin-Destination-Date)				12,113,581	

Source: STB, Carload Waybill Sample

Shipment price per carload ranges from $\$384$ to $\$1,266$ at the 25th and 75th percentiles respectively, with an average price of $\$1,034$. Shipment weight per carload ranges from 16 tons to 102 tons at 25th and 75th percentile, with an average weight of 54 tons. Average travel distance for each shipment is $1,045$ miles, and the 25th percentile of travel distance is 404 miles (650 km). It shows that railroad shipments are mostly long-distance. For the data I use, the median shipment price per ton-mile is 2.65 cents. This value is comparable to the price per ton-mile reported in the industry. In the year 2001, the average price per ton-mile in the United States was 2.32 cents according to the AAR.

I next describe what the competition looks like in this industry. The market is defined at origin–destination level (o–d market). Table 2 shows the total number of o–d markets, the average number of competitors serving each o–d market, and the percentage of interchange lines.

Table 2: Summary Statistics of Market Competition

Year	Number of Waybills	Percentage of Interchange Lines	Number of Competitors in an *o*–*d* Market			Number of *o*–*d* Market (at BEA-to-BEA level)
			mean	25th percentile	75th percentile	
1985	262,703	41%	3	1	3	12,088
1990	323,570	35%	2	1	3	11,835
1995	453,802	26%	2	1	3	11,632
2000	544,738	14%	2	1	2	11,732
2005	611,033	11%	2	1	2	11,611

Source: STB, Carload Waybill Sample

Table 2 shows, first, that the total number of waybills in the waybill sample changed from around $263,000$ to $611,000$ from 1985 to 2005. This shows that the total volume of railroad shipment more than doubled over this period.[28] Meanwhile, the percentage of interchange

[28]In Figures B.1 and B.2, I plot the total ton-miles of freight carried by each transportation mode from 1980 to 2011. The volume of shipment also increased for other transportation modes such as trucking, but the share of railroad shipment among all transportation modes increased in the studied period. In the

lines decreased from 41% to 11% while the total traffic volume doubled. Following the wave of mergers from 1985 to 2005, firms got rid of a large number of interchange lines. The number of o–d markets was relatively stable from 1990 to 2005, with a small decrease from $11,835$ to $11,611$. Therefore, the change of extensive margin after the mergers does not seem to be a significant concern here. Last, the average number of competitors in each o–d market slightly decreased from 3 to 2 from 1985 to 2005, showing that firms conduct oligopolistic competition in most of the local markets, and at least 25% of the local markets have a local monopoly.[29]

4 Definition of a Network

Following Galichon (2016), I define a network $\mathcal{G}$ 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 the nodes to be the centroids of BEA regions[30] and the arcs as rail lines that connect each BEA economic area. Panel (a) of Figure 5 shows the 170 BEA regions in the United States and their centroids. Based on the locations of the BEA regions and their adjacency, I have constructed the virtual network in panel (b).

I next obtain network information for each railroad firm. I denote the network of each firm j as $\mathcal{G}_j$, with arcs $\mathcal{A}_j$ and nodes $\mathcal{Z}_j$. Panel (a) of Figure 6 shows the actual rail network of BN in 1994, while panel (b) shows the virtual network for BN constructed from the actual information. For example, if two adjacent regions a and b are connected by rail lines owned by BN, then nodes $a, b \in \mathcal{Z}_j$ and arc $(a, b) \in \mathcal{A}_j$.

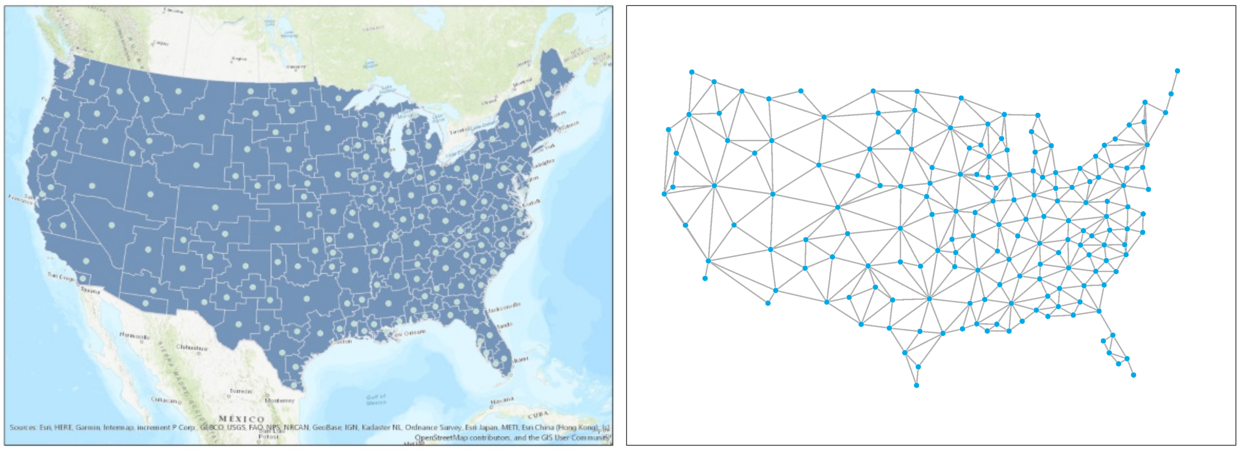
Following the same process, I construct the virtual network for every railroad firm in every year from 1985 to 2005, based on detailed geographic information for each rail line (coordinates) and information about the ancestry of rail lines obtained from the Federal Transit Administration. The geographic coordinates and historical information allow reconstruction of the rail network going back in time. Figure 11 shows the virtual networks of the two merging parties in each merger case between Class I railroads from 1985 to 2005. There were 12 mergers in total in the studied period.

reduced-form analysis, I provide evidence to show that competition from other transportation modes was not the main factor driving down the shipment price of freight railroad.

[29] Here I only show the statistics every five years from 1985 to 2005. The year-by-year table is shown in Appendix B.3, which tells much the same story as in Table 2 here.

[30] BEA economic areas are used by the STB to conduct economic analysis.

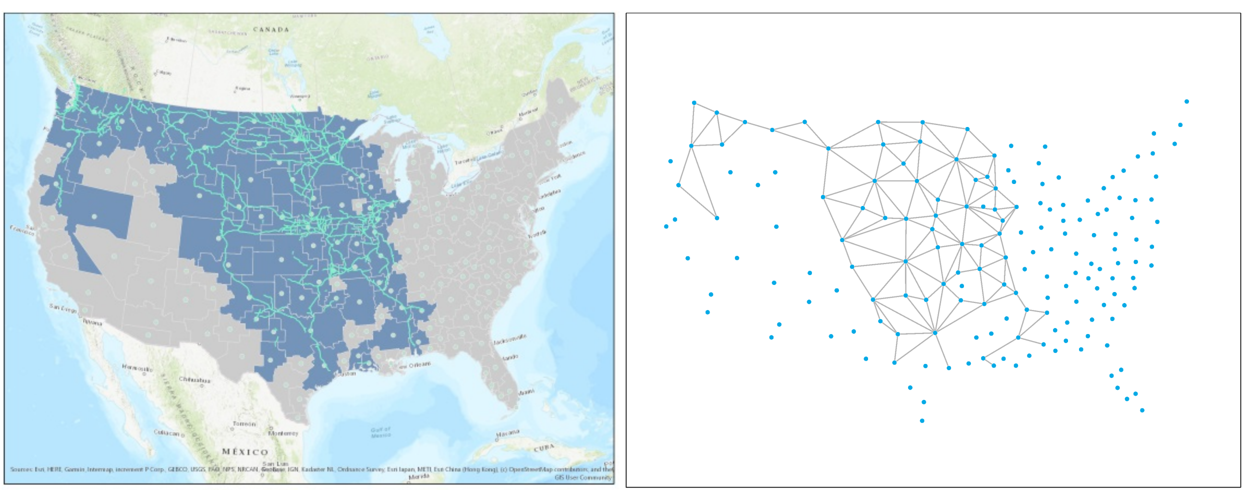
Figure 5: U.S. Rail Network



(a) BEA Regions and Their Centroids (b) Virtual Network

Note: Panel (a) shows the 170 BEA regions in the United States and their centroids. Based on the locations of the BEA regions and their adjacency, I have constructed the corresponding virtual network in panel (b).

Figure 6: BN Rail Network



(a) Actual Rail Network of BN in 1994 (b) Virtual Network for BN

Note: Panel (a) of Figure 6 shows the actual rail network of BN in 1994, while panel (b) shows the virtual network for BN constructed from the actual information. For example, if two adjacent regions a and b are connected by rail lines owned by BN, then nodes $a, b \in \mathcal{Z}_j$ and arc $(a, b) \in \mathcal{A}_j$.

5 Reduced-form Evidence

To provide evidence of efficiency gains, I examine how prices change following railroad mergers. The regression model is specified as

$$\log P_{s,odt} = \mu_{od} + \gamma_s + \lambda_t + \delta_1 D_{s,odt} + X'_{s,odt}\beta + \epsilon_{s,odt},$$

the observation is defined at service-origin-destination-time level, where service s is either single-line service (carried by one railroad firm from origin to destination) or joint-line service (carried by at least two railroad firms with interchange involved). $D_{s,odt}$ is an indicator of whether a merger has happened to firms that provide service s from o to d before or equal to time t, and $X_{s,odt}$ are shipment attributes. I also control for firm, route, and year fixed effects in the regression.

Table 3 shows the estimation results. The results suggest that on average a railroad merger reduces the shipment price by 9.4%. By opening up the mergers and examining each individually, I found that the price effect is largely consistent across individual mergers.[31] Then, to further decompose the effect of railroad mergers on price changes by different route types, I interact the merger dummy with three route types: interconnecting route, competing route, and non-interconnecting, noncompeting route. As explained in section 2, an interconnecting route is one in which two firms conduct interchange and complete the shipment jointly. Results in column 2 of Table 3 show that interconnecting routes have the largest price reduction among all route types, with price decreasing by 11% after mergers. By comparison, the other route types have a price reduction of about 6.5% following mergers.

[31] Table D.2 shows the robustness check results obtained by looking at change of prices following each railroad merger.

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	Yes	Yes
Year FE	Yes	Yes
o–d Route FE	Yes	Yes

Standard errors in parentheses. Clustered at route level.

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

Source: STB, Carload Waybill Sample

However, concerns might arise that these price effects are driven by competition from other transportation modes such as trucking, rather than by 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, they 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, while 94.8% is shipped by rail. By comparison, food or kindred products are largely shipped by trucking: 76.2% of food and kindred products are shipped by trucking, with only 23.5% shipped by rail.[32]

[32] All weights are calculated by total ton-miles of shipment.

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%	76.2%
Total Ton-Miles in 2012 (Rail)	94.8%	23.5%

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

Table 5 shows the estimation results for price effect of mergers for coal and food products respectively. The results show that railroad mergers have a significantly negative price effect for both these categories. 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. As a robustness check, I run the price regression for each type of commodity in Appendix D. 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.

The estimated price effect is comparable to other analysis of freight railroad mergers. In the STB analysis of the Union Pacific—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 in some other industries. For example, Ashenfelter et al. (2015) find that the estimated price reduction caused by merger efficiency is 2% in the brewing industry. In comparison, I find a 9.4% overall shipment price reduction, and a 17.9% average price reduction for coal shipments, which suggests that cost efficiency following mergers is important in the railroad industry.

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

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

Standard errors in parentheses. Clustered at route level.

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

Source: STB, Carload Waybill Sample

The Need for a Model. In this section, I show that prices decrease after mergers, and that the price effect is greater for inter-connecting routes. This indicates that shipment costs decrease after mergers. There are two reasons why before-merger costs might be higher. First, there is misallocation of resources before merger. Between the two merging firms, the marginal productivity of capital might be higher in one firm than the other. Therefore, after merger, resources can be reallocated from the less efficient firm to the more efficient one. I call this first effect "the effect of misallocation."[33] Second, because of elimination of interchange costs after merger, the merged firm can re-optimize routing and benefit from greater economy of scope in the merged network. I call the second effect "the effect of

[33]This will not be true if there is a perfect capital market: that is, if firms can purchase or sell capital at some price r, the marginal productivity of capital will be equalized among firms. There are two reasons why such perfect capital markets do not exist in this industry. First, for physical capital like locomotives, time-to-build must be taken into account. At peak times capital market is constrained. Second, railroad firms have different level of bargaining power or long-term relationship with the upstream suppliers, hence the price of the physical capital varies across firms. In my model, I abstract away from assuming any capital market, assuming instead that in any given year each individual firm has a fixed amount of capital that can be allocated within its own network.

change of network." If we directly compare the changes of cost before and after merger, the difference will capture both of the effects. Some have argued that the effect of misallocation is not merger-specific because misallocation of resources could be alleviated by having a more efficient capital market. Therefore, I build a structural model and conduct counterfactual analysis to distinguish between the two effects. I can then isolate changes in costs and markups caused by change of network after merger. In the structural model, I model firms' endogenous decisions on pricing, routing, and allocation of resources. Because efficiency changes in one part of the network will affect the routing and optimization problem for the whole network, they thereby affect the efficiency in another part of the network. To capture this effect, I allow different origin-destination markets to be interdependent in the cost minimization stage.

6 Model

In the model, railroad firms play a two-stage game. First, firms make routing and allocation decisions to minimize operational cost, conditional on the expected demand in each local market. Second, firms compete in local markets and choose prices simultaneously. In equilibrium, the expected demand in each local market is consistent with the outcome at the pricing stage.

I define a market as an origin–destination pair. Firms provide either single- or joint-line service to serve a market. Single-line service is carried by one railroad firm from the origin all the way to the destination. Joint-line service is carried by at least two railroad firms with interchange involved. Services for each market are exogenous and obtained from the data. For interconnecting routes, I assume that the originating firm of the joint-line service determines the price of the service.[34] The network structure of each railroad firm is also exogenous and obtained from the data.

On the demand side, I assume customers make discrete choices based on shipment price

[34] Based on findings of Alexandrov et al. (2018), I also assume that there is no issue with double marginalization in the pricing of the interconnecting route. Assuming that the origin railroad has all the bargaining power is one way to interpret this assumption. Another is to think of the two railroad firms in the joint-line service as jointly determining the price as one entity, and then dividing the revenue between them in a meaningful way. The only assumption I need is that there is no double-marginalization of pricing. Appendix B.2 documents interviews with managers about how interchange works in this industry. Introducing other mechanisms of revenue sharing over interchange lines (such as Nash bargaining) to my model is possible, but does not provide extra insight into how network structure affects merger effects, which is the key question of this paper. I also assume that firms do not consider the cannibalization between their own single-line service and joint-line service provided in the same o–d market. The last assumption has little impact on the empirical results because in the data a firm rarely provides both single- and joint-line service in the same origin–destination market.

and shipment characteristics. Customers face an outside option, which is shipping by transportation modes other than railroads.

6.1 Demand

In this paper I assume a logit demand of railroad shipment. The assumption of logit demand is standard in estimating transportation demands, such as in Peters (2006) and Grieco et al. (2020). In each origin–destination market, consumer i chooses service s to ship from origin o to destination d. Service s is either single- or joint-line service. For example, shipment carried only by the Union Pacific railway from origin to destination is a single-line service. Shipment carried first by the Burlington Northern railway from origin to interchange station and then by the Santa Fe railway from interchange station to destination is a joint-line service.

The utility function of customer i choosing service s is

$$\begin{aligned} u_{is,od} = \alpha \cdot p_{s,od} + \beta_1 \cdot \log TravelDistance_{s,od} \\ + \beta_2 \cdot \log TotalTrackMiles_{s,od} + \xi_{s,od} + \varepsilon_{is,od}. \end{aligned}$$

Customers care about shipment price $p_{s,od}$ and travel time. Because I do not observe travel time in my data, I use two variables, *travel distance* and *total track miles*, to approximate travel time. *Travel distance* measures the average travel distance of service s from o to d. Because the network of each firm providing the service and therefore the routing provided are different, the travel distance varies for each service. I expect β_1 to be negative, because the longer the travel distance conditional on an o–d market, the longer the likely travel time. *Total track miles* measures the total amount of physical track that the firm providing service s has in the origin and destination area. For example, say the o–d market is from LA to Houston, and the service is a single-line service provided by the Union Pacific railway. Then $TotalTrackMiles_{s,od}$ measures the total amount of physical track that the Union Pacific railway has in the LA and Houston areas. The idea is that the more physical track there is, the easier it is to move things from the customer to the railroad company, thus shortening the travel time.

To control for unobserved market-specific demand factors, as well as efficiencies that are constant within significant subsets of the data, I include fixed effects of o–d markets and firm fixed effects. I also include a standard i.i.d. extreme value type assumption on individual shocks $\varepsilon_{is,od}$.

6.2 The Firm's Problem

Each firm j owns a network $\mathcal{G}_j$ with corresponding nodes $\mathcal{Z}_j$ and arcs $\mathcal{A}_j$. Firms play a two-stage game, as described above. For the cost minimization stage, in equilibrium the expected shipment demand is consistent with the outcome determined at the pricing stage.

There are multiple services $\{s\}_{od}$ serving each o–d market. Service s can be either single- or joint-line service; $s \coloneqq [j_1, j_2]$ where j_1 is the origin railroad and j_2 is the termination railroad.

1. If $j_1 = j_2 = j$, s is a single-line service and carried by railroad firm j from the origin all the way to the destination.

2. If $j_1 \neq j_2$, s is a joint-line service. Shipment from o to d will be carried by firm j_1 from origin o to the interchange station m, and then by firm j_2 from station m to destination d. The location of the interchange station m is specific to each service–origin–destination triple, and exogenously obtained from the data.[35]

Types of services $\{s\}_{od}$ in each o–d market are exogenous and obtained from the data.[36] I solve the model backward.

6.2.1 Stage Two: Local Market Competition

Once firms have made routing and allocation decisions in the first stage, the cost of operation (marginal cost) in each local market is determined. Firms then compete in price in local markets. A market is an origin–destination pair. Firm j chooses the price of each single-line service that it provides, and also chooses the price of each joint-line service for which firm j is the origin railroad.[37]

[35] In the example of Train 9-698-21 in section 2.2, the Burlington Northern and Santa Fe railways provide a joint-line service from LA to Memphis. The shipment is carried by the Santa Fe railway from LA to Avard, OK, interchanges with the Burlington Northern railway, and is then carried by the Burlington Northern railway from Avard, OK to Memphis. In this case, Avard, OK is the interchange station. In practice, the Waybill data show that the location of the interchange station for each service–origin–destination triple is very stable and barely changes

[36] In the United States, the difficulty of expropriating trackage rights has reached a point where virtually no new tracks has been laid in the last fifteen years. Entry into new markets where firms have no physical track is very difficult.

[37] I assume that each service is priced independently even if a firm may participate both a single- and a joint-line service in the same market. For example, imagine that there are three services serving the market from LA to Memphis: a single-line service provided by the Burlington Northern railway, a single-line service provided by the Union Pacific railway, and a joint-line service provided by the two railways together. I assume that the Burlington Northern railway price the single-line service and the joint-line service independently. In reality, the case that a railroad offers both a single- and a joint-line service in the same o–d market is very rare, so I made this assumption to simplify computation. Relaxing this assumption has barely any effect on the results.

The optimization problem for pricing is denoted as

$$\pi_{s,od} := \max_{p_{s,od}} [p_{s,od} - C_{s,od}] \cdot Q_{s,od}(p_{s,od}, p_{-s,od}).$$

The per-unit transportation cost of a service $C_{s,od}$ depends on the routing decision $\mathcal{R}_{s,od}$ and allocation decision $\boldsymbol{I}_j$. Each element $I_{j,ab}$ of $\boldsymbol{I}_j$ measures the amount of resources that firm j allocates to arc (a, b).

For single-line service $s := [j_1, j_2] = [j, j]$, $C_{s,od}$ is specified as:

$$C_{s,od} := C_{s,od}(\boldsymbol{I}_j, \mathcal{R}_{j,od}) = \sum_{(a,b)\in\mathcal{R}_{j,od}} c_{j,ab}(\boldsymbol{I}_j) \tag{1}$$

where $c_{j,ab}$ is the arc-level cost of firm j. The routing $\mathcal{R}_{j,od} \in \mathcal{A}_j$ is a subset of connected arcs that routes firm j from origin o to destination d. Intuitively, equation 1 says that the per-unit transportation cost $C_{s,od}$ is the summation of arc-level costs over a firm j route from o to d.

For joint-line service $s := [j_1, j_2]$, $j_1 \neq j_2$, $C_{s,od}$ is specified as

$$C_{s,od} := C_{s,od}(\boldsymbol{I}_{j_1}, \boldsymbol{I}_{j_2}, \mathcal{R}_{j_1,om}, \mathcal{R}_{j_2,md}) \tag{2}$$

$$= \sum_{(a,b)\in\mathcal{R}_{j_1,om}} c_{j_1,ab}(\boldsymbol{I}_{j_1}) + \sum_{(a',b')\in\mathcal{R}_{j_2,md}} c_{j_2,a'b'}(\boldsymbol{I}_{j_2}) + \eta \tag{3}$$

where η is the interchange cost and m is the interchange station. Equation 2 says that the per-unit transportation cost $C_{s,od}$ of a joint-line service is the summation of cost for firm j_1 from o to m and cost for firm j_2 from m to d, plus the interchange cost η.[38]

I follow Galichon (2016) and Fajgelbaum and Schaal (2020) in defining the per-unit cost of transportation at arc level. The arc-level transportation cost of firm j at arc (a, b) is

[38] In my model I consider joint-line service with only one interchange, because in the data more than 90% of joint-line services involve only one interchange. This assumption can easily be relaxed. For example, if there is more than one interchange, say service s from o to d is $s = [j_1, j_2, \cdots, j_n]$, the general form of transportation cost of service s from origin o to destination d is written as:

$$C_{s,od} = \sum_{j\in J(s)} \sum_{(a,b)\in\mathcal{R}_{j,od_j(s)}} c_{j,ab} + \#_{interchanges} \cdot \eta$$

$$= \sum_{j\in J(s)} \sum_{(a,b)\in\mathcal{R}_{j,od_j(s)}} \left[\frac{\delta_0 Dist_{j,ab}}{I^{\gamma}_{j,ab}}\right] + \#_{interchanges} \cdot \eta$$

where $J(s)$ is the set of firms that provide service s, and $\#_{interchanges}$ is the total number of interchanges incurred in providing service s.

parametrized as[39]

$$c_{j,ab} = \frac{\delta_0 Dist_{j,ab}}{I_{j,ab}^{\gamma}}.$$

The arc-level transportation cost $c_{j,ab}$ depends on the distance between a and b, and the amount of resources firm j allocates to arc (a, b). The efficiency parameter γ is expected to be positive. Therefore, if firm j allocates more resources to arc (a, b), the arc-level transportation cost $c_{j,ab}$ will be smaller. For any arc (a', b') such that $(a', b') \notin \mathcal{A}_j$, the arc-level cost of transportation $c_{j,a'b'}$ is ∞.[40]

The first-order condition with respect to price $p_{s,od}$ is calculated as

$$\frac{\partial \pi_s}{\partial p_{s,od}} := Q_{s,od} + (p_{s,od} - C_{s,od}) \cdot \frac{\partial Q_{s,od}}{\partial p_{s,od}}.$$

A key assumption here is that firms do not consider how pricing affects the optimal routing and allocation decision in the first-stage, i.e., $\frac{\partial C_{j,od}}{\partial p_{j,od}} = 0$. This assumption is consistent with what people do in this industry in practice. At the moment when the pricing department gives quotes to the customers, they do not strategically take into consideration how the resulting demand affects the subsequent operational decision.[41]

Combining with the logit demand, I can then obtain the equilibrium prices $\{p^*_{s,od}, p^*_{-s,od}\}$ and demand $Q_{s,od}(p^*_{s,od}, p^*_{-s,od})$ for each service s in market o–d.

6.2.2 Stage One: Operational Decision in the Network

Given the expected demand $\widetilde{Q}_{s,od}$ in each local market, in the first stage firms choose the optimal routing $\{\mathcal{R}_{j,o_j d_j(s)}\}_{o_j \in \mathcal{Z}_j, d_j \in \mathcal{Z}_j}$ and allocation decisions $\{I_{j,ab}\}_{(a,b)\in\mathcal{A}_j}$ to minimize operational cost. The cost minimization problem is subject to capital allocation and balanced-flow

[39] It is easy to enrich the model by adding geographic characteristics to the cost function such as in Fajgelbaum and Schaal (2020); δ_0 in my model can be further parametrized as

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

[40] I did not include congestion in my model. I can add congestion in the cost function by modifying c_{ab} as a function of total traffic q_{ab} going through arc (a, b). The reason I did not include congestion is that the routing problem would no longer be a linear programming problem. Adding congestion into the model will not provide new insights into the results, but will add significant computational complexity.

[41] See the interview with the business development manager of the Canadian National railway in Appendix B.2. I can relax this assumption by calculating the envelope condition of how optimal routing (a linear programming problem) and optimal allocation react to price, but this will significantly increase the computation time especially in estimation.

constraints.[42]

Denote $J(s)$ as the set of firms that provide service s; then the cost minimization problem of firm j is written as[43]

$$\min_{\{\mathcal{R}_{j,o_jd_j(s)}\},\{I_{j,ab}\}_{(a,b)\in\mathcal{A}_j}} \sum_{s:j\in J(s)} C_{s,o_jd_j(s)}(\boldsymbol{I}_j, \mathcal{R}_{j,o_jd_j(s)}) \cdot \widetilde{Q}_{s,od} \tag{4}$$

such that

Capital allocation constraint:

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

Balanced-flow constraint: for any service s in any market o–d and $\forall m' \in \mathcal{Z}_j$,

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

The intuition for the capital allocation constraint is that each firm j has a fixed amount of capital K_j that it can allocate to the arcs $\mathcal{A}_j$ in its network. The intuition for the balanced-flow constraint is that for each node m', the total inflow of traffic plus the net demand equals the total outflow of traffic.[44]

Let us first look at the routing problem. Firm j's routing problem from origin o_j to

[42] Here is what the notation for the routing decision $\{\mathcal{R}_{j,o_jd_j(s)}\}_{o_j\in\mathcal{Z}_j,d_j\in\mathcal{Z}_j}$ means:

- If s is a single-line service of firm j from o to d, then $\mathcal{R}_{j,o_jd_j(s)} = \mathcal{R}_{j,od}$.
- If s is a joint-line service and firm j is the origin railroad that carries the shipment from origin o to the interchange station m, then $\mathcal{R}_{j,o_jd_j(s)} = \mathcal{R}_{j,om}$.
- If s is a joint-line service and firm j is the termination railroad that carries the shipment from the interchange station m to destination d, then $\mathcal{R}_{j,o_jd_j(s)} = \mathcal{R}_{j,md}$.

[43] If s is a single-line service provided by firm j, then $J(s) = \{j\}$. If s is a joint-line service provided by firm j_1 and j_2, then $J(s) = \{j_1, j_2\}$.

[44] Here are the details of the balanced-flow constraint:

- $\mathbb{1}(\cdot)$ is an indicator function and $\mathbb{1}\{(a,m') \in \mathcal{R}_{j,od_j(s)}\} = 1$ if arc (a,m') is in the routing from o_j to d_j of firm j.
- $a \in \mathcal{Z}_j(m)$ means that a is a neighbor of node m. The total inflow of traffic into node m' is the summation of traffic from all the arcs (a,m') of firm j such that $a \in \mathcal{Z}_j(m)$.
- $D_{j,m'}$ is the net demand at node m'. $D_{j,m'} = \begin{cases} Q_{s,od} & \text{if } m' = o \\ -Q_{s,od} & \text{if } m' = d \\ 0 & \text{otherwise} \end{cases}$

destination d_j is written as

$$\min_{\mathcal{R}_{j,o_j d_j(s)}} \sum_{(a,b)\in\mathcal{R}_{j,o_j d_j(s)}} c_{j,ab} \cdot \widetilde{Q}_{s,od} \tag{5}$$

such that $\forall m' \in \mathcal{Z}_j$, the balanced-flow constraint is satisfied:

$$D_{j,m'} + \sum_{a\in\mathcal{Z}_j(m')} \widetilde{Q}_{s,od} \cdot \mathbb{1}\{(a,m') \in \mathcal{R}_{j,o_j d_j(s)}\} \leq \sum_{b\in\mathcal{Z}_j(m')} \widetilde{Q}_{s,od} \cdot \mathbb{1}\{(m',b) \in \mathcal{R}_{j,o_j d_j(s)}\}.$$

Solving equation 5 is equivalent to solving the minimization problem

$$\begin{aligned} &\min_{\mathcal{R}_{j,o_j d_j(s)}} \sum_{(a,b)\in\mathcal{R}_{j,o_j d_j(s)}} c_{j,ab} \\ \Rightarrow &\min_{\mathcal{R}_{j,o_j d_j(s)}} \sum_{(a,b)\in\mathcal{R}_{j,o_j d_j(s)}} \frac{\delta_0 Dist_{j,ab}}{I_{j,ab}^{\gamma}} \end{aligned}$$

such that $\forall m' \in \mathcal{Z}_j$,

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

The intuition for the routing problem is that firm j chooses the shortest efficiency-weighted route in its own railroad network to travel from origin o_j to destination d_j. Firm j obtains the optimal routing for each market from o_j to d_j by solving a linear programming problem.[45]

The optimal allocation decision is obtained by solving the cost minimization problem in equation 4. By taking the derivatives with respect to $I_{j,ab}$ for every arc $(a,b) \in \mathcal{A}_j$, the

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

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

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

optimal allocation decision is solved as

$$
\begin{aligned}
I_{j,ab} &= \left[\frac{\gamma}{\lambda_j}\sum_{s:j\in J(s)}\left(\delta_0 Dist_{j,ab}\cdot \widetilde{Q}_{s,od}\cdot \mathbb{1}\{(a,b)\in\mathcal{R}_{j,o_j d_j(s)}\}\right)\right]^{\frac{1}{1+\gamma}} \\
&= \left[\frac{\gamma}{\lambda_j}\cdot \delta_0 Dist_{j,ab}\cdot q_{j,ab}\right]^{\frac{1}{1+\gamma}}
\end{aligned}
\tag{6}
$$

where $q_{j,ab}$ is the total amount of shipment running through arc (a,b), γ is the parameter of economy of scope, and λ_j is the Lagrangian multiplier of the capital constraint of firm j.[46] Therefore, for any non-zero $I_{j,ab}$ and $I_{j,a'b'}$, from equation 6 we know that

$$
\frac{I_{j,ab}}{I_{j,a'b'}} = \left[\frac{Dist_{j,ab}\cdot q_{j,ab}}{Dist_{j,a'b'}\cdot q_{j,a'b'}}\right]^{\frac{1}{1+\gamma}}. \tag{7}
$$

Equation 7 shows that the optimal allocation decision means allocating more resources to arcs that carry a larger volume of traffic. Combining results from equation 7 with the capital constraint of firm j where $\sum_{(a,b)\in\mathcal{A}_j} I_{j,ab} = K_j$ yields the solution of the optimal allocation problem.

To sum up, given the expected demand $\widetilde{Q}_{s,od}$ of each service in each origin–destination market, in the first stage firms make routing and allocation decisions by solving the cost minimization problem in equation 4. The optimal routing of firm j is to choose the shortest efficiency-weighted route from origin o_j to destination d_j, and the optimal allocation is to allocate more resources to arcs that carry larger volume of traffic.

In equilibrium, firms choose routing and allocation decisions to minimize operational cost, conditional on the expected shipment demand in each local market. Then, given the operational cost, firms compete in local markets and choose prices simultaneously. In equilibrium, the expected shipment demand $\widetilde{Q}_{s,od}$ is consistent with the outcome determined at the pricing stage $Q_{s,od}(p^*_{s,od}, p^*_{-s,od})$.

To better explain how the model works, Figure 8 presents some comparative statistics showing that when the parameter γ of economy of scope changes, firms' routing and allocation decisions will be different. I show that when the value of γ is larger, the benefit of economy of scope is larger, and hence firms have more incentive to consolidate traffic.

[46] The indicator function $\mathbb{1}\{(a,b)\in\mathcal{R}_{j,o_j d_j(s)}\} = 1$ if arc (a,b) is in the routing of firm j from o_j to d_j. Because the amount of allocation cannot be negative, the optimal level of allocation would be $I_{j,ab} = \max\{I_{j,ab}, 0\}$.

7 Estimation

7.1 Demand Estimation

The utility function of consumer i choosing service s is specified as

$$u_{is,od} = \alpha \cdot p_{s,od} + \beta_1 \cdot \log TravelDistance_{s,od} \\ + \beta_2 \cdot \log TotalTrackMiles_{s,od} + \xi_{s,od} + \varepsilon_{is,od}.$$

The demand estimation follows the standard procedure as in Berry (1994).[47] Therefore,

$$\ln(S_{s,od}) - \ln(S_{0,od}) = \alpha \cdot p_{s,od} + \beta_1 \cdot \log TravelDistance_{s,od} \\ + \beta_2 \cdot \log TotalTrackMiles_{s,od} + \xi_{s,od}.$$

Here, $S_{s,od}$ is the market share of service s in serving market from o to d, while $S_{0,od}$ is the market share of the outside option, which is the share of all other transportation modes serving market from o–d. Usually, economists do not observe the share of outside option when estimating demand. However, in this case I do observe the share of outside option. The data on shipment by other transportation modes is obtained from the Commodity Flow Survey (CFS).[48] Table 6 shows the estimated results using 2012 data.

[47] It is more efficient to estimate demand 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.

[48] The CFS is conducted every five years by the U.S. Census Bureau. The data I have is for 1993, 1997, 2002, 2007, and 2012.

Table 6: Results of Demand Estimation

	(1) OLS	(2) Fixed Effects	(3) Fixed Effects
Price	-0.077**	-0.302***	-0.282***
	(0.036)	(0.038)	(0.038)
Log Travel Distance	1.157***	-0.339***	-0.372***
	(0.058)	(0.107)	(0.107)
Log Amount of Track Miles	0.547***	0.330***	0.349***
	(0.045)	(0.050)	(0.053)
Constant	-14.757***	-2.889***	-3.142***
	(0.440)	(0.740)	(0.744)
Observations	4,481	4,481	4,481
R-squared	0.120	0.038	0.058
Number of Unique o–d Markets		1,420	1,420
Market Fixed Effects		Yes	Yes
Firm Fixed Effects			Yes

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Column (1) shows the OLS results. The coefficient of *price* is significantly negative, but the coefficient of *travel distance* is positive, which is counter-intuitive: the coefficient of *travel distance* is likely to be upward-biased in the OLS regression. This is because customers are more likely to use railroads for long-distance shipping since they are more efficient than other transportation modes such as trucking over long-hauls. To correct for this kind of bias, and to control for unobservable market-specific demand factors, I control for o–d market fixed effects in column (2). The coefficient of *travel distance* turns to be significantly negative after controlling for market fixed effects. This means that conditional on each o–d market, customers are less likely to choose a service with a longer travel distance. Price elasticity is also larger after controlling for market fixed effects. Last, there are concerns that there exists unobserved efficiency and other factors that are constant within railroad firms. To address this concern, I further control for firm fixed effects in column (3). The results in column (3) are very similar to those in column (2). In brief, the results in Table 6 shows that, conditional on each o–d market, customers are more likely to choose services with shorter travel distances and more physical track in the local market.

Given an estimated price coefficient of around -0.3, the average price elasticity of demand in my data is -0.739. The estimated average price elasticity is comparable to estimates found in the transportation literature. For example, Oum (1989) estimated an own-price elasticity of rail demand for Canadian inter-regional freight of -0.598, Wilson et al. (1988) estimated a price elasticity of demand for U.S. road freight grain transport of –0.73, and Beuthe et al.

(2001) estimated demand elasticity for long-distance trips (> 300 km) of -0.63.[49]

Because I do not have a time subscript t in my demand parameters or my model, one concern is that the demand parameters might have changed significantly throughout the studied period. To address this concern, I replicate my demand estimation using data from 1997, 2002, and 2007 (years when CFS data are available). Results in Appendix E show that the estimated demand parameters are relatively stable across the studied time period.

Given the estimated demand parameters, I can then solve the firm's optimization problem and estimate the cost parameters.

7.2 Estimation of Cost Parameters

In section 6, the arc-level transportation cost of firm j at arc (a, b) was parameterized as

$$c_{j,ab} = \frac{\delta_0 Dist_{j,ab}}{I_{j,ab}^{\gamma}}.$$

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

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

Therefore, there are three cost parameters to be estimated, δ_0, γ, and η. The parameter δ_0 captures the average shipment cost per efficient mile, γ captures the effectiveness of allocated resources, and η captures interchange cost. Intuitively speaking, γ can also be interpreted as the level of economy of scope. The larger γ is, the more firms benefit from economy of scope by consolidating traffic.

I use simulated GMM to estimate δ_0, γ, and η. I target four data moments in estimating the parameters:, listed in Table 7.[50]

[49] Graham and Glaister (2004) conducted a useful summary of road traffic–related elasticity estimates across the transportation literature. Compared to the literature, my estimates of price elasticity of demand at -0.727 is within a reasonable range.

[50] The centrality measures of degree and betweenness are defined in 8.2.

Table 7: Targeted Data Moments

	Data Moments	Identification
Average shipping price per loaded car per mile	\$0.65	pin down δ_0
Average difference of price between interconnecting route and non-interconnecting route per loaded car per mile	\$0.26	pin down η
Moments related to network measures		
Effect of degree centrality on price per loaded car per mile	\$-0.0002	pin down γ, δ_0
Effect of betweenness centrality on price per loaded car per mile	\$-0.30	pin down γ, δ_0

The identification argument is as follows: the first moment measures the effect that travel distance has on average shipping price. 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 mile, whence the price. Therefore, the first moment helps pin down the value of δ_0. Conditional on the values of δ_0 and γ, the parameter of interchange cost η is identified by the second moment, the average difference of price between an interconnecting route and a non-interconnecting route. When the value of interchange cost η increases, the price difference between an interconnecting route and a non-interconnecting route increases. Last, γ captures the effectiveness of allocated resources, and the value of γ largely affects the value of the last two moments regrading network measures. If there is no economy of scope ($\gamma = 0$), then only the travel distance between origin and destination matters for cost of shipping. Therefore, there is no benefit at all from consolidating traffic; the connectedness of the station and network structure will not affect shipping expense. If there is economy of scope ($\gamma \neq 0$), as illustrated in the example of section 2.3, the network structure affects how traffic can be consolidated and hence the level of economy of scope. Therefore, the effect of degree and betweenness centrality on price helps identify parameter γ.

Regarding the value of the data moments, average shipping price per loaded car per mile is \$1.73. According to the AAR, in 2001 the average revenue per mile for a loaded car was \$1.69, comparable to the value observed in the data. The effect of betweenness centrality on price is calculated to be $\$-0.30$. To interpret this number, if we compare a station with the highest value of betweenness centrality to a station with the lowest value, the price difference is $\$-0.2$, or about 20% difference in price.[51] The average difference of shipping price between

[51] The value of betweenness centrality is in the range of 0 to 1. The lowest value of betweenness centrality

an interconnecting route and a non-interconnecting route in the data is \$264.43 per loaded car. As a benchmark, in the data the average shipment price is \$1,034 per loaded car. Thus, the interchange cost is equivalent to about 26% of average shipment price.

I estimate the cost parameters by minimizing the weighted distance between data and simulated moments.[52] Table 8 shows the estimated results.[53]

Table 8: Estimation Results for Cost Parameters

	Point Estimate	95% Confidence Interval
δ_0	1.2	$[1.10, 1.29]$
η	217	$[155, 279]$
γ	0.17	$[0.14, 0.20]$

The estimated value of γ is less than 1, indicating that the marginal return of allocating resources to a particular arc is decreasing. Therefore, railroad firms are more likely to allocate resources to multiple arcs, rather than stacking them in only a few arcs. Table 9 compares the data moments with simulated moments under the estimated cost parameters.

Table 9: Comparison of Data and Simulated Moments

	Identification	Data Moments	Simulated Moments
Average shipping price (per loaded car per mile)	pin down δ_0	\$0.65	\$0.65
Average difference of price between interconnecting route and other route (per loaded car per mile)	pin down η	\$0.26	\$0.24
Moments related to network measures			
Effect of degree centrality on price per loaded car per mile	pin down γ, δ_0	\$-0.0002	\$-0.0003
Effect of betweenness centrality on price per loaded car per mile	pin down γ, δ_0	\$-0.33	\$-0.32

From the table, we can see that the model does well in matching the data moments. To evaluate how the parameters respond to different values of the data moments, I conduct a

in the data is 0.02 and the highest value is 0.7. Therefore, the difference is calculated as $\$-0.3*(0.7-0.02) = \$-0.204$. Compared to the average shipping price \$1.01, the change is about 20%.

[52] The weight of the moments is obtained from bootstraps.

[53] I use finite differencing to calculate standard errors of the estimated parameters, and I follow Andrews et al. (2017) in conducting the sensitivity analysis.

sensitivity analysis, with the results shown in Table 10. The results of the sensitivity analysis are obtained by increasing the values of data moments by 10%:

Table 10: Sensitivity Analysis by Increasing Data Moments by 10%

	δ_0	η	γ
Average shipping price (per loaded car per mile)	0.0361	6.0370	-0.0159
Average difference of price between interconnecting route and other route (per loaded car per mile)	0.0050	26.4637	0.0013
Effect of degree centrality on price per loaded car per mile	0.0000	0.0000	0.0000
Effect of betweenness centrality on price per loaded car per mile	0.0445	0.1450	0.0114

The results of the sensitivity analysis verify the identification arguments. We can see that the second moment mostly affects the value of parameter η. The first and last moment largely affect the values of δ_0 and γ, and increases in those two moments move γ in opposite directions. Therefore, these moments help identify the value of δ_0 and γ. However, we can see from the sensitivity analysis that the degree centrality moment does not have much identification power.

8 Counterfactuals and Results

8.1 Changes in Cost and Markup

I first conduct simulations of railroad firms mergers to study the effect of merger on costs and markups. I follow what happened over the period studied by simulating the twelve mergers occurring among Class I railroads in the United States from 1985 to 2005.[54] For example, in simulating the merger between the Burlington Northern railway (BN) and the Santa Fe railway (SF), I fix the total amount of demand in each origin-destination market, fix the network of railroad firms other than BN and SF, merge the networks of BN and of SF, combine the capital owned by BN and SF, and assume the merged firm BNSF makes pricing, routing, and allocation decisions for the newly merged network. Next, I solve for the post-merger equilibrium. By comparing the change of costs and prices before and after

[54] The complete history of mergers in the period studied is shown in Figure A.1.

the merger in each origin-destination market, I calculate the merger's effect. Last, I repeat the same counterfactual analysis for all twelve mergers in the studied period.

Table 11 shows the calculated changes of cost by comparing the after-merger and before-merger equilibria. Averaged over all mergers, shipment cost decreased by 15.49%. There are two reasons that why before-merger cost might be higher: the effect of misallocation, where after merger resources can be reallocated from the less efficient firm to the more efficient one, and the effect of change of network, where the merged firm can re-optimize routing and benefit from greater economy of scope. I design a counterfactual analysis to distinguish between the two effects. In the counterfactual, I allow the two merging firms to share their resources before merger, ensuring there is no misallocation before merger. I then isolate the changes caused by the effect of misallocation by comparing the new counterfactual results with pre-merger results where sharing of resources are not allowed. Last, I isolate the changes caused by change of network by comparing the new counterfactual results with the after-merger results. Table 11 shows that averaged across all mergers, misallocation of resources before merger accounts for 26% of total cost reduction. Network changes and re-optimization of routing account for 74% of total cost reduction after merger.[55]

Table 11: Change of Cost After Merger

	Changes	Decomposition
Change in Cost	-15.49%	100%
— Misallocation of resources		26.02%
— Change of network (re-optimization of routing)		73.98%

To illustrate the two effects after merger, and to further investigate the change in costs and markups, I now use the example of the merger between ATSF and BN to unpack the details. Figure 9 shows the change of allocation of resources following the merger of ATSF and BN. Panel (b) shows the changes of resources by comparing the equilibrium results after merger with those before merger. The most visible result in panel (b) is that resources are reallocated from ATSF to BN after the merger. A large fraction of formerly-ATSF network is colored red (decrease of allocated resources), while a large fraction of formerly-BN network is colored green (increase of allocated resources). This is because before the merger, the marginal productivity of capital of ATSF was lower than that of BN. Therefore, resources were reallocated from ATSF to BN after merger. However, the effect of misallocation tends

[55]Table F.1 shows the decomposition of cost changes of each merger from 1985 to 2005.

to overshadow the effect of change of network. To show the latter effect, panel (c) shows the changes of resources by comparing the equilibrium results after merger with those before merger but allowing firms to share resources before merger. From panel (c) we can see that most reallocation happens in or near the overlapping region of the two merging networks. In the west/east-bound direction, more resources are allocated to the arcs between Amarillo, TX and Omaha, NE. In the north/south-bound direction, more resources are allocated to the arcs between South Dakota and Kansas. In brief, the merged firm allocates more resources to enhance the connection of the two parts of the merged network after the merger.

[Insert Figure 9 here.]

To study how the other merged firms reallocate resources because of network changes, I repeat the same counterfactual analysis for all 12 Class I railroad mergers that happened between 1985 to 2005. Figure 11 shows the colored network for each merger in the studied periods. Figure 12 shows the calculated change of allocation of resources after each merger because of network changes. The results in Figure 12 confirm the finding that in all the mergers, the merged firm allocates more resources to or near the overlapping region of the two merging networks. In another word, after the merger because of elimination of interchange cost, the merged firm will reallocate resources to enhance the connection of the two parts of the merged network, and re-optimize routing to benefit more from economy of scope.

After understanding how resources are being reallocated after merger, I study the implied change of costs and markups driven by change of network. Figure 10 shows the change of costs and markups caused by network changes after the merger of BN and ATSF. The changes are aggregated to destinations. Panel (a) shows the change in costs; the results show, first, that most of the destinations have a cost reduction after the merger. Second, among all the destinations, nodes in the areas around Omaha, NE and Lubbock, TX have the largest cost reduction (about 25%). This is because after the merger, resources are reallocated to such regions. From panel (c) of Figure 9, we know that the arcs between Amarillo, TX and Omaha, NE have the largest increase of resources after the merger. Therefore, destinations near those areas have the largest cost reduction after the merger. Panel (b) of Figure 10 shows the change in markup after the merger. The results suggest that nodes in the before-merger overlapping region have a disproportionately large increase in markup compared to other nodes. This is because the merged firm has a larger increase of market power in the overlapping region compared to other regions.

[Insert Figure 10 here.]

From the results in Figure 10, we can see that on average, the shipment costs decreased while the mark-up increased after the merger because of network changes. However, there is a large degree of heterogeneity regarding change in costs and markups, depending on the location of markets and the topology of the network. To better understand the role of network structure and how it affects effect of mergers, in the next section I look at different centrality measures of a network, and how such measures are related to change of costs and change of markups after a merger.

8.2 Role of Network Structure

First, I calculate the change in costs and markups due to network changes after each merger in the studied period. Then, I regress those changes on certain centrality measures of the merged networks. The regression results show how the values of these centrality measures impact the effect of a merger. Last, I analyze the relationship between average centrality measures and average changes in costs and markups across mergers.

Network Measures. I use three network measures in my analysis.[56] I start with the notion of *degree centrality*. The degree of a node i is the number of neighbors of node i, and it equals to the total number of other nodes (BEA regions) with a connection to node i in the network $\mathcal{G}_j$ of firm j. The degree centrality of node i in network $\mathcal{G}_j$ is written as:

$$\begin{aligned} d_i(\mathcal{G}_j) &= \#\{k : a_{ik} = 1\} \\ &= \sum_{(i,k)\in\mathcal{A}_j} 1 \end{aligned} \tag{8}$$

The degree centrality of node i is larger when the number of links connected to i is larger.

The second measure is *betweenness centrality*, which captures how frequently the node is found on the shortest path from an origin to a destination. It is calculated as follows:

$$B_i(\mathcal{G}) \coloneqq B_i(\mathcal{G}_j) = \sum_{o,d\in\mathcal{Z}_j} \frac{\mathbb{1}\{i \in l(o,d)\}}{(Z_j-1)(Z_j-2)} \tag{9}$$

where Z_j is the total number of nodes in network $\mathcal{G}_j$.

The last measure is the *weighted average neighbor betweenness*. This measure captures the extent to which node i is connected to other highly traveled nodes in the network of firm

[56] I define the network measures similarly to Ciliberto et al. (2019) and Chen et al. (2020). See Jackson (2010) for a more detailed discussion.

j:

$$\bar{B}_i^w(\mathcal{G}_j) = \frac{\sum_{k=1}^{Z_j} a_{ik} B_k}{\sum_{k=1}^{Z_j} a_{ik}} \tag{10}$$

where $a_{ik} = 1$ if $(i,k) \in \mathcal{A}_j$ and 0 otherwise.

I illustrate how to understand the three network measures in Appendix C. In that appendix, I show how the railroad network structure appears in my data when the values of the network measures vary.

8.2.1 How Network Measures Impact Within-Merger Effects of Mergers

In studying this question, I run regressions for each individual merger. I regress changes in costs and markups on centrality measures of each node of the merged network. The changes are calculated by comparing equilibria after and before merger but allowing firms to share resources before merger, so that I could obtain the changes driven by change of network rather than misallocation of resources. The main regression is specified as follows:

$$\Delta y_{j,od} = \alpha + \beta_1 \cdot I_{j,od} + \beta_2 \cdot m_d(\mathcal{G}_j) + \epsilon_{j,od} \tag{11}$$

where $y_{j,od}$ for firm j at market from o to d is the change in either shipment cost or markup. $I_{j,od}$ is an indicator of whether the route is inter-connecting or not, $\mathcal{G}_j$ is the network of firm j, and $m_d(\mathcal{G}_j)$ is the centrality measure of node d (the destination of the o–d market).[57]

Table 12 shows the regression results for the merger of BN and ATSF. Panel (a) shows the results of regressing cost changes on different centrality measures. First, the estimated effect is consistent across different centrality measures: the higher the centrality measure of a node, the larger the cost reduction after the merger. This might be because for nodes with higher centrality measure, there are more opportunities of routing to other origin–destination markets. Therefore, it is more likely that resources will be reallocated to such regions because more markets can benefit from economy of scope by routing through these nodes. When more resources are allocated to those regions post merger, the reduction in shipment cost will be larger. Second, regarding the magnitude of the estimated effect, an increase in degree centrality of 1 results in a 0.5 percentage-point increase in the cost reduction after merger. Intuitively, increasing the degree centrality of a node means having one more connection to the available adjacent nodes. The difference between the smallest and largest degree centrality of a node in the merged network is 9, so the cost reduction for

[57] I also run the regressions on the centrality measures of origins as a robustness check. The results are similar to the case of using destinations.

the node with largest degree centrality is about 5 percentage points larger than for the node with smallest degree centrality. From Table F.1, we know that the average cost reduction of the merger of BN and ATSF is -11.49%. Therefore, we see a big difference in cost reduction between nodes with smallest and largest degree centrality. Panel (b) shows the results of changes in markup. Results for different centrality measures all suggest that nodes with higher centrality measure have larger markup increases post merger. This is because such nodes are more likely to be located in the overlapping region of the two merging networks. Hence, after the merger these nodes experience a greater increase in market power compared to nodes in other regions. Regarding the magnitude of the estimated effect, an increase in degree centrality of 1 results in a 0.1 percentage-point increase in markup. Therefore the increase in markup of the node with largest degree centrality is about 1 percentage point larger than for the node with smallest degree centrality.

[Insert Table 12 here.]

To generalize the findings, I repeat the same analysis for all the mergers that happened in the studied period. The estimated coefficients are shown in Table 13. The results from various mergers are generally consistent with the previous findings: nodes with higher centrality measures have greater cost reductions and larger increases in markup after merger. Averaging over all mergers, an increase degree centrality of 1 results in a 0.6 percentage-point extra reduction in cost and a 0.2 percentage-point extra increase in markup after merger.

[Insert Table 13 here.]

8.2.2 How Network Measures Impact Across-Merger Effects of Mergers

To better summarize how the topology of a firm's network impact merger effects, in Figure 13 I plot the average changes in costs and markups with respect to average network measures for each merger.

[Insert Figure 13 here.]

Panels (a) and (b) of Figure 13 show the comparison between average changes of cost after merger and average network measures of the merged network. The results show that when the average degree centrality of a merged firm's network is larger, the level of average cost reduction is larger too. However, when the average betweenness centrality is larger, the level of average cost reduction is smaller. This might be because when the average degree centrality of a network is larger, there are more routing choices in the network.[58] Therefore, the potential gains from re-optimization of routing are larger after the merger. By comparison, if the average betweenness centrality of a network is larger, the network is more "linear,"[59] hence there are fewer routing choices. Therefore, the potential gains from re-optimization of routing will be smaller after the merger. Comparing among all the mergers, if the average degree centrality of the merged network increases by 1, the average percentage of cost reduction will increase by 3 percentage points after merger. If the average betweenness centrality increases by 0.1, the average percentage of cost reduction will decrease by 2 percentage points after merger.

Panels (c) and (d) of Figure 13 show the comparison between average changes in markup after merger and average centrality measures of the merged network. The results show that when the average degree centrality of the merged network is larger, the increase in average markup is larger. When the average betweenness centrality is larger, the increase in average markup is smaller or negative. Comparing among all the mergers, if the average degree centrality of the merged network increases by 1, the average change of markup will increase by 1 percentage point after merger. If the average betweenness centrality increases by 0.1, the average change of markup will decrease by 2.6 percentage points after merger.

In brief, the results suggest that if the merged firm has higher average degree centrality, the reduction in shipment cost and the increase in markup will both be larger. If the merged firm has higher average betweenness centrality, the average reduction in shipment cost will be lower, but the increase in markup will be lower or possibly negative.

9 Conclusion

I document evidence of improved cost efficiency following the wave of mergers in the U.S. railroad industry from 1980 to 2005. By conducting a reduced-form analysis with detailed route-level shipment data, I find that following the mergers, shipment prices decreased by 9.4% on average after the mergers, and interconnecting routes had the largest price reduction, 11%, of all the route types. However, looking solely at the effect of individual routes is insufficient to understand efficiency gain in this industry. This is because the origin–destination markets in the network are interdependent. To capture this important feature and examine how network structure affects effect of mergers, I propose an optimal transport network model by endogenizing firm's pricing, routing, and allocation decisions. The counterfactual results show that averaged over all mergers, shipment cost decreased by 15.49%. Among

[58]See an illustration of networks with different level of average degree centrality in Figure C.1.

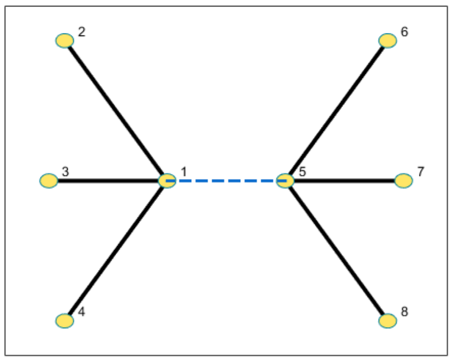
[59]Figures C.2 and C.3 show networks with different levels of average betweenness centrality.

the total cost reductions, misallocation of resources before merger accounts for 26% of total cost reduction, while network changes and re-optimization of routing account for 74% of total cost reduction after merger. Moreover, network structure or topology matters in the freight network industry because it affects how much firms benefit from economy of scope. The counterfactual results show that within a merger, an increase degree centrality of 1 of a node results in a 0.6 percentage-point extra reduction in cost and a 0.2 percentage-point extra increase in markup after merger. Across mergers, if the average degree centrality of the merged network increases by 1, the average change of markup will increase by 1 percentage point after merger. If the average betweenness centrality increases by 0.1, the average change of markup will decrease by 2.6 percentage points after merger.

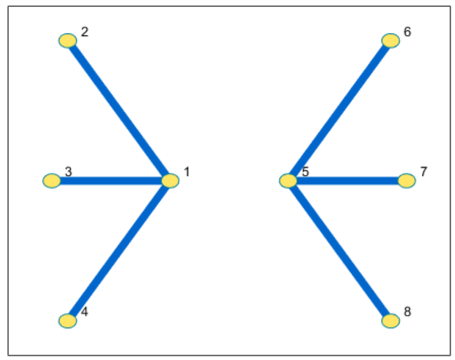
Certain limitations of this paper suggest areas for further exploration. First, the total amount of capital of each firm is fixed. One could look at how a free capital market affects the predicted results by relaxing this assumption. Second, it is difficult to integrate two large networks into one. For example, when the Union Pacific railway acquired the Southern Pacific railway, integration of their networks was challenging, with 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 have been more lawsuits alleging collusion by railroad companies since 2004, by which time the main mergers were completed. These features are not captured in my model but are worth exploring.

Figure 7: Illustrative Example

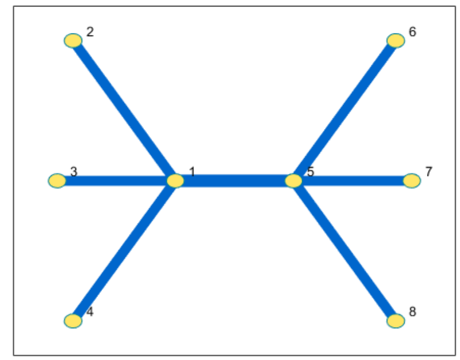
Note: Figure 7 shows the toy example of two networks A and B. Panel (a) shows the network of A, with two firms I and II. Firm I owns nodes 1 through 4. Firm II owns nodes 5 through 8. There are six within-firm traffic routes, $1 \rightarrow 2$, $1 \rightarrow 3$, $1 \rightarrow 4$ within firm I, and $5 \rightarrow 6$, $5 \rightarrow 7$, $5 \rightarrow 8$ within firm II; and there are six across-firm traffic routes, $1 \rightarrow 6$, $1 \rightarrow 7$, $1 \rightarrow 8$, and $5 \rightarrow 2$, $5 \rightarrow 3$, $5 \rightarrow 4$. Each connected arc has a travel cost of 1, and an across-firm traffic incurs an extra interchange cost η. So, the cost of traveling from $1 \rightarrow 2$ is 1, and the cost of traveling from $1 \rightarrow 5$ is $1 + \eta$ in Network A. Network B in panel (d) has exactly the same set-up. Panels (b) and (c) shows the traffic volume of network A when the interchange costs are 0.5 and 0.1 respectively. Panel (e) and (f) show the traffic volume of network B when interchange costs are 0.5 and 0.1 respectively. Comparing panels (b) and (e) shows that firms I and II have the exact same network in network A and network B, the only difference being the networks connect to each other. Think of the "fork" being placed in different directions in network A and network B.



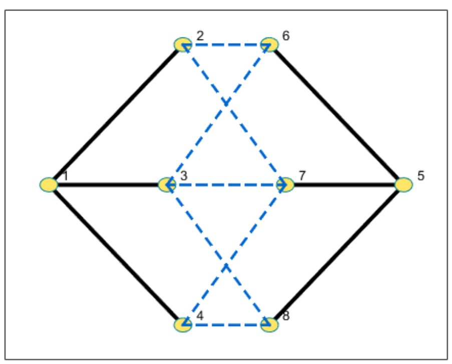
(a) Network A



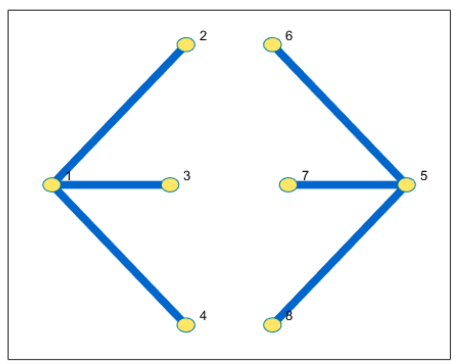
(b) Traffic volume when interchange cost is 0.5



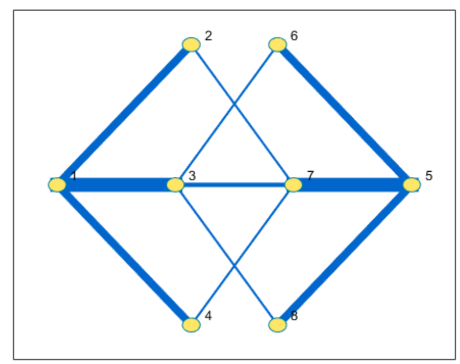
(c) Traffic volume when interchange cost is 0.1



(d) Network B



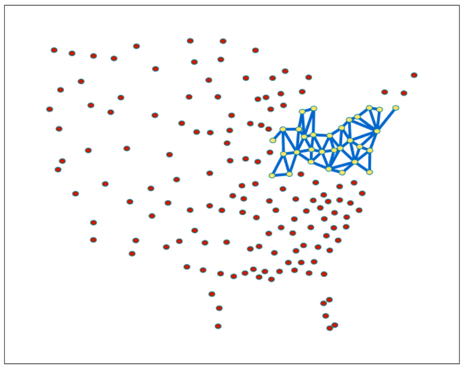
(e) Traffic volume when interchange cost is 0.5



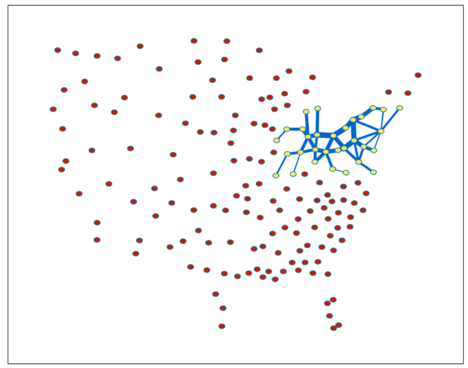
(f) Traffic volume when interchange cost is 0.1

Figure 8: How Value of γ Affects Allocation and Routing Decisions

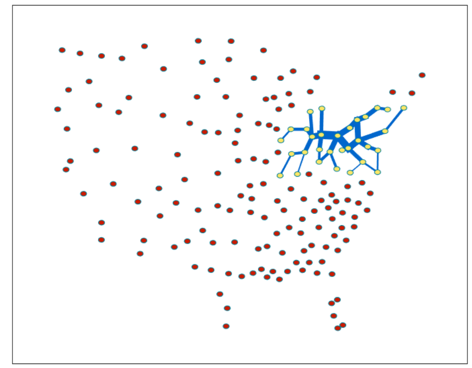
Note: Figure 8 shows how Conrail's routing and allocation decisions change when the value of γ changes. Panels (a) to (c) show the allocation decision; line thickness shows the amount of resources allocated. Panels (d) to (f) show the routing decision for origin 3 and destination 7 when the value of γ changes. When $\gamma = 0$, there is no economy of scope, resources are evenly allocated to all arcs owned by Conrail in panel (a), routing from 3 to 7 adopts the shortest distance $3 \rightarrow 10 \rightarrow 7$ in panel (d). When γ is non-negative, there is economy of scope so it is more cost-efficient to consolidate traffic and allocate more resources to routes with larger traffic volume. From panels (b) and (c) we see that when γ increases, the allocation is more consolidated within "major" routes. Regarding routing, as γ increases, the optimal routing is no longer following the shortest distance, because the routing now takes advantage of the lower cost of going through "major" routes ("highway" vs. "country road"). From panels (d) through (f), the optimal routing changes from $3 \rightarrow 10 \rightarrow 7$ in panel (d), to $3 \rightarrow 10 \rightarrow 8 \rightarrow 7$ in panel (e), and to $3 \rightarrow 10 \rightarrow 9 \rightarrow 8 \rightarrow 7$ in panel (f).



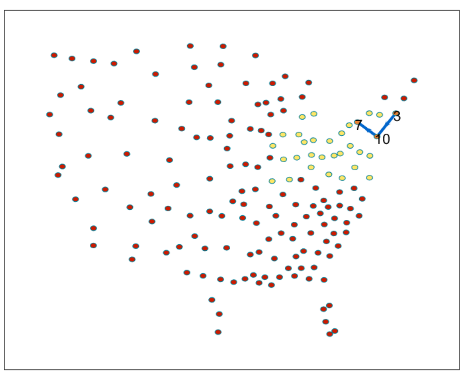
(a) Allocation of Resources, $\gamma = 0$



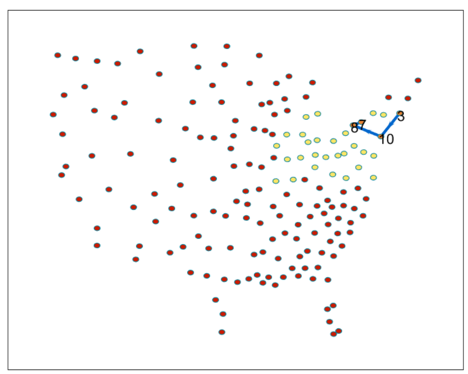
(b) Allocation of Resources, $\gamma = 0.5$



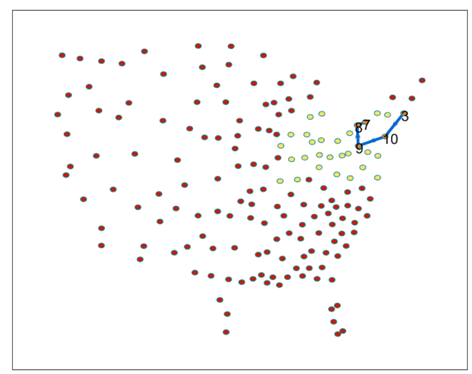
(c) Allocation of Resources, $\gamma = 0.85$



(d) Routing of $3 \rightarrow 7$, $\gamma = 0$



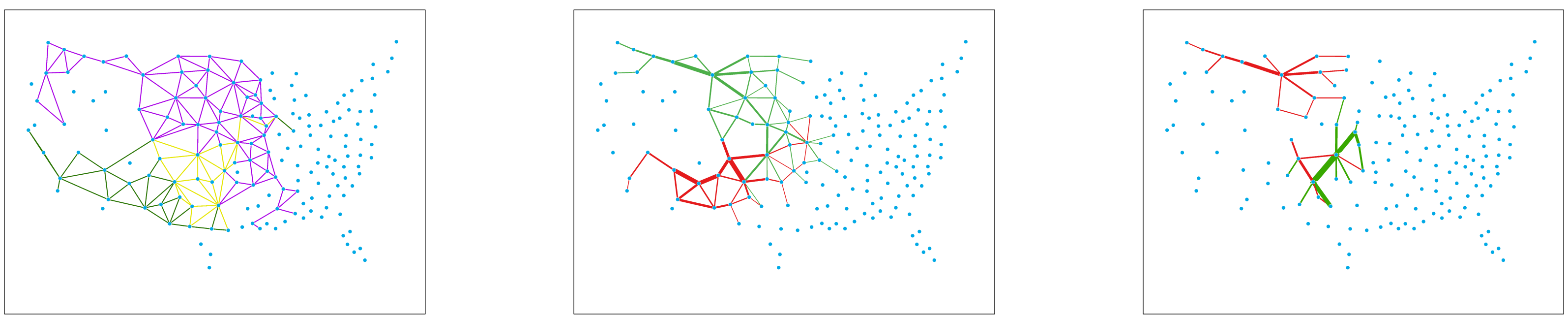
(e) Routing of $3 \rightarrow 7$, $\gamma = 0.5$



(f) Routing of $3 \rightarrow 7$, $\gamma = 0.85$

Figure 9: Changes in Allocation of Resources After ATSF–BN Merger

Note: Figure 9 shows the change in allocation of resources following the merger of ATSF and BN. Panel (a) shows the combined network of the two merging firms. Green arcs show the network owned only by BN, purple the network owned only by SF, and yellow the overlapping region of the two networks. Panels (b) and (c) show the change in allocation of resources. Green represents increased allocation after merger, while red represents decreased allocation. The line thickness represents the magnitude of change. Panel (b) shows the changes by comparing the equilibrium allocation of resources after merger with allocation of resources before merger. Panel (c) shows the allocation changes by comparing the equilibrium allocation of resources after merger with that before merger but allowing firms to share resources before merger. So, in the latter case the marginal productivity of capital is equalized between the two merging firms before merger.



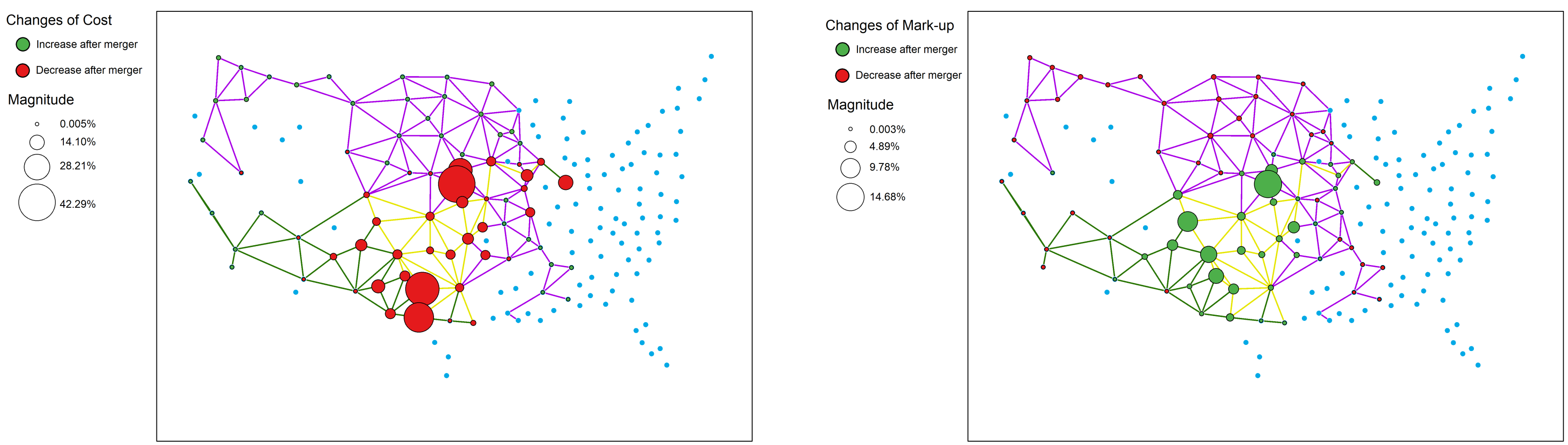
(a) Network of BNSF

(b) After-merger compared to before-merger

(c) After-merger compared to before-merger (allow for sharing of capital before merger)

Figure 10: Changes in Cost and Markup Because of Network Change

Note: Figure 10 shows the change in cost and mark-up caused by network change after the merger of BN and ATSF. The changes are calculated by comparing the equilibrium costs and markups after merger with costs and markups before merger, allowing firms to share resources before merger. The map is colored with purple showing the network owned only by BN, green showing the network owned only by SF, and yellow showing the network owned by both firms. The changes are aggregated by destinations. The size of each node represents the magnitude of changes. Red means reduction, while green means increase after merger. Panel (a) shows the calculated changes in costs. Panel (b) shows changes in markups.

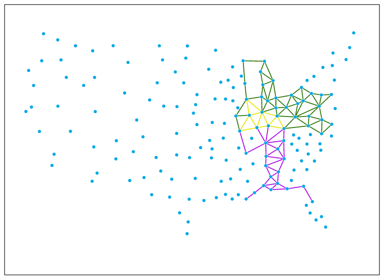


(a) Change in Costs

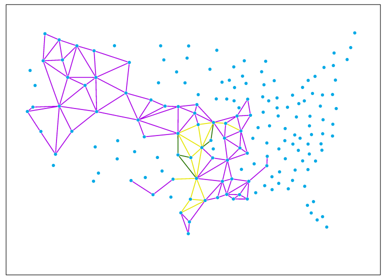
(b) Change in Markups

Figure 11: Networks for Each Merger Case

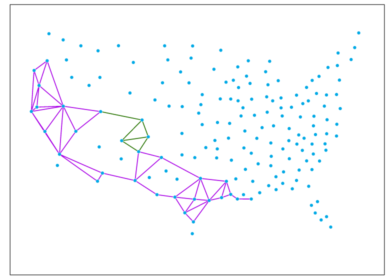
Note: Figure 11 shows the virtual networks of the two merging parties in each merger case between Class I railroads from 1985 to 2005. There were 12 mergers in total. Within each merger (firm1 + firm2), the network of firm1 is marked in green, that of firm2 is marked in purple, and the overlapping part is marked in yellow. For example, in panel (a) the network solely owned by COBO before the merger is marked in green, the network solely owned by SBD is marked in purple, and the overlapping region is marked in yellow.



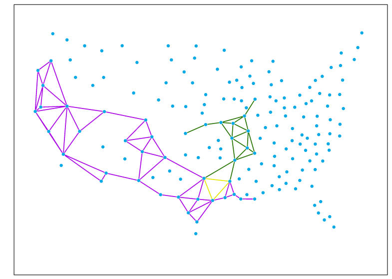
(a) 1986, COBO + SBD



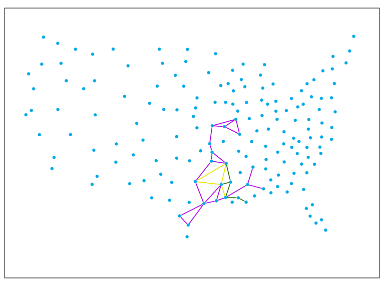
(b) 1988, MKT + UP



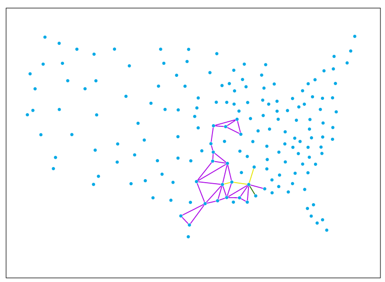
(c) 1988, DRGW + SP



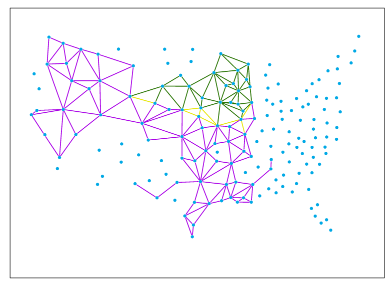
(d) 1992, SSW + SP



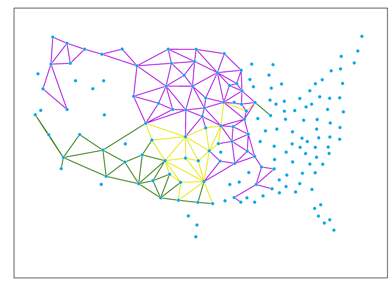
(e) 1992, LA + KCS



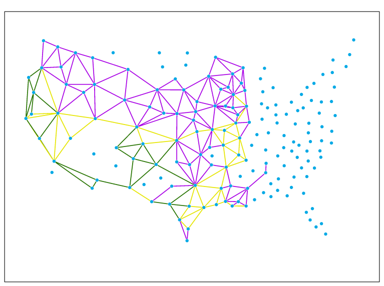
(f) 1993, MSRC + KCS



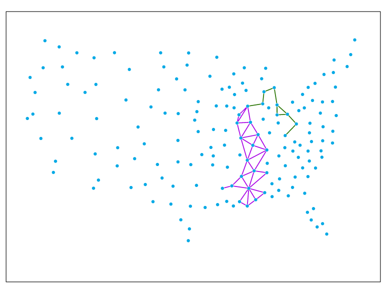
(g) 1995, CNW + UP



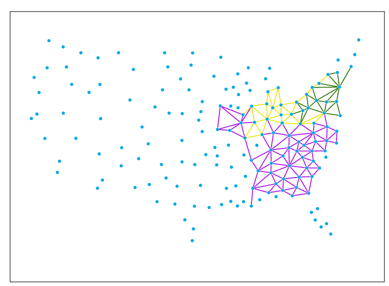
(h) 1996, ATSF + BN



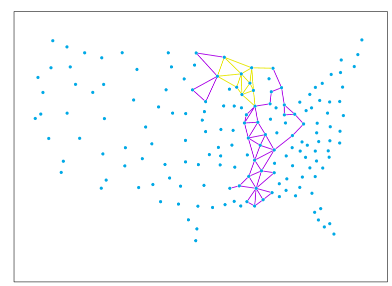
(i) 1996, SP + UP



(j) 1998, CN + IC



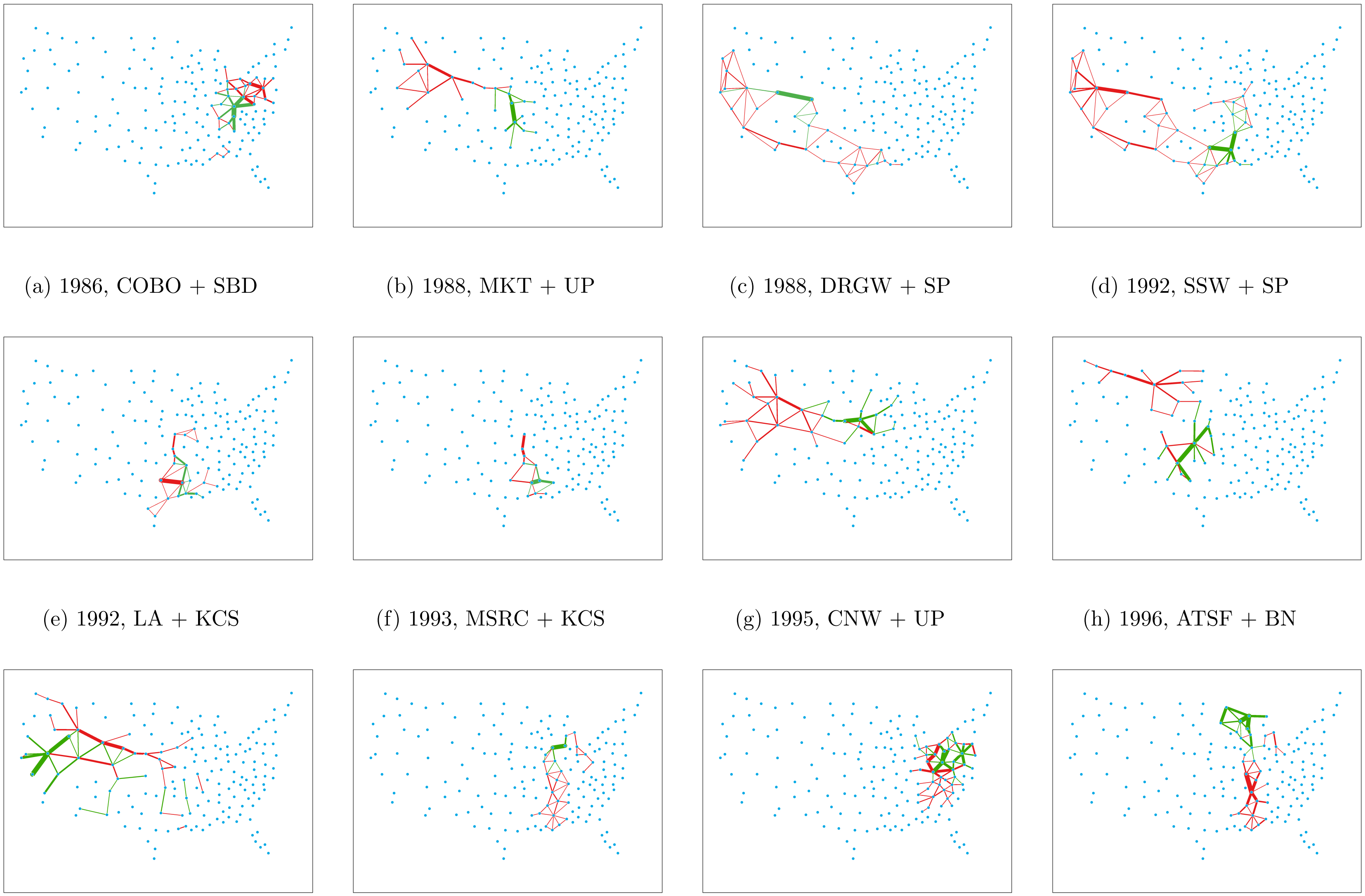
(k) 1999, CR + NS



(l) 2004, WC + CN

Figure 12: Change in Allocation of Resources

Note: Figure 12 shows change in allocation of resources after each merger. The change is calculated by comparing allocation after and before merge, allowing for capital sharing before the merger. The link thickness measures the magnitude of changes, green represents increased resources, and red represents decreased resources.



(a) 1986, COBO + SBD

(b) 1988, MKT + UP

(c) 1988, DRGW + SP

(d) 1992, SSW + SP

(e) 1992, LA + KCS

(f) 1993, MSRC + KCS

(g) 1995, CNW + UP

(h) 1996, ATSF + BN

(i) 1996, SP + UP

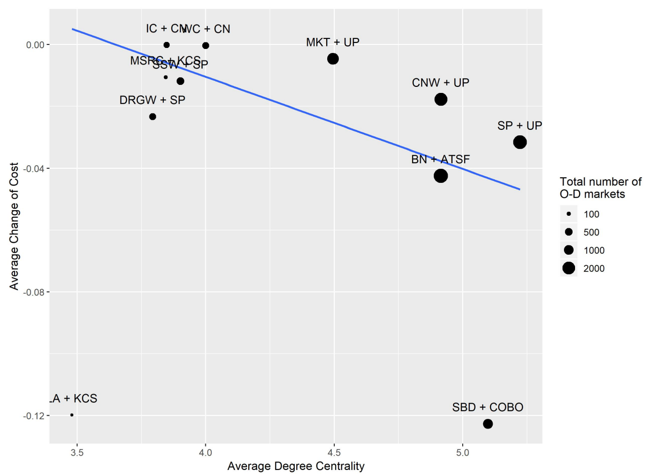
(j) 1998, CN + IC

(k) 1999, CR + NS

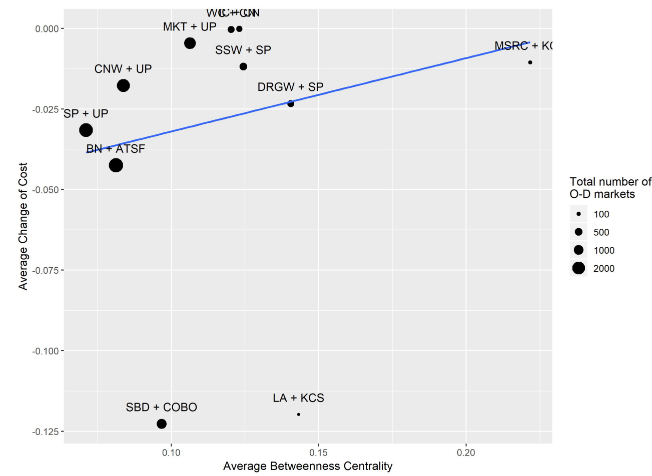
(l) 2004, WC + CN

Figure 13: Average Merger Effects vs. Average Network Measures

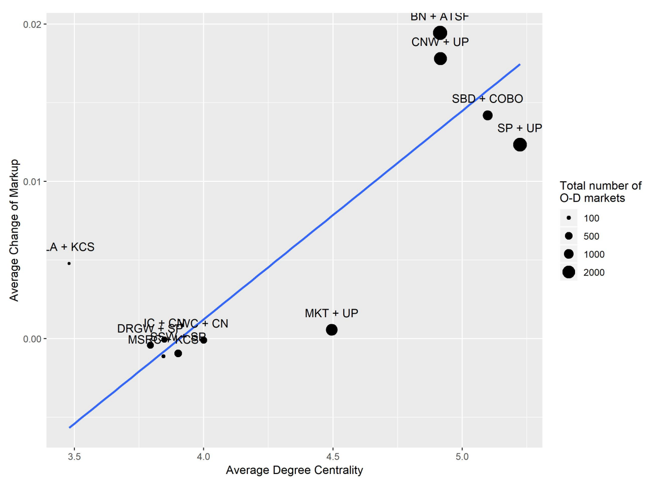
Note: Panels (a) and (b) show the comparison between average cost changes after merger and average network measures (degree and betweenness centrality) of merging firms. Panels (c) and (d) show the comparison between average markup changes after merger and average network measures (degree and betweenness centrality) of merging firms. Size of dot represents the total number of o–d markets in the particular merger.



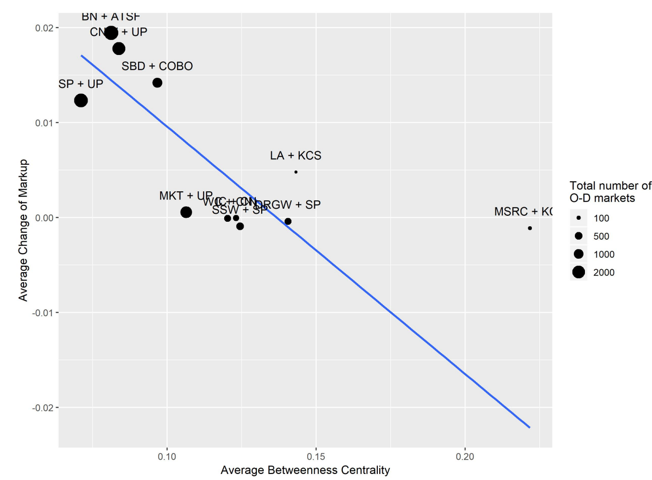
(a) Average Cost Changes vs. Average Degree Centrality



(b) Average Cost Changes vs. Average Betweenness Centrality



(c) Average Markup Changes vs. Average Degree Centrality



(d) Average Markup Changes vs. Average Betweenness Centrality

Table 12: How Does Network Structure Affect Merger Effects?

Note: Table 12 shows the results of regressing merger effects on different centrality measures. The regression is at firm–market (firm–origin–destination) level. Degree centrality measures the total number of arcs connected to each node. The higher the degree centrality, the more connections a node has to its neighboring nodes. Betweenness centrality measures how frequently the node is found on the shortest path from an origin to a destination (the "hubness" of a node). Panel A shows the results of regressing change in costs on centrality measures of destination node, while panel B shows the results of regressing change in markups. Column (1) shows the results of degree centrality, column (2) shows the results of betweenness centrality, and column (3) shows the results of weighted average of neighboring betweenness centrality.

Panel A: Regress change in costs on centrality measures of destination

	(1) Change in Cost	(2) Change in Cost	(3) Change in Cost
Indicator of Interchange	-0.268***	-0.267***	-0.265***
	(0.00751)	(0.00757)	(0.00758)
Degree Centrality	-0.00586***		
	(0.000742)		
Betweenness Centrality		-0.175***	
		(0.0354)	
Weighted Average of Neighboring Betweenness Centrality (WANB)			-0.148*
			(0.0614)
Observations	2746	2746	2746

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Panel B: Regress change in markups on centrality measures of destination

	(1) Change in Markup	(2) Change in Markup	(3) Change in Markup
Indicator of Interchange	0.0206***	0.0209***	0.0204***
	(0.00198)	(0.00198)	(0.00198)
Degree Centrality	0.00114***		
	(0.000196)		
Betweenness Centrality		0.0593***	
		(0.00927)	
Weighted Average of Neighboring Betweenness Centrality (WANB)			0.0990***
			(0.0160)
Observations	2746	2746	2746

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 13: Estimated Coefficients of Network Measures for Each Merger

Note: Table 13 shows the estimated coefficients of network measures for each merger. The regression is at firm–market (firm–origin–destination) level. Degree centrality measures the total number of arcs connected to each node. The higher the degree centrality, the more connections a node has to its neighboring nodes. Betweenness centrality measures how frequently the node is found on the shortest path from an origin to a destination (the "hubness" of a node). Panel A shows the value of estimated coefficients by regressing change in costs on centrality measures of destination. Panel B shows the results for change in markups.

Panel A: Regress change in costs on centrality measures of destination. Estimated coefficients:

	(1)	(2)	(3)	(4)
	Degree Centrality	Betweenness Centrality	Weighted Average of Neighboring Betweenness Centrality (WANB)	Number of Unique Markets
1986 SBD + COBO	-0.00913***	-0.267***	-0.556***	1106
	(0.00134)	(0.0441)	(0.067)	
1987 MKT + UP	-0.00250***	-0.0503***	-0.0412*	1664
	(0.000445)	(0.0102)	(0.0165)	
1989 DRGW + SP	-0.0029	-0.0042	0.139	373
	(0.00198)	(0.0428)	(0.0886)	
1990 SSW + SP	-0.00111	-0.0804*	-0.0806	532
	(0.00177)	(0.0394)	(0.0841)	
1992 LA + KCS	-0.0222*	0.225	0.679	75
	(0.00985)	(0.201)	(0.373)	
1993 CNW + UP	-0.00418***	-0.0632**	-0.0559	2115
	(0.000622)	(0.0212)	(0.0327)	
1993 MSRC + KCS	-0.00463*	-0.0181	-0.0267	90
	(0.00199)	(0.0324)	(0.0519)	
1995 BN + ATSF	-0.00586***	-0.175***	-0.148*	2746
	(0.000742)	(0.0354)	(0.0614)	
1996 SP + UP	-0.00501***	-0.0258	0.428***	2474
	(0.00117)	(0.0528)	(0.0842)	
1997 IC + CN	0.0000865	-0.0178	-0.0308	290
	(0.000611)	(0.0114)	(0.0257)	
2000 WC + CN	-0.00257**	-0.0204	0.143***	398
	(0.000784)	(0.0147)	(0.0328)	

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Panel B: Regress change in markups on centrality measures of destination. Estimated coefficients:

	(1) Degree Centrality	(2) Betweenness Centrality	(3) Weighted Average of Neighboring Betweenness Centrality (WANB)	(4) Number of Unique Markets
1986 SBD + COBO	0.00338***	0.163***	0.328***	1106
	(0.000657)	(0.0213)	(0.0322)	
1987 MKT + UP	0.000349***	0.00811***	0.0108***	1664
	(0.0000847)	(0.00194)	(0.00313)	
1989 DRGW + SP	0.000241	0.00979*	0.00145	373
	(0.000202)	(0.00432)	(0.00904)	
1990 SSW + SP	0.000386	0.0206*	0.0242	532
	(0.000423)	(0.00937)	(0.02)	
1992 LA + KCS	0.0121*	-0.0681	-0.281	75
	(0.00507)	(0.104)	(0.195)	
1993 CNW + UP	0.000682**	0.0135	0.0324**	2115
	(0.000216)	(0.0073)	(0.0112)	
1993 MSRC + KCS	0.00206	0.0154	0.0202	90
	(0.00126)	(0.0203)	(0.0325)	
1995 BN + ATSF	0.00114***	0.0593***	0.0990***	2746
	(0.000196)	(0.00927)	(0.016)	
1996 SP + UP	0.000862***	0.0275***	-0.00901	2474
	(0.000149)	(0.00672)	(0.0108)	
1997 IC + CN	-0.0000947	0.00282	0.00864	290
	(0.000127)	(0.00238)	(0.00536)	
2000 WC + CN	0.000494***	0.00427	-0.0183**	398
	(0.000144)	(0.00271)	(0.0061)	

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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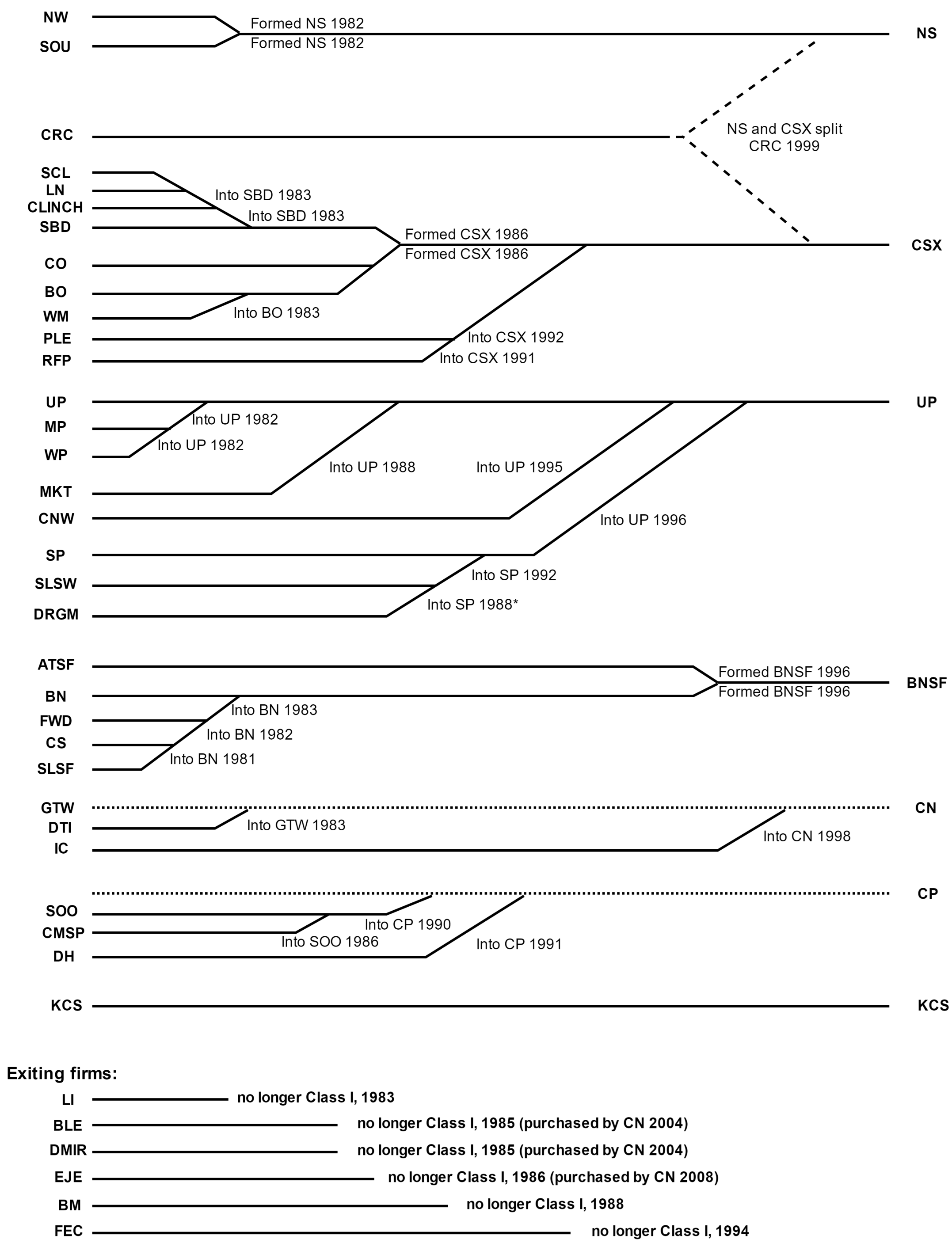
A History of American Railroads

A.1 Merger History

Figure A.1: Merger History of Railroads



A.2 Regulation Changes in the U.S. Railroad Industry

Here I document a brief history of regulation changes in the U.S. railroad industry. The information is collected from multiple sources by the Surface Transportation board and other government resources.

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

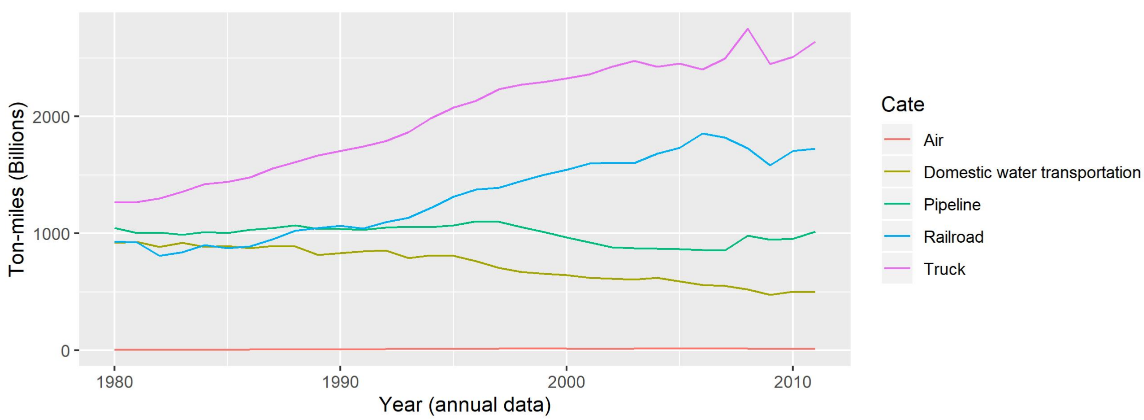
- 2013, Rate Regulations Reforms: remove limit of simplified-SAC, raise limit of three-benchmark to $4 million (we see 6 rate cases after 2016, but all are using full-SAC method)

B Details of U.S. Railroad Industry

B.1 Industry Statistics

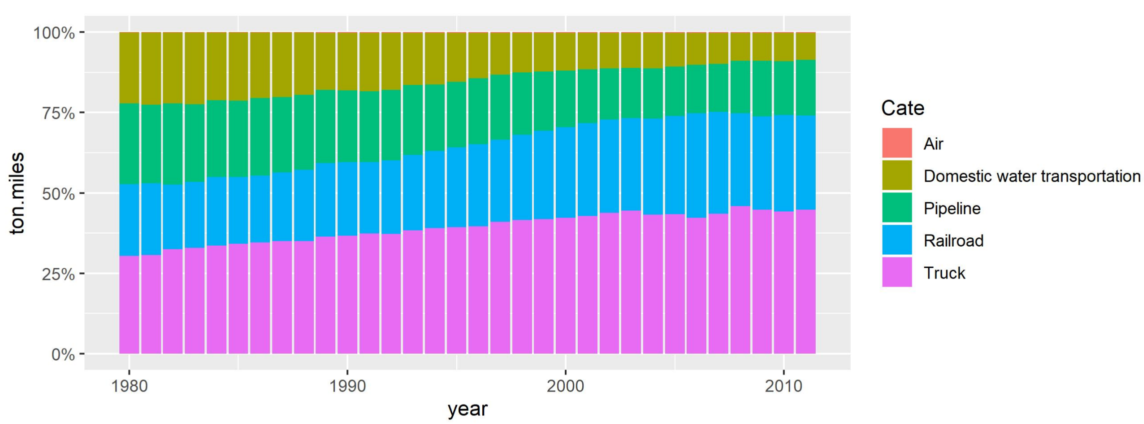
Figure B.1 and B.2 plots the total ton-miles of freight carried by mode, from 1980 to 2011 Importance of railroad industry among all the transportation mode. We can see that the U.S. railroad industry only accounts fo a small proportion of total ton-miles of freight (around 20%), and even accounts for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

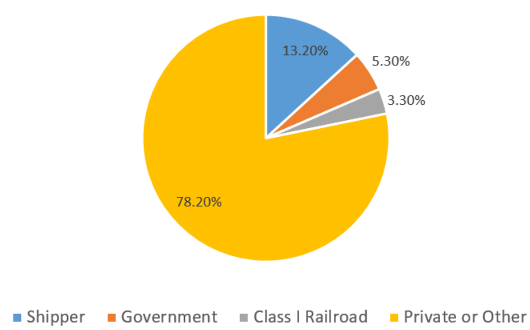
U.S. Freight Railroad Industry 2012

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.

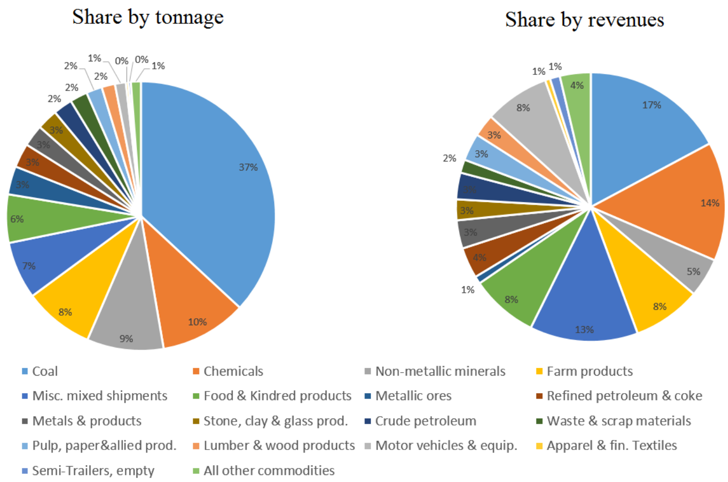
Figure B.4: Ownership of Regional and Short Lines



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

B.2 Documentation of Interviews

Below I document the interviews I conducted with people working in this industry (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."

B.3 More Summary Stats of Waybill Data

Table B.1: Summary Statistics of Market Competition (Annually)

Year	Number of Waybills	Percentage of Interchange Lines	Number of Competitors in an O-D Market			Number of O-D Market (at BEA-to-BEA level)
			mean	25th percentile	75th percentile	
1984	262,626	41%	3	1	3	12,135
1985	262,703	41%	3	1	3	12,088
1986	276,177	38%	3	1	3	11,907
1987	300,324	35%	3	1	3	11,957
1988	322,257	35%	3	1	3	11,905
1989	324,936	36%	3	1	3	11,846
1990	323,570	35%	2	1	3	11,835
1991	314,705	32%	2	1	3	11,583
1992	346,632	31%	2	1	3	11,695
1993	373,868	29%	2	1	3	11,849
1994	426,092	27%	2	1	3	11,899
1995	453,802	26%	2	1	3	11,632
1996	457,505	25%	2	1	3	11,510
1997	473,070	23%	3	1	3	11,740
1998	496,856	20%	2	1	3	11,675
1999	524,856	15%	2	1	3	11,573
2000	544,738	14%	2	1	2	11,732
2001	522,927	14%	2	1	2	11,514
2002	535,722	13%	2	1	2	11,381
2003	554,967	13%	2	1	2	11,473
2004	580,572	12%	2	1	2	11,474
2005	611,033	11%	2	1	2	11,611
2006	632,748	11%	2	1	2	11,327
2007	611,421	10%	2	1	2	11,025
2008	568,584	10%	2	1	2	10,964
2009	477,526	10%	2	1	2	10,242
2010	533,364	10%	2	1	2	10,485

Source: STB, Carload Waybill Sample

Table B.1 shows that the year-by-year change tells the same story as in Table 2. First, total number of waybills in the waybill sample (the waybill sample is 2% of total waybills) changed from around $263,000$ to $533,000$ from year 1985 to 2010. This shows that total volume of railroad shipment doubled from 1985 to 2010. This is consistent with the story I show in figure 1. Meanwhile, the percentage of interchange lines decreased from 41% to 10% while the total traffic volume doubled. It shows that following the wave of mergers from 1985 to 2010, there is a significant decrease of interchanges. The number of O-D markets is relatively stable across the years, with a small decrease from $11,835$ to $11,611$ from year 1990 to 2005. Therefore, the change of extensive margin after the mergers does not seem to be a big concern. Last, the average number of competitors in each O-D market slightly decreased from 3 to 2 from 1985 to 2010. It indicates that firms conduct oligopolistic competition in the local markets.

C Illustration of Network Measures

Here is how to understand the four network measures. First, figure C.1 shows the average degree centrality of each firm in year 2004. Panel (a) shows the average degree centrality (average number of neighbors of each node) of the seven railroad firms in 2004. We can see that NS has the highest average degree centrality of about 5 while CN has the lowest average degree centrality of about 3. Panel (b) and (c) show the network of NS and CN respectively. We can see that NS are more "connected" than CN, in the sense that for each node in NS, there are more connections to other adjacent nodes.

[Insert Figure C.1 here.]

Figure C.2 shows the average betweenness centrality of each firm in year 2004. Intuitively, average betweenness centrality measures the availability of "alternative routes" in traveling among node-pairs within a network. Panel (a) shows that KCS has the highest average betweenness centrality of 0.2, which means 20% of all shortest routes between node-pairs within the network of KCS pass through the same nodes. Put this in a real context, it means something like 20% of all traffics within the network of KCS needs to go through Kansas City. Panel (a) also shows that UP has the lowest betweenness centrality of 0.06. Therefore, the hubness of nodes in UP is much smaller than the hubness of nodes in KCS. But it also means that there are less alternative routes to travel among node-pairs within the network of KCS. To better explain this point, I will show a more extreme example in figure C.3, where I compare the network of UP and CN in 1986.

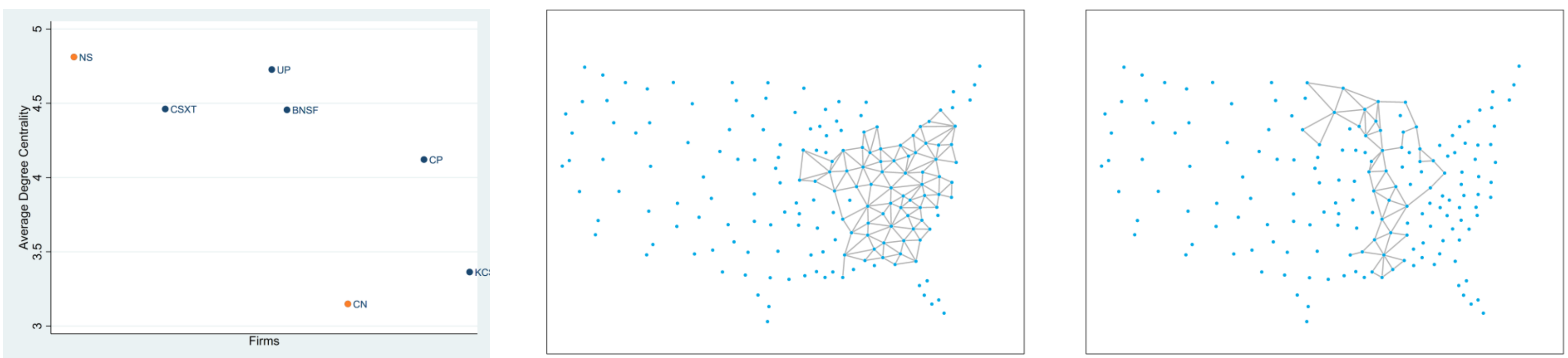
[Insert Figure C.2 here.]

In the example of figure C.3, UP has an average betweenness centrality equals to 0.1 and CN has an average betweenness centrality equals to 0.4, four times larger. It means among all the node pairs within CN's network, 40% of the routes go through the same nodes on average. By comparing panel (a) and panel (b) in figure C.3, you can see that the network of CN is quite "linear". That is to say, the more "linear" the network is, the larger the average betweenness centrality will be.

[Insert Figure C.3 here.]

Figure C.1: Average Degree Centrality of Firms in 2004

Note: figure C.1 shows the average degree centrality of each firm in year 2004. Panel (a) shows the average degree centrality (average number of neighbors of each node) of the seven railroad firms in 2004. We can see that NS has the highest average degree centrality of about 5 while CN has the lowest average degree centrality of about 3. Panel (b) and (c) show the network of NS and CN respectively. We can see that NS are more "connected" than CN, in the sense that for each node in NS, there are more connections to other adjacent nodes.



(a) Average Degree Centrality

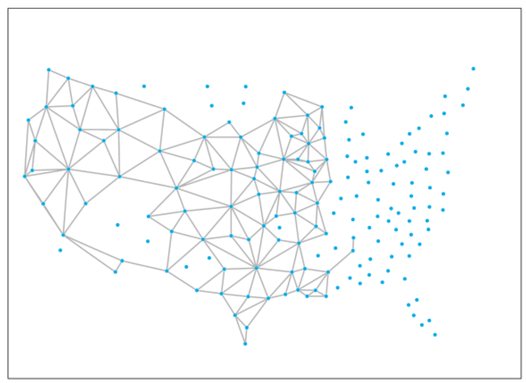
(b) Network of NS

(c) Network of CN

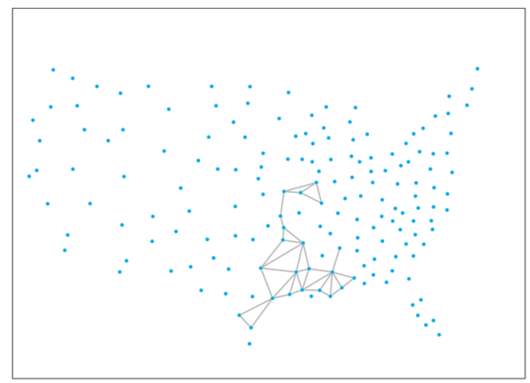
Figure C.2: Average Betweenness Centrality of Firms in 2004

Note: figure C.2 shows the average betweenness centrality of each firm in year 2004. Intuitively, average betweenness centrality measures the availability of "alternative routes" in traveling among node-pairs within a network. Panel (a) shows that KCS has the highest average betweenness centrality of 0.2, which means 20% of all shortest routes between node-pairs within the network of KCS pass through the same nodes. Put this in a real context, it means something like 20% of all traffics within the network of KCS needs to go through Kansas City. Panel (a) also shows that UP has the lowest betweenness centrality of 0.06. Therefore, the hubness of nodes in UP is much smaller than the hubness of nodes in KCS. But it also means that there are less alternative routes to travel among node-pairs within the network of KCS.

(a) Average Betweenness Centrality



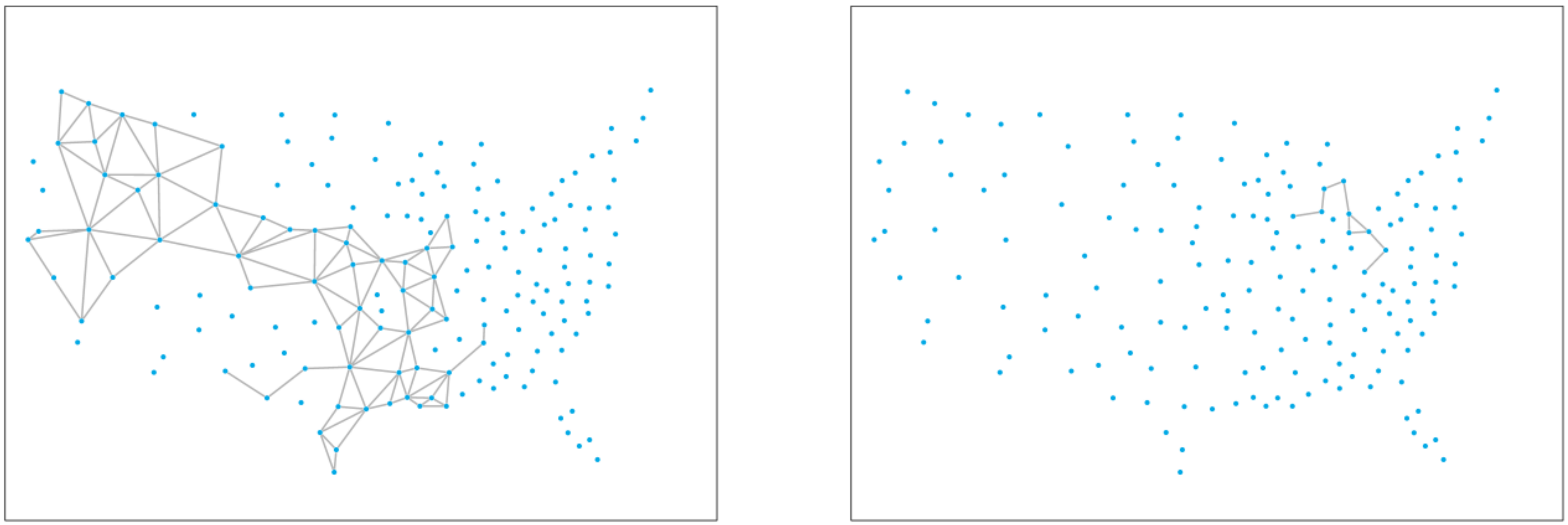
(b) Network of UP



(c) Network of KCS

Figure C.3: Average Betweenness Centrality: UP vs. CN in 1986

Note: figure C.3 aims to show how network structure affects average betweenness centrality. UP has an average betweenness centrality equals to 0.1 and CN has an average betweenness centrality equals to 0.4, four times larger. It means among all the node pairs within CN's network, 40% of the routes go through the same nodes on average. By comparing panel (a) and panel (b) in figure C.3, you can see that the network of CN is quite "linear". That is to say, the more "linear" the network is, the larger the average betweenness centrality will be.



(a) Network of UP (with average Betweenness Centrality= 0.1)

(b) Network of CN (with average Betweenness Centrality= 0.4)

D Robustness Check for Reduced-form Analysis

First as a robustness check of the price effect of mergers, I run the price regression for each type of commodity. Table D.1 shows a complete summary statistics of commodities shipped by rail from waybill data.

Table D.1: 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

Then I study effect of merger on price changes case-by-case. Table D.2 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 D.2: 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 D.3: 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

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.

E Robustness Check for Demand Estimation

The first concern is that the demand parameters changed a lot across years. To address this concern, I replicated the demand estimation in year 1997, 2002 and 2007 (when CFS data is available). Table E.1 shows the estimated results of 2007.

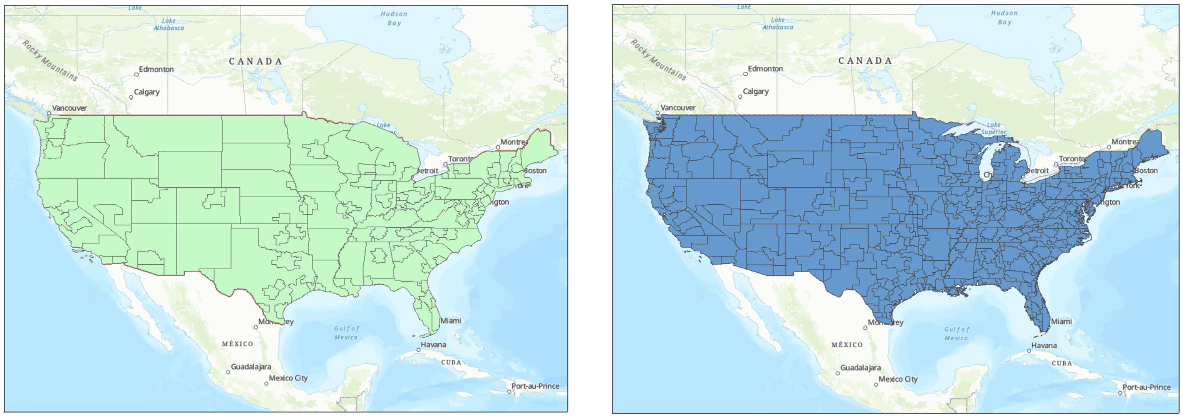
Table E.1: Results of Demand Estimation Using 2007 Data

	(1)	(2)	(3)
	OLS	Fixed Effects	Fixed Effects
Price	-0.280***	-0.419***	-0.410***
	(0.032)	(0.031)	(0.031)
Log Travel Distance	1.340***	-0.179**	-0.178**
	(0.051)	(0.087)	(0.086)
Log Amount of Track Miles	0.535***	0.408***	0.378***
	(0.038)	(0.041)	(0.044)
Constant	-15.373***	-4.156***	-4.250***
	(0.379)	(0.602)	(0.614)
Observations	5,323	5,323	5,323
R-squared	0.152	0.069	0.083
Number of marketID		1,440	1,440
Market FE		Yes	Yes
Firm FE			Yes

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In my main demand estimation, I define each market to be state. The definition of market is broader than what I use in the model. In the model I define market as BEA area to BEA area rather than state to state. The reason I used the definition of state to state in demand estimation is because of data limitation of CFS data. To address the concern that state-to-state level demand parameters are significantly different from BEA-to-BEA level, I replicated the main analysis in finer definition of market, as in CFS area to CFS area. CFS area is the finest definition of an area in the CFS data. As a comparison, there are 50 states, 170 BEA areas, and 130 CFS areas. Figure E.1 illustrates the CFS areas and BEA areas in a topographic map. Shipment information at CFS area level is only available in 2012, therefore I only do this analysis using 2012 data.

Figure E.1: CFS area v. BEA area



(a) CFS areas of 2012 (131 areas in total) (b) BEA areas (170 areas in total)

Table E.2: Results of Demand Estimation in CFS Area

	(1) OLS	(2) Fixed Effects	(3) Fixed Effects
Price	0.114***	-0.211***	-0.198***
	(0.021)	(0.028)	(0.028)
Log Travel Distance	1.396***	-1.070***	-1.013***
	(0.036)	(0.132)	(0.133)
Log Amount of Track Miles	0.286***	0.175***	0.188***
	(0.025)	(0.037)	(0.040)
Constant	-11.862***	5.853***	5.091***
	(0.258)	(0.888)	(0.893)
Observations	11,825	11,825	11,825
R-squared	0.158	0.037	0.050
Number of marketID		7,422	7,422
Market FE		Yes	Yes
Firm FE			Yes

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table E.2 shows the estimated results of demand in CFS area. The estimated coefficients are very similar to those estimated in the main specification in Table 6. Therefore, it means that using a broader definition of market does not significantly change the results in demand estimation.

F More Counterfactual Results

Table F.1: Change of Cost After Merger

	Change of Cost	Decomposition (Misallocation of resources)	Decomposition (Change of Network)
1986 SBD + COBO	-23.87%	12.78%	87.22%
1988 MKT + UP	-3.92%	21.69%	78.31%
1988 DRGW + SP	-7.82%	68.87%	31.13%
1992 SSW + SP	-2.06%	26.49%	73.51%
1992 LA + KCS	-30.77%	0.36%	99.64%
1993 MSRC + KCS	-2.17%	10.87%	89.13%
1995 CNW + UP	-4.92%	32.69%	67.31%
1996 BN + ATSF	-11.49%	35.38%	64.62%
1996 SP + UP	-8.55%	41.30%	58.70%
1998 IC + CN	-5.74%	85.05%	14.95%
1999 CR + NS	-27.15%	14.23%	85.77%
2004 WC + CN	-2.20%	17.01%	82.99%