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An economic investigation into railroad pricing and car allocation programs

Gregory Roy Pautsch
Iowa State University

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An economic investigation into railroad pricing and car allocation programs

by

Gregory Roy Pautsch

A Dissertation Submitted to the
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CHAPTER 1

INTRODUCTION

The function of the United States grain distribution system is to transport grain from farms to final end-users. Final end-users are either domestic processors in major cities, foreign users located overseas, or feedlots in rural America. The system moves grain via the nation's roadways, waterways, and rail lines.

The entire United States highway system contains approximately 3.9 billion miles of road. The local road system, which serves rural residents and farms, comprises of 2.7 billion road miles, while the interstate and expressway system consists of about 52,000 road miles. The arterial and collector road system connects local roads to the interstate and expressway system and contains approximately 1.16 billion miles of road.

The nation's inland waterway system consists of over 15,000 miles of nine-foot navigable channels. The system contains 167 lock sites with 216 lock chambers. The nation's largest waterway is the Mississippi River system consisting of 5,965 miles of navigable channels which flows from the Twin Cities to the Gulf of Mexico.

The United States railroad system contains 162,470 miles of road. The two largest grain hauling railroads are the Burlington Northern Railroad (BN) and the Union Pacific Railroad (UP). The BN operates of 23,088 miles of road stretching from the Midwest to the Pacific Northwest and to the Gulf of Mexico. From 1986 to 1990 the BN was the nation's leading grain carrier, hauling a yearly average of 370,800 carloads of grain. The second leading grain hauling railroad during the 1986 to 1990 interval was the UP, hauling an average of 277,500 carloads of grain each year. The UP contains 20,261 miles of road connecting the Midwest to New Orleans, the Pacific Ocean, and the Texas Gulf.

Figure 1.1 shows the grain distribution system as an intricate network involving numerous grain handlers. Grain moves from farms to domestic and foreign end-users many different ways. Farmers haul grain with trucks and tractor-wagon combinations to nearby facilities, which depending upon location, may include local country elevators, terminal and subterminal elevators, river elevators, or domestic processors. Country elevators are grain handlers located in rural areas and transport grain by rail, truck, and rail-truck combination to other elevators or domestic end-users. Subterminal elevators are large grain handlers located at major crossings of the transportation system which transship grain to other grain handlers including domestic end-users by rail, truck, and rail-truck combination. Terminal elevators

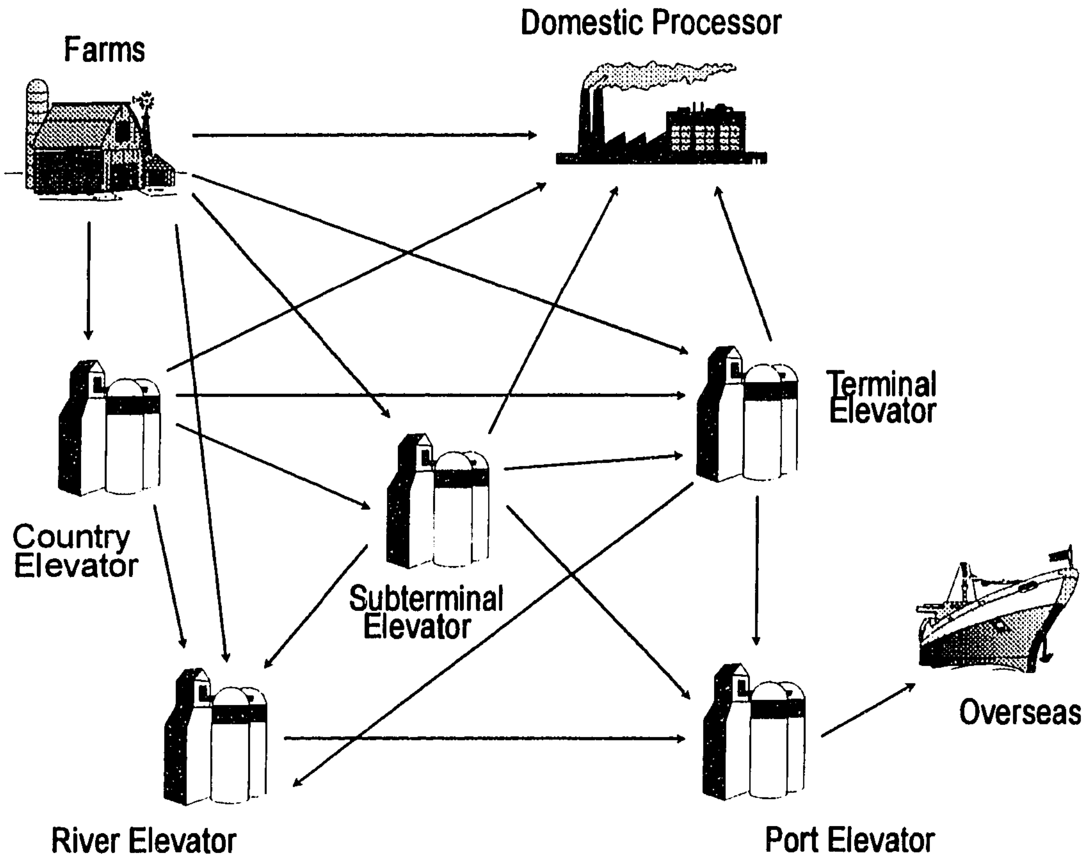


Figure 1.1. Grain distribution system.

are large grain handlers located in major cities which ship grain by rail, truck, and rail-truck to river elevators, port elevators and domestic end-users. River elevators located on major tributaries ship grain by barge to port elevators located along the coastal areas of the Atlantic and Pacific Oceans, the Gulf of Mexico, and the Great Lakes. Port elevators ship grain to overseas markets in large ocean vessels.

Railroad Industry

The exact quantities of grain hauled by trucks, railroads, and barges is difficult to obtain since grain is hauled by several modes while moving from the point of origin to final end users. Furthermore, the amount of grain hauled by the trucking industry is not recorded by any organization. Table 1.1, however, shows the quantities of grain hauled by railroads and barges as reported by the Association of American Railroads for the period 1980-1990. The quantity of grain hauled by the railroad industry ranged from a high of 5.4 billion bushels of grain in 1988 to a low of 4.04 billion bushels of grain in 1985. During the interval, the average annual quantity of grain hauled by the railroad industry was 4.72 billion bushels, more than twice as much as the amount hauled by the barge industry. The railroad industry provides

Table 1.1. Quantity of grain hauled by railroads and barges in billions of bushels, 1980-1990.

Year	Quantity Railroad	Quantity Barge	Percent Change Railroad	Rail Market Share
1980	5.00	2.15	+13.4	70.0
1981	4.38	2.29	-12.4	65.7
1982	4.22	2.51	-3.7	62.7
1983	4.67	2.42	+10.7	65.9
1984	4.82	2.35	+ 3.2	67.2
1985	4.04	2.04	-16.6	66.4
1986	4.31	1.85	+ 6.7	70.0
1987	5.15	2.24	+19.5	69.7
1988	5.40	2.32	+ 4.9	69.9
1989	5.03	2.41	-6.9	67.7
1990	4.89	N/A	- 2.8	N/A

a vital link in the transport of grain from its point of origin to final end users.

Despite the vital importance of the railroad industry to the movement of grain, the railroad industry with tariff rates, has been consistently plagued with problems of grain car shortages and surpluses [Baumel and Nelson, 1970; ICC, 1991]. A tariff rate is a posted price which shippers either accept or reject. Currently, for a change in tariff rates to occur, railroads must notify shippers 20 days in advance of the change. Therefore, under current regulatory practices, tariff rates are unable to respond instantaneously to changes in demand. Barges, trucks, and ocean vessels experience greater rate flexibility and are able to respond quickly to changes in demand. A study which examined the relationships between rail and truck market shares of barley and wheat transported from North Dakota to Eastern markets found the rail market share to be more responsive to total shipments than the truck market. The greater responsiveness indicates the rail industry provides the additional capacity when total shipments rise [Wilson, 1984].

The continuing car shortages and surpluses are caused by the rigidity of the tariff system coupled with an erratic demand for U.S. grain exports. Table 1.1 also shows the percent change in rail car loadings from the prior year during the 1980s and early 1990s. During the 1980s, three instances of severe car shortages occurred in the grain industry [Dempsey, 1990; Fitzpatrick, 1990]. First, in 1980 the amount hauled by railroads increased 13.4 percent and decreased 12.4 percent the following year. Massive grain movements to the Soviet Union led to the sharp increase and subsequent decrease in rail car loadings. The high demand for rail transportation in 1980 left many shippers without grain cars. A second car shortage occurred in 1987, when the policies of the Export Enhancement Program managed by the Commodity Credit Corporation of the United States Department of Agriculture increased grain car loadings by 19.5 percent. The Export Enhancement Program accelerated grain exports by granting bonuses to exporters causing wheat sales to expand overseas. The Commodity Credit Corporation also began selling its huge wheat inventory, resulting in the release of an average of 13.7 million bushels of wheat each week. The third major car shortage of the 1980s occurred in late 1989 when the Soviet Union purchased the equivalent of 94,000 grain cars to be delivered before the end of the 1989. Shipper demand for rail cars was intensified by low water levels and navigational problems on the Mississippi River. The railroad industry actually hauled more grain the previous year indicating the car shortage was caused by the Soviets desiring a large amount of grain in a very short period of time. Currently, there is a major car shortage due to the record breaking 1994 crop and the closing of the Mississippi River.

The major U.S. grain export ports are located along the Gulf of Mexico and the Pacific Ocean coastlines. In 1991 approximately 2.7 billion bushels of grain flowed through Gulf of Mexico ports to foreign end users, amounting to 70 percent of all grain exports. The Pacific Ocean ports exported 800 million bushels of grain or about 20 percent of all grain exports. Formerly, the major importers of U.S. grain were Japan and the old Soviet Union. During the 1990/91 crop year the United States exported 93.6 million metric tons of grain overseas. Japan was the leading importer of U.S. grain with 22.7 million metric tons and the old Soviet Union was second with 12.0 million metric tons [USDA, 1992].

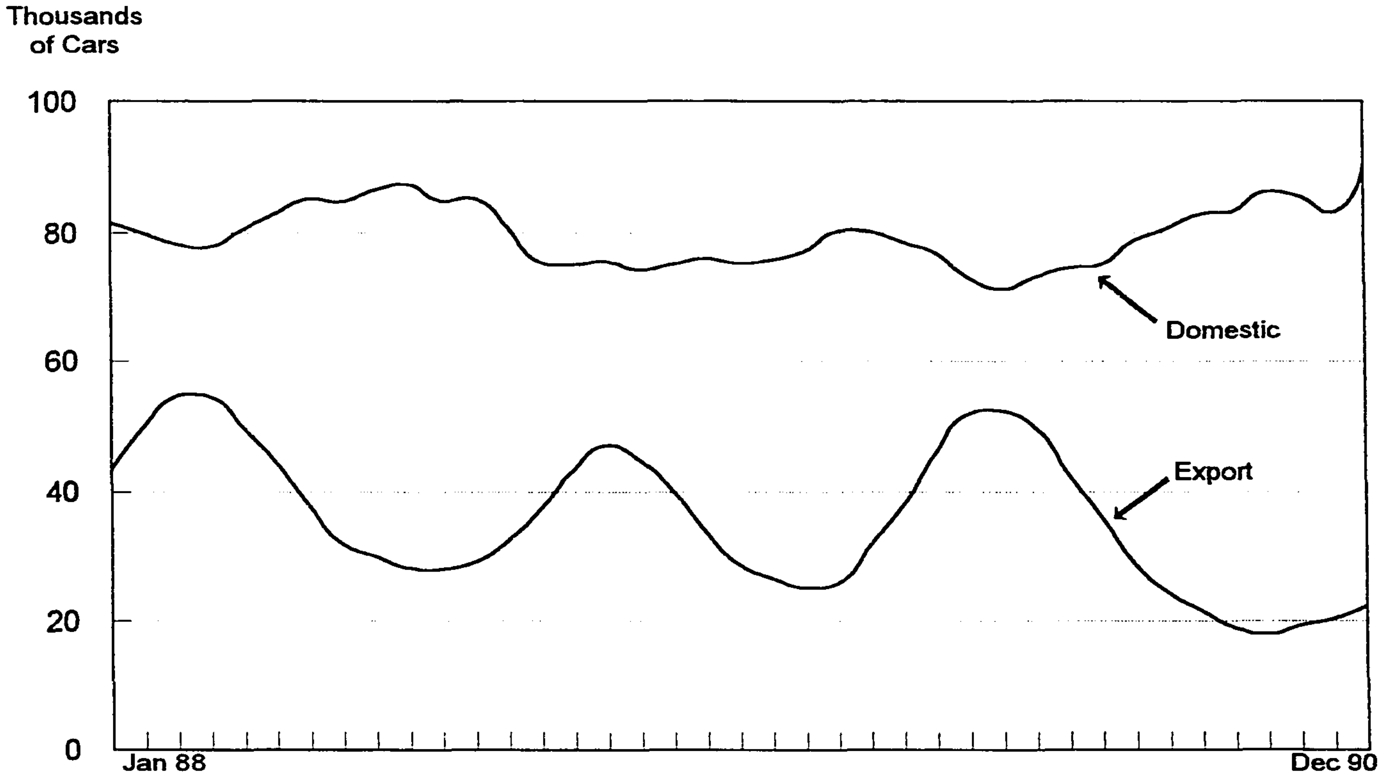
The breakup of the Soviet Union into the smaller independent Soviet Republics implies the days of the Soviets buying an enormous quantity of grain and creating inverted markets may never re-occur. Furthermore, most railroad experts agree that exports to the Soviet Republics will decrease significantly when they modernize their agricultural industries [Unknown, 1993]. In the near future, however, exports to the republics appear to be strong if Congress passes loan guarantees allowing them to purchase grain. Also, in the future Japan will continue to be a major importer of U.S. grains. The future of NAFTA and GATT play major roles in the future of grain exports to China, Mexico, and the rest of the world. Other legislation such as possible taxes on the barge industry also affect the share of grain hauled by railroads to export markets.

The instability of grain exports and the subsequent volatility in rail car demand are caused by (1) political events such as grain embargoes, guaranteed export credits, and the granting of most favored nation trading status, (2) government programs such as the Export Enhancement Program and acreage reduction programs, (3) weather affecting both grain production and the navigation of the nation's waterways.

The recent trend in rail car loadings for domestic and export markets is shown in Figure 1.2 [Pautsch et al., 1991]. Grain car loadings to domestic end-users tend to be relatively stable while grain car loadings to export markets are fluctuating throughout the 1988-1990 period. If there is a surge in the demand for U.S grain exports, the demand increases for all forms of transportation, the barge and trucking industries respond with increasing rates making rail transportation with rigid rates a more attractive form of transportation. The result is shippers demanding more service than the railroad can produce at the prevailing tariff rates. Conversely, if there is a sudden decrease in the demand for U.S. grain exports, the demand for all forms of transportation falls, the barge and trucking industries respond with decreasing rates making rail transportation with rigid rates a less attractive form of transportation. In this case, shippers demand less service than the railroad is willing to produce at prevailing tariff rates. The fluctuating nature of grain exports along with rigid railroad rates cause persistent car shortages and surpluses.

Projected Future Grain Car Shortages

A study analyzing recent trends in domestic and export grain movements, U.S. grain production, and rail car additions/retirements predicted continuing periods of car shortages into the 21st century [Norton and Klindworth, 1989]. Table 1.2 shows the projected grain car deficits for 1993-2001 for various percentage decreases in car cycle times. Projected car deficits are used as an indicator of future car supply problems. A projected car deficit is defined as the



* Moving Average

Source: U.S. Department of Agriculture, "Grain Transportation Situation".

Figure 1.2. Grain car loadings, Class I Railroad, by four week periods.*

difference between the projected average fleet of grain cars and the projected annual peak requirement for grain cars in a given year. Regardless of the assumption concerning decreases in car cycle times, car deficits are present in 1993 and continue into the next century. This indicates the grain industry will experience rail car supply problems throughout the next decade.

Table 1.2. Norton and Klindworth projected grain car fleet deficits, 1993-2001.

	Annual percentage decreases in grain car cycle times						
Year	0.0	0.5	1.0	1.5	2.0	2.5	3.0
			1,000 cars				
1993	14.0	11.5	9.2	6.8	4.5	2.3	0.1
1994	19.4	16.4	13.4	10.6	7.8	5.1	2.5
1995	25.3	21.7	18.2	14.8	11.5	8.3	5.2
1996	30.3	26.0	22.0	18.0	14.3	10.6	7.1
1997	34.9	30.0	25.4	20.9	16.6	12.5	8.6
1998	38.6	33.2	28.0	23.0	18.3	13.8	9.5
1999	42.8	36.7	30.9	25.4	20.2	15.3	10.5
2000	47.1	40.4	34.0	28.0	22.3	16.9	11.8
2001	50.6	43.2	36.3	29.7	23.6	17.8	12.4

The next section discusses the effects of car shortages on shippers relying on rail transportation. Shippers located within 100 miles of a waterway or a domestic processor have an alternative to rail and are not as severely affected as other shippers. During high grain export demand periods, these shippers are able to truck grain to river terminals or to domestic processors and avoid the problems associated with the lack of rail cars.

Effects of Grain Car Shortages on Shippers

The presence of car shortages has many effects on grain shippers relying on rail transportation. First, shippers lose the ability to move grain in a timely fashion due to a lack of grain cars. Shippers experience increasing interest costs from holding rather than selling and shipping their grain. The opportunity to use or invest their receipts from grain sales is delayed from late car placement. During the Fall of 1990 and Winter of 1991 the Churchs Ferry Farmer Co-op in North Dakota reported car orders being filled as much as 75 days after the desired want date. From this delay, the co-op held grain more than 60 days beyond the originally planned shipping date. The interest costs from holding the grain absorbed their entire margin from the sale [Haugeberg, 1990]. A general manager of Central Washington Grain Growers, Inc., states that in early 1988, the interest rate was 9% and the cash price of wheat was $2.82 a bushel. The interest cost resulting from a 30 day delay in shipping a 26 car train was $1,789.90 or 2.1 cents per bushel [Anderson, 1990]. From the Fall of 1989 to the Spring of 1990, the Edison Co-op Association in Nebraska incurred interests costs of $4,104,000 on inventory awaiting shipment [Goding, 1990].

Second, if the delay for rail transportation is long, the amount of grain owned by elevators may exceed its capacity. The excess grain will have to be stored on the ground and the elevator may cease buying grain from farmers. During the 1989 wheat harvest, the Farmers Grain and Supply Company had to store 43,000 bushels of wheat on the ground at a cost of 0.084 cents per bushel due to the lack of service [Tunnel, 1990]. Elevators may insure against the additional costs of storing grain on the ground by increasing its storage capacity. However, avoiding these additional outside storage costs due to the lack of timely rail service by increasing capital costs is not cost efficient.

Third, shippers often contract with grain exporters and domestic processors for the delivery of grain months in advance. These grain contracts usually have clauses penalizing shippers for failure to deliver the grain by the contracted date. In 1989, the Wallace County Co-op Equity Exchange in Kansas received discounted prices for late shipments due to the inability of obtaining timely rail service [Tunnel, 1990].

Fourth, the rail freight rate may change from the time cars are ordered to the delivery of the cars. In the period from September 1987 to December 1989, the Farmers Union Mercantile and Shipping Association experienced at various times increases in freight rates while waiting for grain cars [Tunnel, 1990].

Fifth, to avoid the added costs of delayed rail service, shippers often turn to alternative and higher priced modes of transportation. In 1990, the Farmers Union Mercantile and Shipping Association shipped 200,000 bushels of wheat by truck to alleviate the rising costs from the lack of rail service. The price for truck delivered wheat was five cents per bushel less than the price for rail delivered wheat resulting in $10,000 of reduced revenue [Tunnel, 1990]. In 1990, the Farmers Grain and Supply Company sold 60,000 bushels of wheat for truck shipment due to the backlog of rail car orders. The price differential between rail delivered and truck delivered wheat was six cents a bushel [Tunnel, 1990]. In both of these cases, lower prices were paid to farmers due to their inability of receiving timely rail service.

Finally, the inability to obtain prompt rail service may force shippers out of some markets. In an inverted market where grain is more valuable now than in the future, shippers will want to sell and ship as much grain as possible in a very short period of time. The shippers receiving cars benefit from such a situation, while shippers unable to obtain service lose very profitable sales.

Investment in Covered Hopper Cars

A solution proposed by the National Grain and Feed Association to alleviate car shortages is to expand the existing fleet of grain cars [NGFA, 1990]. Table 1.3 shows the additions to the grain car fleet from 1970 to 1989 by both shippers and railroads. From 1983 to 1989 railroads added only 699 railroad cars while shippers have added 887 private cars.

Table 1.3. C113 Covered hopper cars installed by year built and ownership, January 1, 1989 ULMER File.

Year Built	Private Cars	Railroad Cars	All Cars
1970	1,883	4,775	6,658
1971	1,015	6,043	7,058
1972	2,474	3,442	5,916
1973	4,138	9,450	13,588
1974	5,794	5,308	11,102
1975	2,554	4,586	7,140
1976	192	2,971	3,163
1977	856	3,458	4,314
1978	5,103	4,590	9,693
1979	14,199	7,337	21,536
1980	13,628	14,861	28,489
1981	5,137	7,395	12,532
1982	1,356	661	2,017
1983	139	92	231
1984	165	76	241
1986	0	7	7
1987	30	0	30
1988	0	524	524
1989	553	0	533

During the 1970s, the ICC attempted to encourage investment in rail cars through a per diem incentive program, which doubled the rate of return for rail cars during high demand periods. Per diem charges are the rate a railroad charges another railroad for the use of their cars. The program resulted in an over investment in rail cars and a decrease in equipment utilization. The program gave railroads the incentive to keep their cars on other rail lines in order to earn the increased per diem charges. In 1980, the ICC rescinded the program and allowed the market to determine per diem rates. As a result of the over investment in rail cars during the 1970s and the lower per diem rates, the period from 1983 to 1989 saw very little investment in rail cars as railroads reduced their fleets.

Recently, however, railroads have begun to slowly add new grain cars to their fleets. Since 1990, the BN has acquired about 3000 new covered hopper cars. During the period from 1993 to 1995 the Chicago and NorthWestern Railroad is scheduled to add approximately 1000 covered hoppers, the Kansas City Southern Railroad will be adding about 300 covered hoppers, and the Union Pacific Railroad will be adding 3,400 covered hoppers to its fleet. Conrail has rebuilt about 700 covered hopper in 1993. The Canadian Pacific Railroad is also in the process of adding 900 covered hopper cars to be ready for use in the U.S. and Canada sometime in 1994. Finally, Canadian Pacific is currently entering in covered hopper swap agreements with U.S. railroads. Swap agreements allow Canadian cars to go south to help with the U.S. harvest and in return American cars go north to help with the Canadian harvest.

Despite the recent investments in grain cars, the unstable nature of the demand for grain cars continues to leave railroads with little incentive to invest in grain cars which satisfy the needs of all shippers. New additions to fleet may be used only during export surges. An investment in grain cars requires up to $500 per month to cover interest and depreciation costs [Baumel, 1990]. If maintenance, insurance and administration costs are included, a monthly return of about $600 may be needed to cover costs. The high cost of acquiring a grain car plus the instability of grain car demand leaves little incentive for railroads to acquire a fleet of cars sufficient to continually satisfy the needs of shippers. The likelihood of a railroad acquiring a fleet of grain cars needed to ameliorate the temporary and intense periods of demand prompted a railroad spokesman to ask rhetorically [Howe, 1990], "Do you build a church big enough for Easter Sunday?" The ICC has acknowledged the non-feasibility of railroads acquiring a fleet of cars to completely satisfy the temporary surges in demand [ICC, 1989].

The national grain car fleet is also aging and many grain cars are in need of replacement. The expected life of a grain car is approximately 25 to 30 years. The 1989 fleet of grain cars were analyzed and 34 percent of the grain cars owned by railroads were over 20 years old, 36 percent were between 10 and 20 years old, and 30 percent were less than 10 years old. The private fleet was not as old as the railroad fleet, only 12 percent were more than 20 years old, 34 percent were between 10 and 20 years old, and 54 percent were less than 10 years old [Kober, 1990]. The age of the current grain fleet and the recent trend in rail car acquisitions has the grain industry concerned about the future availability and condition of the national fleet of grain cars [Howe, 1990; Kaufman, 1990; Housh, 1990].

Increasing the Grain Carrying Capacity of a Fleet

Railroads are trying alternative methods rather than investing heavily in grain cars to better serve the continual needs of its shippers. Railroads are trying to use its existing fleet more efficiently in order to increase its grain carrying capacity. Railroads have increased the average payload of cars by buying rail cars with higher weight limits and lower empty weights. Both types of innovations have allowed the amount of grain carried by rail cars to increase. For example, box cars had a 50 to 70 ton weight limit and had an empty weight of 60,000 pounds. Today the standard net weight limit for covered hopper cars is 100 tons and covered hoppers tare weight is less than 43,000 pounds [Burger, 1991]. Currently, newly built covered hoppers have net weight limits of 110 tons.

Railroads are also trying to increase their "effective" fleet by decreasing car cycle times. Car cycle time is the time interval between when a loaded car begins a trip and when the car is emptied and ready to be loaded again. By decreasing car cycle times, the existing fleet is able to haul more grain and improve service to shippers. The UP reported that during the first half of 1990, it lowered its grain car cycle time from 23.0 days to 21.6 days, allowing the existing fleet to move 4,000 more carloads than the first half of the previous year [Gotschall, 1990]. The BN has reduced its car cycle time from 26.3 days in 1981 to 17.6 days in 1990, which allowed the average number of trips per month made by a covered hopper car to increase from 1.16 to 1.74 trips per month [Sperry, 1991].

The methods used by railroads to decrease car cycle times include programs which encourage the rapid loading and unloading of grain cars at origin and destination points, programs eliminating interchange delays such as mergers and run-through agreements, preventive maintenance programs which eliminate the out of service time for grain cars, programs designed to improve communication between shippers, receivers, and the railroad, and programs encouraging the scheduling of rail movements [Burger, 1991; Weaver, 1991]. Many of these methods have been used extensively over the past 10 years and over the last few years railroads have experienced diminishing returns in reducing car cycle times from all approaches except scheduling service [Burger, 1991].

Scheduling service allows railroads to reduce car cycle times. Railroads are able to plan and coordinate future movements better when they have locked in business ahead of time. Also, having service locked in ahead of time gives the railroad some indication of future demand. Railroads are then able to make more informed fleet sizing decisions. A recent study of the BN Certificate of Transportation market where shippers bid for guaranteed service for a specified future time period indicated that the railroad obtains valuable information regarding future demand. This additional information is used in capacity decisions such as fleet sizing and in operational practices to reduce car cycle times [Wilson, 1991].

During the 1980s, transportation consultants at Arthur D. Little identified and monitored five major trends occurring in the railroad industry [Burger, 1991]. These trends are:

1) Graduated Contraction - which refers to the reduction of track and employees since the 1930s.

2) Easing of Regulation - which includes the Staggers Act of 1980 and the Shippers Act of 1984.

3) Operational Restructuring - which includes the emergence of marketing, corporate mergers, regional railroad spinoffs, locomotive run-through or power sharing arrangements, and interline cooperation agreements.

4) Labor Deregulation - includes the formation of regional

carriers, negotiation of labor agreement concessions, and the attempts to modify current rail labor law.

5) Scheduled Service - includes efforts by railroads to have service scheduled beforehand which increase grain car productivity and improve customer service levels.

The consultants at Arthur D. Little believe that the trend toward scheduled service is the only trend that will continue extensively throughout the 1990s to increase railroad revenues, improve service to shippers, and improve asset productivity [Burger, 1991].

Staggers Act of 1980

Congress passed the Staggers Act of 1980 in response to the financial woes of the railroad industry, such as the Chicago, Rock Island and Pacific Railroad liquidation and the Chicago, Milwaukee and St. Paul Railroad bankruptcy. The Act was designed to simultaneously improve the financial condition of railroads and enhance service to shippers and the public by improving track conditions and rail car availability [US Congress, 1980b]. Staggers allows railroads and shippers to enter into contracts for rates and shipping services including car supply. Staggers gave railroads increased rate flexibility and the ability to innovate with new service offerings. Specifically, the Act encourages railroads to offer premium services to increase the utilization of railroad assets. The Staggers Act is the foundation for the car ordering systems presently used in the railroad industry.

Following the passage of the Staggers Act, railroads began negotiating contracts with shippers for car supply services. Rates and the specifics of the car supply service were mutually agreed upon by the railroad and the shipper. Some railroads continue contracting but the two largest grain hauling railroads have been developing alternative advanced car ordering shippers. The BN has developed a Certificate of Transportation (COT) program where shippers bid for the opportunity to receive the premium service of guaranteed car supply. The UP offers guaranteed car supply to shippers based on historical use. Each of these programs was developed to improve the financial condition of the railroad, better serve shippers, and encourage more efficient use of railroad assets. These programs allow shippers to order guaranteed service up to five months in advance. Railroads are able to make more informed fleet sizing decisions and better schedule future grain movements increasing the productivity of grain cars.

Purpose of Research

The purpose of this dissertation is to investigate the effects of guaranteed service on the welfare of shippers and railroads. The analysis compares a car ordering system offering guaranteed service and conventional tariff service with the standard pre-Staggers car ordering system offering only conventional service. Shippers order conventional service on a spot basis and the railroad fills conventional service car orders on a reactionary first-come first-serve basis. Shippers order guaranteed service in advance without complete knowledge of grain market conditions. The railroad must fill all guaranteed car orders or pay a penalty for failure to perform.

Chapter 2 examines in more detail the characteristics of recent grain car ordering systems employed by railroads. The direction of future grain car ordering systems is discussed. Chapter 3 reviews recent court cases brought before the ICC as a result of these newly formed grain car ordering systems.

Chapter 4 presents the pre-Staggers rail car allocation system of shippers ordering conventional tariff service on a spot basis and the railroad filling the orders on a reactionary basis. First, the sequence of decisions is discussed along with the environment facing grain shippers and the railroad. Next, the effect of increased variability on shipper and railroad welfare is examined. The case of the railroad and grain shippers having symmetric information is compared to the original asymmetric case of grain shippers having more grain market information. Finally, the effect of the relative size of per unit operating to per unit capacity costs on railroad and shipper welfare is investigated.

Chapter 5 presents a rail car allocation system offering guaranteed service as well as conventional tariff service. First, the sequence of decisions is discussed along with the new environment facing grain shippers and the railroad. Next, the effects increased variability and the relative size of per unit operating costs to per unit capacity cost on shipper and railroad welfare are examined. The informational and rail car productivity effects of guaranteed service on shipper and railroad welfare are identified. A comparison of the two rail allocation systems is also discussed. Finally, the effects of placing an upper limit on the amount of guaranteed service a railroad can produce is investigated.

CHAPTER 2

RAILROAD CAR ORDERING SYSTEMS

Before 1980, the traditional tariff service was the only type of service offered by railroads. Rail service was provided entirely on a reactionary basis in which railroads tried to meet the last minute shipper requests for empty cars or movement of loaded cars. Car orders were rarely made more than a few days in advance and car movement orders were generally placed by shippers within 24 hours of the desired shipping date.

Railroads were required to provide identical service at rigid pre-determined rates to all shippers. The railroads lacked any prior information on the plans of shippers, which hampered capacity and operational planning. Railroads were forced to function with this system prior to 1980, because of heavy government regulation of the railroad industry.

Railroad car ordering systems, however, have been changing rapidly since the deregulation process of 1980 [US Congress, 1980a; US Congress, 1980b]. The newly deregulated environment encourages modal rivalry, prompting railroads to reduce costs through improved asset utilization. With increased competition, suddenly shipper complaints of long delays in receiving cars and the differing needs among shippers became very significant to the railroads. Hence, railroads began to experiment with new types of car ordering systems. After viewing the consequences of these new systems, railroads either made slight modifications or performed complete overhauls.

This chapter discusses in detail the evolution of the current advanced car ordering systems used by the two largest grain carrying railroads, the BN and UP railroads. Also, the newly formed advanced car ordering system of the Canadian Pacific Rail System's Soo Line will be discussed. Finally, possible future directions of advanced grain car ordering systems will be presented.

Burlington Northern Railroad

The BN has had two types of advanced car ordering systems since the passage of the Staggers Act. The original system used private contract negotiations between individual shippers and the BN to determine price and car allocation. The BN found several undesirable properties of the contracting system and changed to their current Certificate of Transportation program (COT). The COT program determines price and allocates guaranteed service through a quasi auction.

Contracting

After the passage of the Staggers Act, the BN and many other railroads began offering both tariff and contract service. In contract service, the process of car allocation, price determination, and all other aspects of rail movements is done through private negotiations between the railroad and individual shippers. The car allocation process is done through guaranteed car supply contracts. These contracts state the negotiated number of covered hopper cars, the negotiated time window for car placement, and location for car placement. In case of railroad non-performance, the contracts also stated a negotiated per day penalty and a negotiated maximum penalty payable by the railroad. Shippers pay a non-refundable negotiated sum of money for the guaranteed car supply contract. The terms of guaranteed car supply contracts were confidential and proprietary. All other transportation services provided by the railroad were determined separately either by tariffs, contracts, exempt circulars, or quotations.

Contract service offered with tariff service gave shippers the options of obtaining non-guaranteed car supply through tariff service or guaranteed car supply under privately negotiated terms. Contract service allowed railroads to increase asset utilization since part of the demand for its services was known ahead of time. Other types of contracts negotiated within contract service were origin contracts, destination contracts, switching contracts, and demurrage contracts.

Currently, smaller grain carrying railroads continue to use contract service in conjunction with tariff service. The BN, however, found several undesirable repercussions arising from contract service [Weaver, 1991]. First, the administration of contracts became very burdensome. The BN would enter into many different types of contracts and on numerous occasions several contracts were applicable to the same movement, making administration very difficult. Second, privately negotiated contracts are kept confidential, barring the flow of information into the market and inhibiting the discovery of a market clearing price. Third, contract service can discriminate against small shippers. Large shippers, exporters, and domestic processors can guarantee railroads sizable tonnage of grain for reduced rates and better service, leaving small shippers with a sizable disadvantage. Finally, contracts occasionally limited shipper access to markets. A few large grain handlers could negotiate large contracts with reduced rates to the same destination effectively barring the rest of the grain industry from selling to that region.

Certificate of Transportation Program

In response to the above consequences occurring from contract service the BN developed its Certificate of Transportation (COT) program during the last half of 1987.

The COT program, like contract service, is designed to provide shippers forward transportation rates with guaranteed car supply and allow the BN to lock in future business. The COT program, however, eliminates the private and confidential negotiation process connected with contract service.

In the COT program, shippers bid for guaranteed car supply. After the bidding process, the BN reveals the winning bids on many news services, allowing price information to freely flow in the market. COTs provide shippers with greater flexibility than contracts, since COTs are not tied to specific origins and destinations. Shippers changing their marketing plans can buy and sell COTs from each other in an unstructured secondary market. This secondary market allows shippers desiring COTs and shippers no longer needing COTs to interact to their mutual benefit.

Specifically, a COT is a BN guarantee for car supply within a specified month. Between 2:00 and 3:00 pm Central Time on the day of the tender, shippers wishing to obtain a guaranteed supply of cars within a designated future month on a specified corridor bid against each other for the available supply of COTs. The BN announces the minimum acceptable bid and the number of COTs available for sale before bids are submitted. After 3:00 pm the auction concludes and the BN discloses all winning bids at or above the minimum acceptable price and the number of COTs sold. The BN does not disclose the recipients of the COTs.

Each COT has a future shipping period for the delivery of the cars, either the first half or the last of a designated month. A specific want date is stated by the shipper, but the BN only guarantees car placement during the shipping period. The shipper, also, has the obligation to place a car order by stating the names of the facilities at which the cars are to be placed prior to the fifth calendar day before the shipping period.

Table 2.1 shows the evolution of the COT program [Weaver, 1991]. Initially, in January 1988, the shipment size of COTs was in 54-car units and the entire winning bid was to be paid immediately after the auction. To avoid discriminating against small shippers, the BN added single car COTs and eventually reduced the COT prepayment to one-fourth of the winning bid with the balance due at the time of the car order.

Initially, the BN COT program only offered COTs on their east and west corridors hauling corn, sorghum, and soybeans. Presently, the COT program also hauls barley, wheat, grain products, oats, and rye on 14 major BN corridors. In an effort to allow market forces to influence the allocation of cars, the BN modified its initial program to allow shippers to change corridors up to 10 days prior to the delivery window at a price of $200 per car. The BN amended its initial policy by setting the minimum acceptable bid to be both above and below

Table 2.1. The evolution of the COT program.

Feature	COTs I (Pilot) 1/88	COTs II 6/88	COTs III 4/89	COTs IV 1/91
Commodity	Corn, sorghum, and soybeans only	Adds barley and wheat to include all major whole grains and oil seeds	No change (NC)	Added grain products, oats, and rye
Corridors	East-West	All major grain corridors	Directional unchanged, but allows for corridor change up to 10 days prior to delivery period for $250/car	Reduced corridor change to $200/car
Shipment Size	54-car units	Corn, sorghum, soybeans: 54 cars and singles Wheat: 26 cars and singles Barley: 26 cars and singles	NC	NC
Prepayment	Advance payment of full COT price	1/2 of COT price, prepayment, with balance due at time of car order	1/4 of COT price with balance due at time of car order	NC
Interest on Prepayment	90-day, T-Bill rate, refunded after receipt of prepayment in full	Commercial interest rate as published in Wall Street Journal. Refunded after receipt of prepayment in full	Commercial interest rate unchanged but interest discounted from prepayment balance due	NC
Publication Media	Commodity News Service and PC-compatible Bulletin Board	Commodity News Service, Bonneville Telecommunications and PC-compatible Bulletin Board	Added ACRES	NC
Minimum Bid	Tariff level	Below tariff, depending on market	NC	NC
Default Provision	Up to 100% of base value at RR option	NC	Up to 25% of base value at RR option	NC

the tariff level, depending on perceived market conditions.

To ensure the promise of guaranteed car supply during the specified time frame, the BN pays a penalty of $50 per car for each day car placement is delayed with a maximum payment of $400 per car. However, for the period from January 1988 to December 1990, the BN had fulfilled its promise of guaranteed car supply 99.9 percent of the time [Sipe, 1991]. If shippers do not use the cars associated with their COTs, the BN keeps the entire COT prepayment as a failure-to-use penalty.

Conventional or Tariff Service

In 1988, the BN changed the main features of the way non-COT cars order (tariff service) were handled. First, the BN began assessing a $50 per car cancellation penalty for shippers canceling non-guaranteed car orders. Originally, shippers could cancel car orders at any time, leading shippers to over order rail cars during periods of perceived car shortages. Consequently, the BN lacked information concerning the demand for its services because shippers freely canceled their car orders. Operational planning and fleet sizing decisions were very difficult. Secondly, the BN began restricting the number of days in advance car orders were accepted. Finally, the BN began publishing a list of outstanding car orders with an estimate of when they will be filled. These changes were made to allow the BN to increase asset utilization and to better inform shippers.

Currently, the car order cancellation penalty has increased from $50 to $200 per car. Car orders unfilled fifteen days after the want date can be canceled without penalty, a reduction from the previous thirty day requirement. Also, the BN accepts car orders for only up to seven weeks in advance. If the seven week estimated capacity of the BN becomes fully reserved, additional car orders are not accepted. The BN has never guaranteed the delivery of tariff service cars, but has taken steps to reduce the uncertainty surrounding tariff service.

Union Pacific Railroad

The UP has had two advanced car ordering systems since the passage of the Staggers Act. In the first system, the UP announced the quantity of guaranteed car service available for a specified future month. Shippers ordered guaranteed service over the phone and the UP allocated the quantity of guaranteed service on a first-come first-serve basis. The system turned into a phone lottery where the winning shippers whose telephone calls were answered received guaranteed service. Shippers kept on hold did not receive guaranteed service. The second system, a historical use based program, was developed to alleviate the problems of the phone lottery. The historical use program allocates guaranteed car placement service among shippers based on the historical number of railroad owned cars placed at each location.

Phone Lottery

The first UP advanced car order system was introduced in September 1989. For the first time, shippers located along the UP could order covered hopper cars in advance and receive a guarantee that the cars would arrive in a timely manner. Shippers specified the commodity to be shipped, the location for car placement, the total number of cars needed, and the earliest and latest dates for car placement. The car placement dates were to be in the same month and at least seven days apart. The UP only guaranteed the delivery of grain cars sometime during the month of the desired car placement window, not within the desired car placement window. For example, if a shipper specified August 7 to August 14 as the car placement period, the UP only guaranteed to place the cars sometime in August.

Shippers could cancel guaranteed car orders without charge if the car order was unfilled on either the day after the desired car placement period, the day after the desired month, or within seven days after a line haul rate increase. Otherwise, the penalty for canceling a guaranteed car order was $70 per car. If the UP failed to fill a guaranteed car order, payment to the shipper was $70 per car for all cars not physically or constructively placed during the desired month.

The shipper, after receiving payment, had the option of canceling the order without charge or having the UP fill the car order the next month on a priority basis.

The UP did not guaranteed all car orders. Only the car orders which the UP believed they could fill during the designated month received the car placement guarantee. Car orders failing to receive guaranteed placement were placed on the stand-by list. Orders on the stand-by list were filled on a first-come, first-serve basis whenever cars became available. Stand-by orders may or may not be filled. Shippers could cancel stand-by list orders at any time without penalty. At the end of each month, all unfilled stand-by car orders were eliminated from the car ordering system. Shippers had to place new car orders the following month to replace the eliminated orders. These unfilled stand-by car orders did not receive the $70 per car compensation from the UP nor were they filled on a priority basis after the desired month.

This car allocation program, however, had a major flaw in the distribution of guaranteed service. On the first Tuesday of every month, the UP announced the amount of guaranteed service to be allocated in a specified future month. At 9:00 a.m. shippers were able to order cars for guaranteed delivery four months in advance and for earlier months provided those months had unfilled guaranteed capacity. Shippers ordered cars over the phone and guarantees were distributed on a first-come, first-serve basis. The difference between receiving guaranteed car placement and being placed on the stand-by list was as little as a few seconds. Shippers failing to receive guaranteed car placement were placed on the stand-by list and continued to bear the costs and the risks of unreliable rail service.

During the end of 1989 and early 1990, the UP monthly guaranteed car supply was fully reserved within minutes of being offered. Table 2.2 shows that the average time needed to exhaust the guarantee car capacity was 6 minutes and 27 seconds for unit trains and 24 minutes and 10 seconds for single cars [Truckor, 1990]. Many shippers were put on hold, only to discover later that the guaranteed car supply was fully reserved. Hence, during periods of high rail car demand, the original UP advanced car ordering system became the equivalent of a lottery or a radio station give-a-way where the first callers receive free tickets to a rock concert and the remaining callers are left frustrated.

Historical Use Based Program

On January 1, 1991, in response to shipper complaints, the UP changed to its present advanced car ordering system of using a monthly car loading base to allocate guaranteed car supply [Machalaba, 1990; Truckor, 1990]. The monthly base is determined on a historical four-year average of railroad provided cars at each location. If a facility has been recently built or expanded, the UP establishes a base that is agreeable to both the UP and the shipper. Shippers are given the base number of cars at each location. Car orders at each location can be guaranteed by applying the car order against the base.

Table 2.2. Union Pacific Railroad phone lottery.

Offering Month	Car Category	Cars Offered	Sold out in minutes
November 1989	Unit trains	6,000	6:15
	Single cars	6,500	36:00
December 1989	Unit trains	5,300	6:11
	Single cars	7,000	25:00
January 1990	Unit trains	5,300	6:55
	Single cars	6,000	14:30

To have car orders guaranteed, shippers are required to place the order at least one month prior to the desired car placement month. Any unused portion of a monthly base is canceled without penalty at the end of the period. All car orders beyond the base or made less than one month in advance are not guaranteed and are treated as stand-by orders. The penalty for railroad non-performance and shipper cancellation of guaranteed car orders remained at $70 per car. The treatment of stand-by orders is the same as in the phone lottery advanced car ordering system. Stand-by orders do not receive a guarantee. If not filled at the end of the month, stand-by orders are withdrawn from the system requiring the shipper to place a new order for the following month.

The UP reasoning for using a historical base to allocate guaranteed car supply is to increase the predictability and equity in guaranteed car placement [Machalaba, 1990]. Currently, shippers located along the UP receive guaranteed car placement allocated on a historical basis and stand-by car placement. The UP historical use car allocation system is an alternative to the Burlington Northern method of allocating guaranteed service through the use of an auction. Each system, however, was formed to improve service to shippers, to improve utilization of railroad assets, and allow more informed railroad fleet sizing decisions by increasing the predictability of future rail car demand.

Canadian Pacific Soo Line

The Soo advanced car ordering system allows shippers to bid for the advanced acquisition of guaranteed transport for wheat and durum. The Soo puts an amount of guaranteed car placement or Protected Equipment Rate Exchanges (PERXs), available to shippers for as much six months in advance. Shippers bid for the right to obtain a PERX. Winners are guaranteed delivery of grain cars sometime during a specified two week window. The Soo PERX system is very similar to the

Burlington Northern COT program, but there a few differences [Burke, 1993]. First, PERX are not associated with a minimum acceptable bid allowing shippers to freely bid for advanced guaranteed service both above and below the tariff rate. Secondly, PERX are non-transferable and are tied to an origin. COTs are tied to a corridor and are transferable in a secondary market. Finally, the Soo commits less than 20 percent of its fleet to production of PERX, whereas the BN limits the number of grain cars to production of COTs to 40 percent of its fleet.

Future Car Ordering Systems

Several other possible types of advanced car ordering systems have been discussed. First, a system separating car costs from line haul costs called the "zero base" plan has been proposed [Harding, 1991]. Shippers would be allowed to book line haul service and grain cars for future time periods. The grain cars could be the shipper's own private cars, cars acquired from railroads, or cars from other shippers. Rates for grain cars would be market driven and could change on short notice. If a grain car owner prices cars too low, its cars will be quickly booked and the owner will increase its price. On the other hand, if a grain car owner prices its cars too high, the cars will sit idle forcing the owner to reduce its price [Harding, 1991]. The main idea of the program is to allow market forces to dictate the value placed on covered hopper cars. The market would shift cars from one region to another and to signal the need for additional covered hopper cars.

Second, the notion of priority pricing used in the utility industry has been discussed as a method to price railroad services [Wilson, 1989 and 1991; Kalt, 1991]. The railroad would offer many types of service (priority classes) where shippers with a higher priority would receive cars before shippers with a lower priority. Currently, rail car allocation programs distinguish between only two classes - guaranteed and tariff. One method to implement a priority pricing scheme is the use of an auction similar to the BN COT program and SOO PERX system. In these systems, the COT or PERX holders receive guaranteed delivery of cars, the higher priority, and the other shippers use general tariff service and are not guaranteed the timely delivery of grain cars.

An alternative method of implementing a priority pricing system is for the railroad to set the price rather than shippers bidding for various types of service. This system, called the Rail Car Pricing system, allows shippers with a higher value for transportation to receive cars over shippers with lower values but also has shippers paying the same price for the same type of service [Pautsch et al., 1991].

Fourth, several railroad companies have expressed interest in using airline yield management techniques to manage their grain car inventories [Chicago Board of Trade, 1991; Davies, 1991a and 1991b]. Airline yield management models consist of pricing and allocating seats to various fare classes [Belobaba, 1987; Kraft et al., 1986]. Airline seat inventory control models treat prices as exogenously determined through competitive forces and concentrate solely on allocating seats among fare classes to maximize expected revenue. The use of airline yield management techniques to the management of grain car inventory has been investigated [Pautsch et al., 1991]. The analysis assumed the railroad offers two types of service and found the allocation of grain cars across corridors and types of service which maximized expected revenue of the railroad.

Finally, railroads are looking into the possibilities of becoming a scheduled carrier similar to the airline industry [Robinson, 1991; Burger, 1991; Welty, 1991]. Recent technological advances, such as advanced train control systems, have made it possible for railroads to become scheduled carriers. However, railroads remain uncertain about the possible long term benefits from installing this latest high cost technology [Welty, 1991].

The BN has implemented a process which should eventually transform the BN into a scheduled carrier [Robinson, 1991].

The current BN COT program is expected to eventually evolve into a visionary program called Integrated Network Management (INM). INM will allow shippers to choose from among several types of service options based on the needs of the shipper. The INM system is very similar to the airline industry and to the railroad industry in Europe. INM will allow shippers to know, at the time the freight is purchased, the precise time their grain will be shipped. Shippers who move their grain on a time sensitive basis will be able to choose a higher quality service at premium rates. Shippers with grain movements that are not time sensitive can choose a lower quality of service or can choose stand-by service at discount rates [Robinson, 1991]. The railroad should be able to better utilize its rail cars by knowing in advanced precisely what is to be shipped, how much is to be shipped, when the shipment must move, and the destination of the shipment. The amount of reduction in car cycle times will depend significantly on the ability to match traffic flows with asset use throughout the BN system [Robinson, 1991].

Scheduled doublestack rail service has begun in the movement of sea containers. The Shipping Act of 1984 gave railroads the authority to provide scheduled service on a contracted basis. The Act was designed to [U.S. Congress, 1984]:

1) establish a non-discriminatory regulatory process for the

common carriage of goods by water in the foreign commerce of the United States with a minimum of government intervention and regulatory costs,

2) provide an efficient and economic transportation system in the ocean commerce of the United States that is, insofar as possible, in harmony with, and responsive to, international shipping practices, and

3) encourage the development of an economically sound and efficient United States flag liner fleet capable of meeting national security needs.

In attempting to create an efficient transportation system the Act clarified the immunity of intermodal activities from antitrust statues [Casavant and Wilson, 1991]. The Act allowed ocean liner companies, unhappy with the effects of unreliable doublestack rail service in the movement of sea containers, to contract for rail service with scheduled service requirements. Railroads found they were able to meet the scheduled time requirements for delivery with surprising consistency and the resulting asset productivity in the doublestack business far exceeded all other intermodal activities [Burger, 1991].

Grain Car Ordering System Summary

Table 2.3 displays the main features of the different grain car ordering systems discussed in this chapter. The evolution of the car ordering systems used by the BN, UP, and Canadian Pacific are summarized.

Table 2.3. Comparison of alternative grain car ordering systems.

Railroad/Program	Placement Guarantee	Penalty Paid By		Car Allocation	Pricing Mechanism
		RR	Shipper		
	Days	----$/day----			
BN:					
COT	15	50	COT prepayment	Auction	Bidding
Non-COT	none	0	200	First-come First-serve	Tariff
UP:					
Phone Lottery	30	70	70	Telephone Request	Tariff
Historical Use	30	70	70	Historical Shipping Use	Tariff
Stand-by orders	none	0	0	First-come First-serve	Tariff
Soo:					
PERXs	2 weeks			Auction	Bidding
Tariff	none	0	0	First-come First-serve	Tariff
Pre-Staggers	none	0	0	First-come First-serve	Tariff
Guaranteed Car Supply Contract	negotiated	negotiated	negotiated	contract	contract

CHAPTER 3

RECENT COURT CASES

The Staggers Act of 1980 provided railroads with the power to offer premium services encouraging better utilization of their assets. The development of new car allocation programs, however, has been met with shipper resistance. Two recent court cases heard before the Interstate Commerce Committee (ICC) as a result of railroads trying to increase rail car productivity are: (1) Docket Number 39169, Shippers Committee, OT-5 vs The Ann Arbor Railroad Company et al., (hereinafter called SCOT-5 case) and (2) Docket Number 40169, National Grain and Feed Association vs The Burlington Northern Railroad et al., (hereinafter called COT case).

SCOT-5 Case

Shippers Committee, OT-5 (SCOT-5) is an association of grain elevators, domestic processors, grain export companies, and rail car leasing companies which use and supply private covered hopper cars. Private cars are rail cars owned or leased by shippers. These cars are traditionally controlled by shippers. Shippers are able to demand that their cars be returned immediately after unloading.

Leasing or purchasing rail cars provide shippers with increased flexibility. First, if railroad equipment is unavailable, shippers may use their private cars to avoid lost or delayed sales. Second, shippers may use private cars to store grain near their customers to ensure swift delivery and achieve a marketing advantage over their competitors. Also, if grain receivers do not unload railroad owned cars in a timely manner, the railroad assesses demurrage charges. Private cars, however, are exempt from such charges. Finally, shippers receive compensation from the railroad each time a railroad uses its private car.

In 1983 the SCOT-5 group filed a complaint before the ICC citing [ICC News, 1989]:

(1) alleged railroads violations in the registration of private cars for purely commercial reasons,

(2) the challenge to the railroad's right to determine whether particular shipments will use railroad owned cars or private cars.

The SCOT-5 group was seeking the opportunity for shippers investing in private grain cars to earn a proper return on their investment during periods of car surplus as well as during car shortages. Specifically, the group coveted unimpeded access to the rail system for private covered hopper cars along with market based compensation for the use of private cars.

The group also wanted to change the newly created BN practice of refusing to accept private cars. The BN was offering to lease private cars with the stipulation of maintaining control of the cars. The BN sought to maintain control in order to decrease car cycle times and improve fleet efficiency. Shippers, however, lost control over their investment and could no longer strategically use private cars to maximize their earnings.

In 1984, an administrative law judge issued an interim decision stating it was unlawful for railroads to prohibit private cars from using their rail lines. Moreover, the law judge ruled that it is in the public interest for private cars to have free access to the rail system. The judge ordered the parties to negotiate a sharing agreement specifying how private cars would be used during periods of car surplus. The railroads quickly appealed the decision.

A sharing agreement could not be reached because both parties possessed different definitions regarding market based compensation and open access. Five years later, in 1989, the judgment was withdrawn and a new ruling was issued. First, the ICC ruled railroads cannot deny registration to private cars except for mechanical, safety, or storage considerations. Secondly, the commission ruled that railroads have the right to use their own cars over private cars whenever railroad equipment are available.

The effect of this decision was to reduce the potential return to private cars, discouraging private car ownership and allowing railroads to earn a greater return on rail car investment. After hearing the decision a grain company official stated, "...the commission has relegated the entire private grain fleet to a secondary status" [Abramson, 1989]. Martin Fitzpatrick, an administrator of the Department of Agriculture's Office of Transportation, added that the ICC ruling, " ...will probably discourage investment by private shippers and could very well impact future car supply" [Abramson, 1989].

The SCOT-5 group, wishing to clarify the meaning of when railroad equipment are available, requested the case be reopened. The SCOT-5 group wanted to know exactly how many days late railroad equipment could be before shippers had the right to use their own cars. But on September 11, 1990 the ICC decided not to reopen or clarify their ruling regarding the use of private cars. The ICC ruled that the shippers did not present enough new evidence to reopen or clarify the case [Brown, 1990].

COT Case

The National Grain and Feed Association (NGFA) is an organization representing domestic processors along with country, terminal, and port elevators. The organization includes 40 state and regional feed and grain associations and has more than 10,000 grain and feed companies as members.

The NGFA had many objections concerning the equitable treatment of shippers in the BN's newly created COT program. First, the NGFA argued the BN receives an unfair informational advantage by disclosing only the winning bids and not all the COT bids [Casavant, 1991]. The BN sets the total number of COTs available and the minimum acceptable bid for each corridor based on the information from all past bids submitted by shippers. Shippers, on the other hand, prepare COT bids and the number of COTs to bid on with the knowledge of only the past winning bids. The NGFA, therefore, contended the BN creates for itself an unfair informational advantage by withholding all the demand information from shippers it receives from the COT auction.

Second, the NGFA contended the BN has the incentive to exploit grain car supply in order to increase revenues [Casavant, 1991]. The NGFA asserted the BN has unfair control over the total number of grain cars on the BN, the allocation of grain cars across BN corridors, and the division of grain cars between COT and tariff service on each corridor. Specifically, the NGFA complained that by setting the minimum acceptable bid and the number of COTs available on a corridor the BN has the incentive to increase the value of its COT service by decreasing its tariff service reliability. By making tariff service less reliable, shippers lose an alternative to COT service. Shippers needing to move grain over the BN will then submit higher bids in order to ensure the acquisition of grain cars. Furthermore, by controlling the allocation of cars across corridors, the BN is able to manipulate car supply and practice price discrimination in order to maximize profits on individual corridors [Casavant, 1991]. The BN charges a $200 per car fee for changing COT corridors, thus creating a barrier between corridors and segregating the corridors into separate markets.

Third, the NGFA contended the COT program violates the BN's common carrier obligation. A definition of a transporter's common carriage obligation does not appear in case law. However, from historical precedents, it appears to be an obligation to offer transportation service either for the movement of commodities or passengers to all who would demand such service on terms and conditions applicable to all [Pautsch et al., 1991]. Using the common carrier obligation, shippers contend that all shippers in a similar circumstance as a COT recipient should be able to obtain COT service at the same price.

Finally, the NGFA asserted the COT program increases the riskiness of tariff service. The NGFA complains every grain car committed to the COT program reduces the number of cars in tariff service [Casavant, 1991]. During periods of car shortages, as the percentage of grain cars in the COT program increases, the average waiting time for tariff service increases causing greater hardship on shippers using tariff service. Also, the BN established a $50 per car penalty for shippers canceling tariff service increasing the risk associated with ordering tariff service.

On January 28, 1992 the ICC ruled the COT program did not defy any ICC rule or cause the BN to violate its common carrier obligation. An ICC commissioner described the COT program as, "...one of the few truly innovative carrier marketing programs arising out of the Staggers Act" [Cawthorne, 1992]. Another commissioner was encouraged by the steps the BN had taken to address the concerns of small shippers and added the commission would be open to hear future complaints about the COT program [Brown, 1992]. NGFA officials were disappointed in the decision and stated that, "...in major and potentially precedent setting cases such as the this one, the majority of the ICC is issuing decisions that give short shrift to shipper concerns on rail transportation matters" [Cawthorne, 1992].

CHAPTER 4

PRE-STAGGERS PROGRAM

Prior to the Staggers Rail Act of 1980, railroads provided only conventional tariff service to grain shippers. This type of grain car ordering system will be called the pre-Staggers car allocation system and is described in Figure 4.1.

In the ensuing analysis grain shippers are assumed to be identical and possess identical information sets. Each shipper has an initial inventory of grain denoted as y. The analysis is formulated as a one period model. At the beginning of the period, grain shippers either sell grain using conventional tariff service or store the grain. At the end of the period the grain shipper salvages its remaining grain inventory. Storage costs are incurred on all grain stored to the end of the period.

Grain shippers are assumed to acquire information about their grain salvage value (z) before learning the price of grain (p). After receiving their grain market information shippers know a high (low) salvage value indicates shipper aggregate demand for conventional rail service will be lower (higher) on average for a given price of grain.

Shippers order conventional tariff service, q_i^d, based on the realizations of p and z. However the railroad, with less

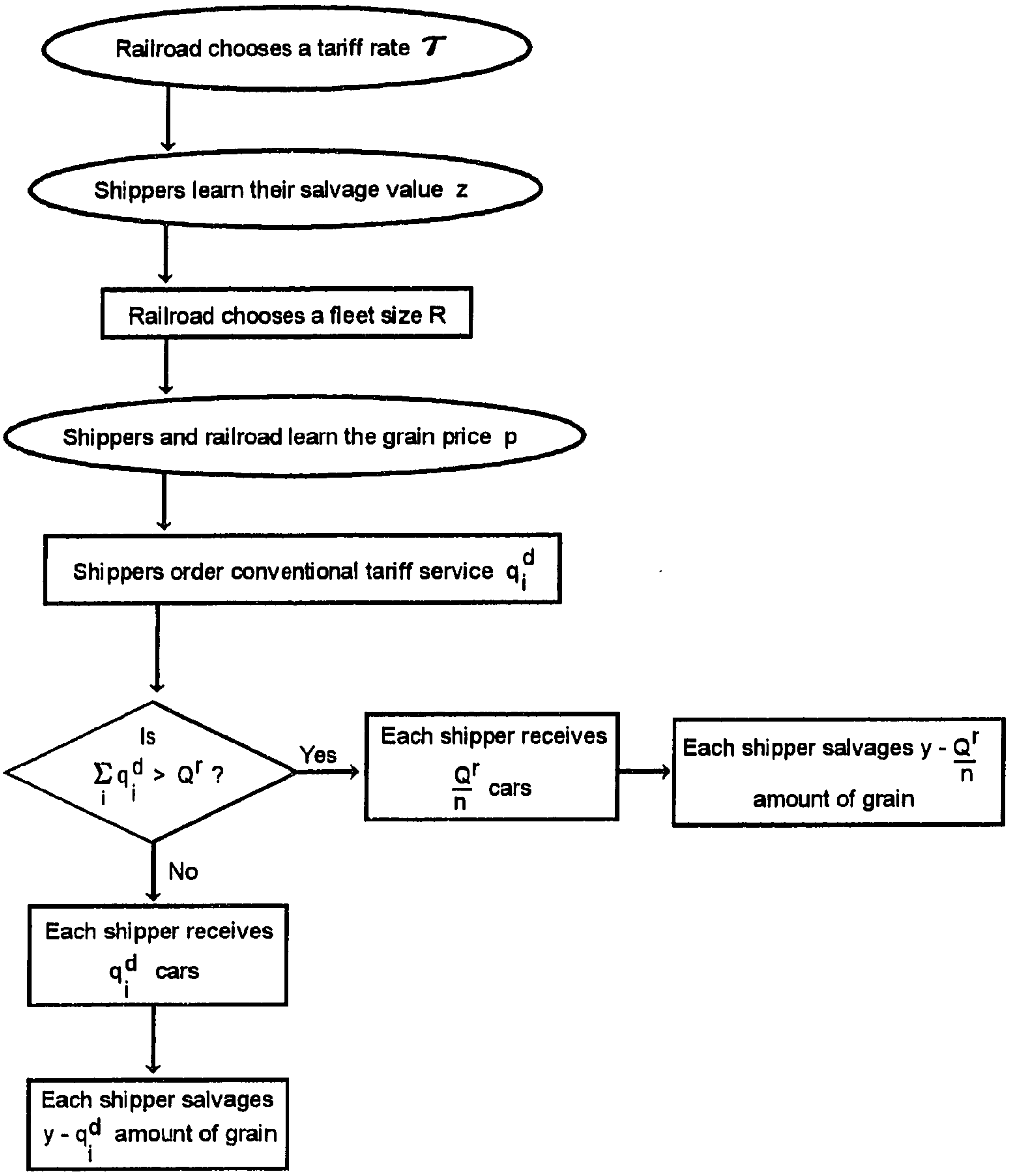


Figure 4.1. Sequence of decisions for the pre-staggers car allocation system.

grain market information, chooses its tariff rate (t) and fleet size (R) without knowing the grain price and the shipper salvage value. The likelihood of the railroad choosing a tariff and fleet to satisfy the demand for its service is remote. If there is excess demand for conventional tariff service, the railroad is assumed to allocate its service equally among the n shippers. If there is excess supply of rail service, each shipper receives its conventional service car order. Grain not moved by conventional service is stored and then salvaged by the shipper.

This chapter presents the formal analysis of the pre-Staggers car allocation system used extensively by railroads prior to 1980. The similarities of the railroad tariff and fleet decisions to the uncertainty literature concerning peak load pricing and monopoly models is presented. Next, the formal analysis of the pre-Staggers shipper and railroad decision making process is discussed. Third, the effect of the relative size of unit operating costs and unit capacity costs on the tariff and capacity decisions of a monopolist railroad is examined. Fourth, the effects of market type and demand stabilizing policies on the railroad tariff and fleet size decisions are also studied. Finally, the effects of the railroad having the same grain market information as shippers is presented.

Literature Review

Firms making price and capacity decisions before knowing the state of demand have been investigated in the peak load pricing literature and monopoly models under uncertainty.

Peak Load Pricing Models

The problem of public utility pricing and capacity decisions under random demand was formulated as the utility finding the price and capacity which maximizes expected social welfare [Brown and Johnson, 1969]. Expected social welfare was defined as expected consumer surplus plus expected utility profit. Demand was allowed to be random in an additive and multiplicative fashion. Per unit capacity costs ($B) and per unit operating costs ($b) were assumed to be constant. Under the additive and multiplicative settings, the optimal price under uncertainty was found to be less than the optimal price in a deterministic setting. The deterministic price is equal to unit operating costs plus unit capacity costs, while the price under uncertainty is only equal to unit operating costs. This pricing scheme under uncertainty allows the utility to recover its operating costs but not its capacity costs, indicating the utility will need to be subsidized.

Capacity under additive uncertainty was found to be greater than under the deterministic setting. With multiplicative uncertainty, capacity is usually greater than under the deterministic setting unless demand is very elastic and capacity costs are very large [Brown and Johnson, 1969].

Subsequent analysis relaxed the assumptions made in the original analysis. In particular, the assumptions of rationing to those with the highest valuations and costless rationing were altered.

Rationing schemes other than rationing to those with the highest value were studied under additive uncertainty [Visscher, 1973]. If output is rationed to those with the lowest valuations, then price under uncertainty is equal to the deterministic price. Capacity can be less under uncertainty when demand is very elastic and costs are very high. Also, rationing output randomly was investigated [Visscher, 1973]. In this case, the optimal price is in the interval [b,b+B] and capacity may be less than or greater than capacity in the riskless setting.

Rationing to those with low willingness to pay and random rationing of available capacity were studied under multiplicative uncertainty [Carlton, 1977]. In both cases, the optimal price exceeds the deterministic price (b+B) and the firm no longer needs to be subsidized. In fact, the firm makes positive profits when rationing to those with the lowest valuations. The optimal capacity in either case may be greater than or less than the deterministic capacity.

The original finding of a public utility needing to be subsidized prompted an alternative analysis [Sherman and Visscher, 1978]. A constraint such that expected revenues equal expected costs was incorporated when deriving welfare maximizing price and capacity. The result is a stochastic version of the welfare maximizing Ramsey prices.

The original assumption of costless rationing was also relaxed [Crew and Kleidorfer, 1976]. A per unit cost of rationing was added which represented the cost of ranking consumers. The resulting price of the utility exceeded marginal operating costs.

Monopoly Models

A monopolist choosing output and price before knowing demand was studied [Mills, 1962; Karlin and Carr, 1962]. The monopolist was assumed to have constant per unit cost of production and capacity. Demand uncertainty was modeled in an additive [Mills, 1962] and in a multiplicative fashion [Karlin and Carr, 1962]. A monopolist facing random demand will price its output lower and its output may be greater or less than the riskless case. In general, the more inelastic the demand, the greater the wedge between the monopoly price and marginal costs indicating a higher loss in missing potential sales. Hence, output would likely be greater under uncertainty when demand is very inelastic. With multiplicative demand uncertainty, optimal price is always greater than the deterministic case.

Shipper Environment

This section presents the shipper information structure, the shipper optimal choice of conventional rail service, the amount of conventional rail service actually received by shippers, and the loss in shipper profit due to car shortages.

Shipper Information Structure

Shippers are assumed to have identical grain inventories, identical salvage values, storage functions, and possess the same information. Consequently, all shippers will have a higher (lower) than average salvage value which will lead to a lower (higher) than average demand for conventional rail service. This structure allows for the replication of the fluctuating demand for covered hopper cars presently occurring in the railroad industry.

The shipper salvage function net of storage costs is shown in equation 4.1. The amount of grain salvaged is represented by m. Each shipper is assumed to receive z for each bushel of grain salvaged. However, each shipper is assumed to incur storage costs when salvaging grain. The grain storage function is assumed to be convex and is represented by vm^2 with $v>0$. Furthermore, the marginal net salvage value of grain (net of storage costs) is assumed positive for all salvage quantities, i.e. $z-2vy>0$ for all z. These assumptions ensure shippers will either sell none, all, or part of their grain inventory using conventional tariff service. The assumptions imply the first derivative with respect to the amount salvaged is positive and its second derivative is negative in the relevant range $m \epsilon [0,y]$.

$$sv(m) = zm - vm^2 \tag{4.1}$$

where:

sv= the net value of salvaging m bushels of grain.

m= quantity of grain salvaged.

z= shipper salvage value known only by shippers.

v= shipper storage cost parameter known by all agents.

Shippers are assumed to have complete information when ordering conventional tariff service. Shippers learn their salvage value z, the grain price p, the tariff rate t, the fleet size R, and the number of trips each rail car in conventional service completes α_n. Shippers calculate the railroad conventional tariff service capacity as $\alpha_n R$. Shippers know the aggregate demand for conventional tariff service given the tariff rate, salvage value, and grain price.

Given the railroad capacity and shipper aggregate demand, shippers know if their conventional service car order will be rationed. The rationing rule imposed by the railroad is that during car shortages, the railroad capacity is allocated equally among the shippers. Therefore, each shipper knows it is unable to influence the amount of conventional service it receives by over-ordering rail cars.

Shipper Demand for Conventional Tariff Service

Since shippers are unable to influence the amount of conventional service they receive during car shortages, shippers are unable to strategically over-order conventional tariff service. Shippers order only the desired amount of conventional service. Each shipper determines the amount of conventional service to order by maximizing profit as shown in equation 4.2.

$$\underset{q_i^d}{\text{Max}} \quad s\pi_i = (p-t)q_i^d + z(y-q_i^d) - v(y-q_i^d)^2 \tag{4.2}$$

where:

$s\pi_i$= profit for the ith shipper.

p= price of grain.

t= tariff rate.

y= grain inventory.

q^d_i= conventional rail service demand for the ith shipper.

$y-q^d_i$ = amount of grain the ith shipper desires to salvage.

The first order condition, shown in equation 4.3, implies the shipper equates the marginal revenue from selling grain delivered by rail [p-t] to its opportunity cost which is the marginal revenue from salvaging grain $[z-2v(y-q^d_i)]$.

$$[p-t] - [z-2v(y-q_i^d)] = 0 \tag{4.3}$$

Figure 4.2 shows the shipper's optimal choice of the conventional service car order q^{d*}_i. If the shipper places an order for $q^{d'}_i$ rail cars, the marginal revenue from selling grain delivered by rail exceeds the marginal revenue from salvaging grain and the shipper will increase its rail car order to maximize its profits. Similarly, an order for $q^{d''}_i$ rail cars results in the marginal revenue from salvaging grain to exceed the marginal revenue from selling grain delivered by rail and the shipper will decrease its rail car order.

Equation 4.4 rearranges the first order condition and solves for q^{d*}_i to give the optimal amount of conventional service to order as a function of the marginal revenue from selling grain delivered by rail (p-t).

$$\begin{aligned} q_i^{d*} &= 0 && \text{if } p-t \leq z-2vy \\ &= \frac{p-t-z+2vy}{2v} && \text{if } z-2vy \leq p-t \leq z \\ &= y && \text{if } p-t \geq z \end{aligned} \tag{4.4}$$

The ith shipper demand for conventional service is shown in Figure 4.3. If the marginal revenue from selling grain delivered by rail is less than or equal to the marginal revenue from salvaging the y^{th} bushel of grain (z-2vy), the shipper will not order conventional rail service. Similarly, if the marginal revenue from selling grain delivered by rail is greater than or equal to the marginal revenue from salvaging the first bushel of grain (z), the shipper orders

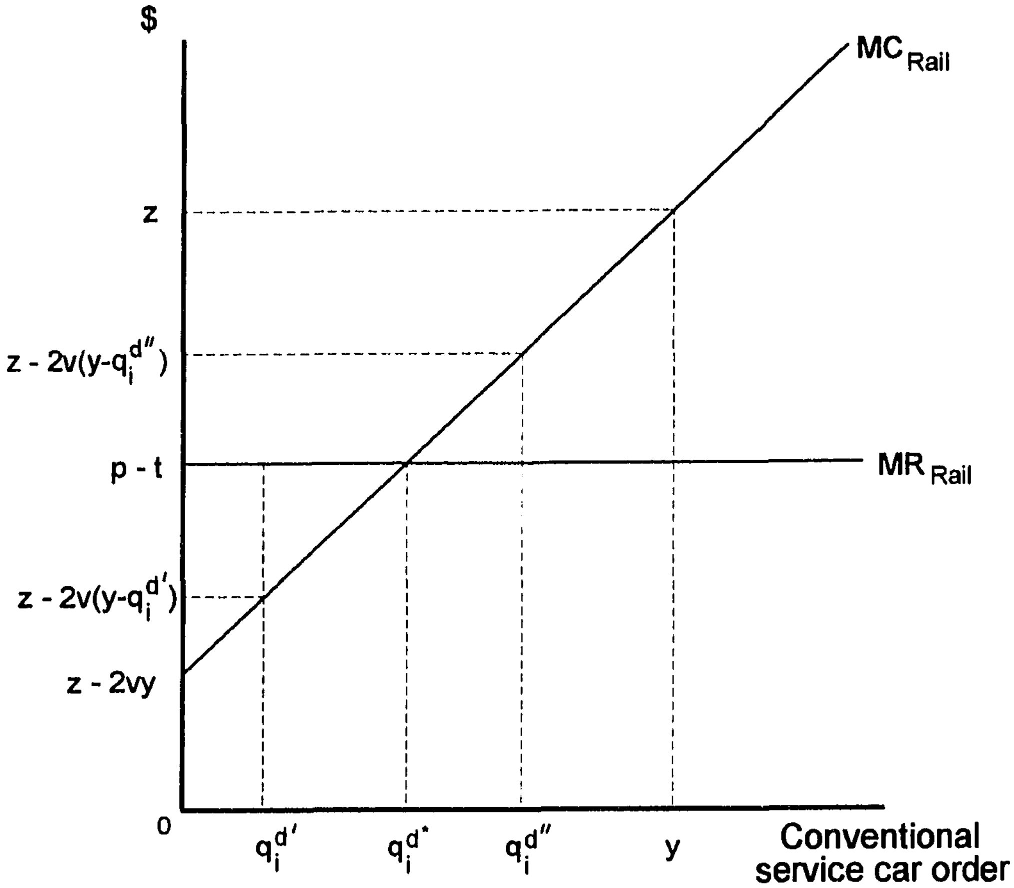


Figure 4.2. Shipper optimal choice of conventional service.

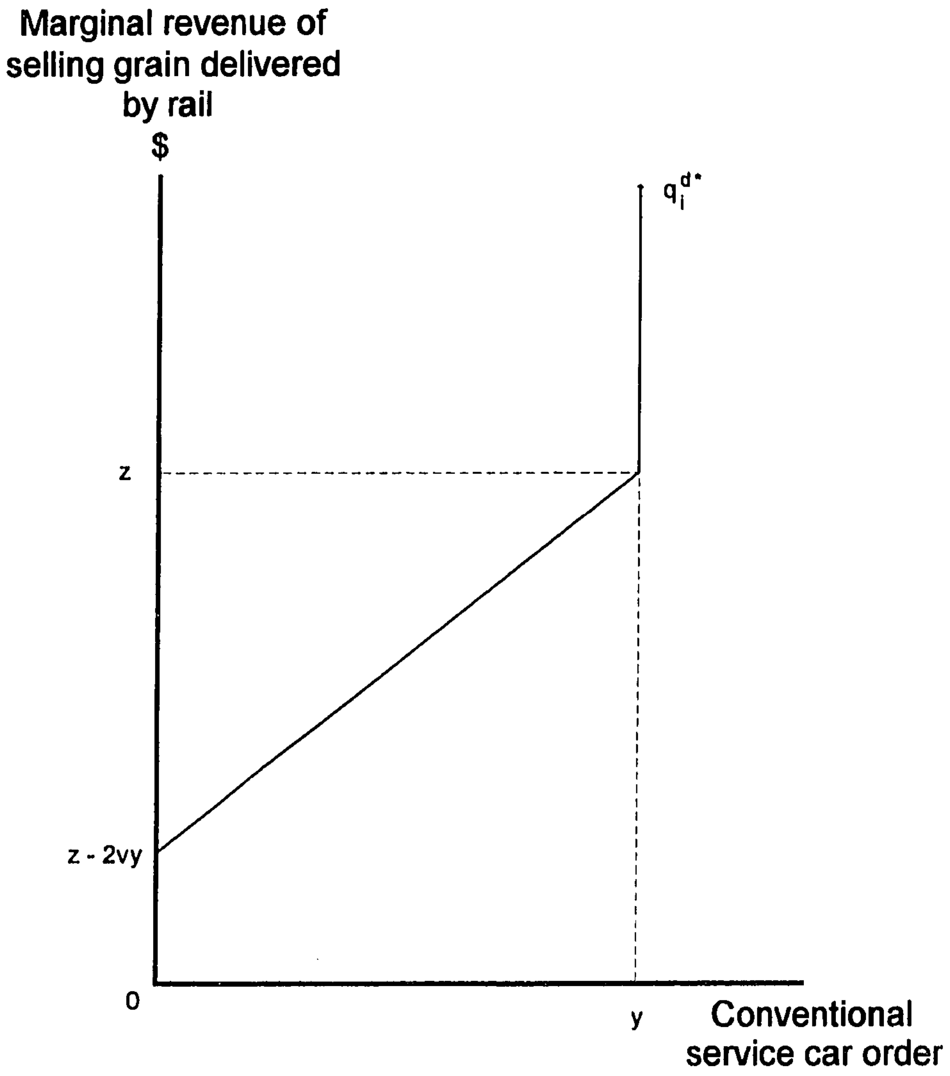


Figure 4.3. Conventional service car order as a function of the marginal revenue of selling grain delivered by rail.

conventional rail service to move its entire inventory of grain. Consequently, if the marginal revenue from selling grain delivered by rail is in the interval $(z-2vy,z)$ the shipper orders conventional rail service to move a portion of its inventory.

For notational convenience, define $\tau=t/2v$ to be a normalized tariff rate. Similarly, define $\rho=(p-z)/2v$ to be the single random variable dictating demand for conventional rail service. A high value of ρ represents a large grain price relative to the shipper's net salvage function. If ρ is high, shippers desire to move a large quantity of grain by conventional rail service. Conversely, a low value of ρ represents a low grain price relative to the shipper's net salvage function and shippers desire to ship a small quantity of grain by conventional rail service. Equation 4.5 shows the conventional service rail demand for a shipper as a function of τ and ρ. Since all shippers are identical the subscript i is dropped.

$$
\begin{array}{llll}
q^{d*}-\min[\max[\rho-\tau+y,0],y] & & & \\
\text{where;} & & & \\
q^{d*}- & 0 & \text{if} & \rho<\tau-y \\
 & -\rho-\tau+y & \text{if} & \rho\epsilon[\tau-y,\tau] \\
 & -\ y & \text{if} & \rho>\tau
\end{array}
\qquad (4.5)
$$

The aggregate demand for conventional rail service, Q^d, is equal to the number of shippers multiplied by the conventional service demand for a representative shipper as shown in equation 4.6.

$$Q^{d}(\rho,\tau)=nq^{d*}(\rho,\tau) \tag{4.6}$$

Amount of Conventional Service Received by Shippers

Shipper profit depends on the number of cars received from the railroad rather than the number of cars the shipper orders. The amount of conventional service a shipper receives is equal to the minimum of the shipper's car order q^d and the shipper's rationed quantity. During periods of car surpluses each shipper receives its entire car order. However, during car shortages, car orders are rationed and each shipper receives an equal proportion of the railroad's conventional service capacity, denoted as $Q^r(R)/n$. The assumption of identical shippers eliminates the possibility of shippers receiving more cars than they desire during car shortages. Equation 4.7 presents the amount of cars a shipper receives from the railroad.

$$
\begin{aligned}
&k=\min\left[q^{d*}(\rho,\tau),\ \frac{Q^{r}(R)}{n}\right]\\
&\text{which implies;}\\
&k=q^{d*}(\rho,\tau)\quad \text{if}\ \ Q^{d}(\rho,\tau)\leq Q^{r}(R)\\
&\quad=\frac{Q^{r}(R)}{n}\quad \text{if}\ \ Q^{d}(\rho,\tau)\geq Q^{r}(R)
\end{aligned}
\qquad (4.7)
$$

where:

k=amount of conventional service a shipper receives.

q^d=amount of conventional service a shipper orders.

Q^d=aggregate conventional service ordered by shippers.

Q^r=railroad capacity of conventional service.

In Figure 4.4, q^{d*} represents the shipper conventional service order and k represents the amount of conventional service the shipper receives from the railroad. The maximum value of ρ at which the shipper does not order rail service is defined as $\rho^{o}=\max[\rho\,|\,q^{d*}(\rho,\tau)=0]$. Similarly, the minimum value of ρ at which the shipper orders conventional rail service to move its entire inventory of grain is defined as $\rho^{y}=\min[\rho\,|\,q^{d*}(\rho,\tau)=y]$. The shipper orders conventional rail service to move a portion of its grain inventory when $\rho\epsilon(\rho^{o},\rho^{y})$.

Shippers, however, do not receive their entire car order if aggregate demand for conventional service exceeds the conventional service capacity of the railroad. In Figure 4.4, the value of ρ at which shipper aggregate demand for conventional rail service equals the railroad capacity of

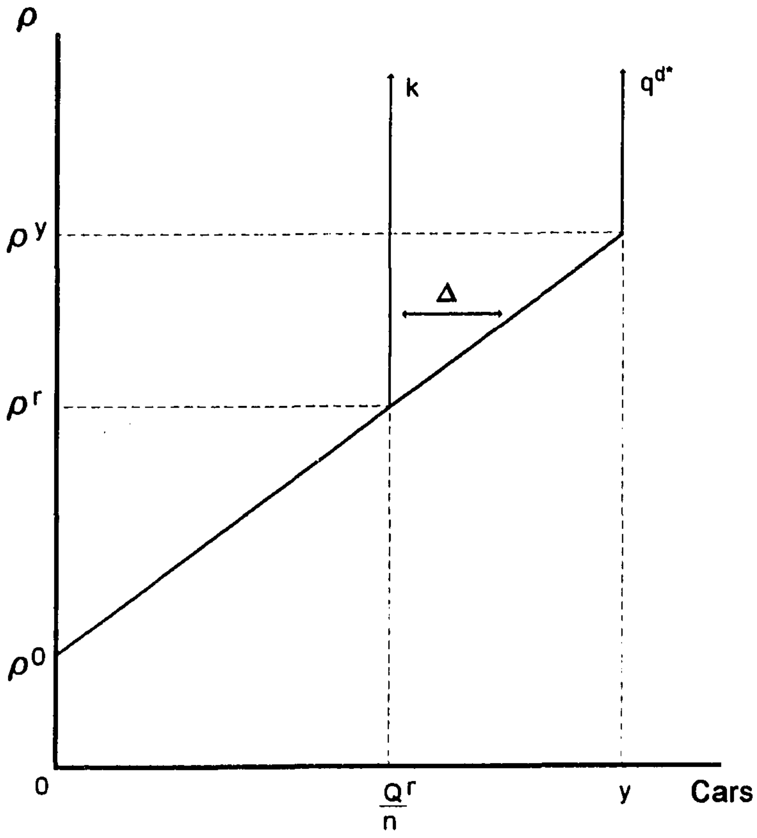


Figure 4.4. Shipper car shortage.

conventional rail service is represented as ρ^r. Shippers receive their entire car order if ρ is less than or equal to ρ^r and their car orders are rationed if ρ is greater than ρ^r. The car shortage experienced by a shipper due to rationing is measured by Δ and is equal to the distance between q^{d*} and k. As ρ rises, shippers demand more conventional service but continue to receive only the rationed quantity, hence the car shortage increases in the interval $[\rho^r,\rho^y]$. The car shortage experienced by a shipper reaches a maximum and becomes constant for $\rho \geq \rho^y$, since shippers cannot sell more grain than their initial inventory.

Loss in Shipper Profit Due to Rationing

Desired shipper profit is defined as the profit earned if the shipper receives all of the conventional service it orders. By inserting shipper conventional service demand into the shipper profit function and recalling $2v(\rho-\tau)=(p-t-z)$, the desired shipper profit, $ds\pi$, is written as equation 4.8

$$\begin{array}{rll} ds\pi = & zy-vy^2 & \text{if } \rho<\tau-y \\ = & zy+2vy(\rho-\tau)+v(\rho-\tau)^2 & \text{if } \rho\varepsilon[\tau-y,\tau] \\ = & zy+2vy(\rho-\tau) & \text{if } \rho>\tau \end{array} \qquad (4.8)$$

Actual shipper profit is the profit earned based on the number of cars it receives from the railroad. Recall that shippers receive their conventional service demand during car surpluses and Q^r/n rail cars during car shortages. Hence, actual shipper profit, $as\pi$, is written as equation 4.9.

$$as\pi = \begin{cases} 2v(\rho-\tau)q^{d}+zy-v(y-q^{d})^{2} & if\ \rho\leq\tau-y+\frac{Q^{r}}{n} \\ 2v(\rho-\tau)\frac{Q^{r}}{n}+zy-v\left(y-\frac{Q^{r}}{n}\right)^{2} & if\ \rho\geq\tau-y+\frac{Q^{r}}{n} \end{cases} \qquad (4.9)$$

The loss in shipper profit due to rationing (L), shown in equation 4.10, is equal to the difference between desired shipper profit and actual shipper profit. The loss in shipper profit is zero when $\rho\leq\rho^{r}$, since the railroad is able to completely fill all car orders for conventional tariff service.

$$L = \begin{cases} 0 & \text{if } \rho<\rho^{r} \\ 2v(\rho-\tau)\left(y-\frac{Q^{r}}{n}\right)+v(\rho-\tau)^{2}+v\left(y-\frac{Q^{r}}{n}\right)^{2} & \text{if } \rho\varepsilon[\rho^{r},\rho^{y}] \\ 2v(\rho-\tau)\left(y-\frac{Q^{r}}{n}\right)+v\left(y-\frac{Q^{r}}{n}\right)^{2} & \text{if } \rho>\rho^{y} \end{cases} \qquad (4.10)$$

Figure 4.5 shows the shipper loss due to rationing as a function of ρ. The figure assumes the shipper storage cost parameter v is constant, so an increase in ρ reflects an increase in the grain price relative to the salvage value z. Differentiating the loss function with respect to ρ, shows the slope of the loss function in $(\$,\rho)$-space to be $2v\Delta$, where Δ is the car shortage experienced the shipper. The car shortage is $(\rho-\tau+y)-Q^{r}/n$ if $\rho\epsilon[\rho^{r},\rho^{y}]$ and $y-Q^{r}/n$ if $\rho\geq\rho^{y}$. The loss curve is convex after ρ^{r}, since the car shortage experienced by a shipper increases as ρ increases. The loss curve is linear

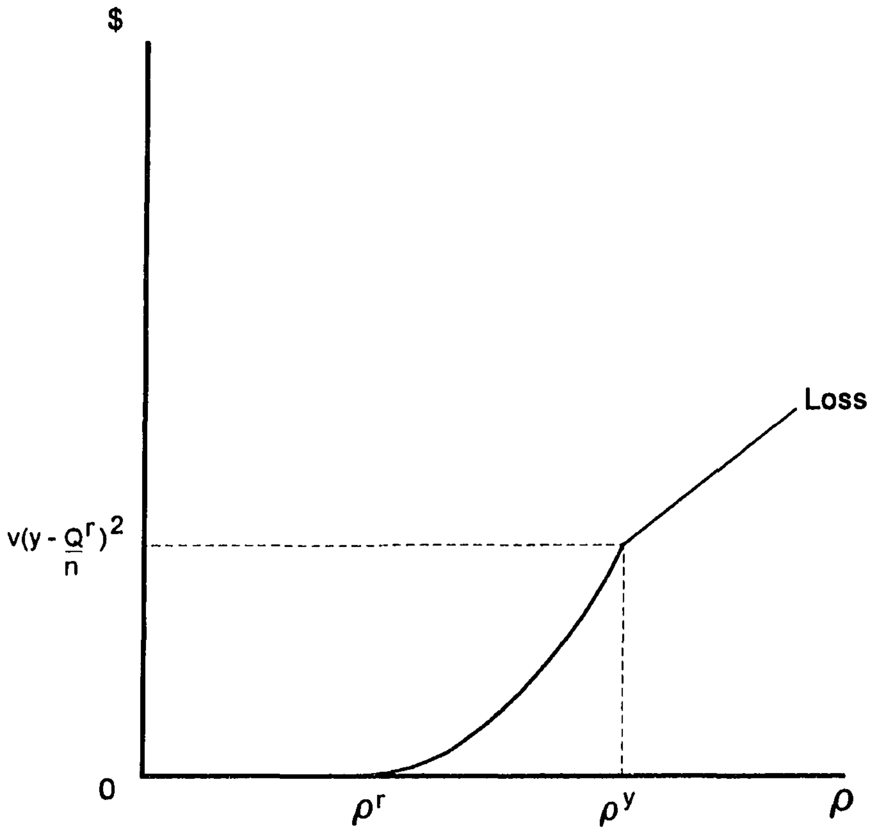


Figure 4.5. Shipper loss due to rationing.

after ρ^{Y}, since the car shortage becomes constant due to the shipper initial inventory constraint.

Railroad Environment

This section presents the optimal production level of conventional tariff service, the railroad subjective probability beliefs about shipper aggregate demand for conventional tariff service, and the railroad optimal tariff rate and fleet size decisions.

Production of Conventional Service

The amount of conventional service produced by the railroad depends on its fleet size, tariff rate, and shipper demand for conventional service. The railroad chooses a fleet size and a tariff rate before shipper demand is known. After the railroad receives the conventional service car orders, the railroad decides how much of its fleet to put into the production process.

Each rail car placed in the production of conventional service is assumed to be able to generate a fixed constant number of trips, α_n, and is acquired at a constant cost of \$B per car. The railroad variable cost function of making Q trips is assumed to be linear with a constant marginal operating cost of \$b per trip as shown in equation 4.11.

$$C[Q]=bQ \text{ with } C'[Q]=b \text{ and } C''[Q]=0 \text{ for all } Q \tag{4.11}$$

Given its fleet size and the parameters which determine shipper demand for conventional service (ρ and τ), the railroad determines the profit maximizing number of cars to put into conventional service. The objective of the railroad is stated in equation 4.12.

$$\begin{gathered}\underset{R_n}{\text{Max}}\ \pi=(2v\tau-b)\alpha_n R_n - B\,R \\ \text{subject to } R_n \leq R \text{ and } \alpha_n R_n \leq Q^d(\rho,\tau)\end{gathered} \tag{4.12}$$

where:

R_n=number of cars placed in conventional service.

α_n=marginal product of a car in conventional rail service.

R =railroad fleet size.

Q^d=shipper aggregate demand for conventional rail service.

The first constraint states the number of rail cars used in the production of conventional service, R_n, must be less than or equal to the number of cars in the fleet. The second constraint states that the railroad cannot produce more conventional service than shippers demand. Combining the two constraints, implies the number of rail cars put into conventional service is less than or equal to $\min[R, Q^d/\alpha_n]$. The number of rail cars in the fleet indicates the maximum number of cars available for conventional service, while the ratio Q^d/α_n, indicates the minimum number of cars needed to satisfy shipper demand for conventional service.

The first order condition for the unconstrained maximization problem is stated in equation 4.13.

$$\frac{\partial\pi}{\partial R_n}=\alpha_n[2v\tau-b] \qquad (4.13)$$

Equation 4.13 is positive, since the railroad always chooses, ex ante, a tariff rate such that the constant marginal revenue of hauling a grain car is greater than the constant marginal cost of hauling. Therefore, either the demand constraint or the capacity constraint is binding. The optimal number of cars to put into the production process is denoted as R_n^* and is equal to $\min[R,Q^d/\alpha_n]$.

If aggregate demand for conventional service exceeds the conventional service capacity of the railroad, the railroad fleet size is binding. The railroad desires to put more cars into conventional service but is unable to due to the fleet size constraint. In this case, the railroad produces its conventional service capacity level of $\alpha_n R$ by placing its entire fleet in the production of conventional service, $R_n^*=R$. However, if aggregate demand for conventional service falls short of railroad capacity, the demand for conventional service is binding. The railroad wants to use its entire fleet to produce conventional service but shipper demand is insufficient to keep the entire fleet active. The railroad produces Q^d amount of conventional service by placing a part of its fleet into the production of conventional service,

$R_n^*=Q^d/\alpha_n$ and the remaining portion of the railroad fleet, $R-Q^d/\alpha_n$, is idle.

The maximum profit of the railroad, given its fleet size, tariff rate, and demand for conventional service is shown in equation 4.14.

$$\begin{aligned}&\pi(\rho,\tau,R)=(2v\tau-b)\alpha_n R_n^*-BR\\&\text{where;}\\&R_n^*=\min\left[R,\frac{Q^d(\rho,\tau)}{\alpha_n}\right]\end{aligned}\tag{4.14}$$

Railroad Subjective Probability of Aggregate Demand

The railroad does not know shipper aggregate demand for conventional rail service when choosing its tariff rate and fleet size, since the shipper salvage value (z) and the future price of grain (p) are unknown to the railroad. The railroad, however, knows the probability distributions of p and z and thus knows the probability distribution of $\rho=(p-z)/2v$, where v is the shipper storage parameter. The railroad uses the probability distribution of ρ to form its subjective probability about shipper aggregate demand for conventional rail service.

The probability distribution function, $\phi(W)$, shown in equation 4.15, represents the railroad subjective probability that shipper aggregate demand for conventional service will be less than or equal to W. Since all q^d are the same, the probability that shipper aggregate demand for conventional rail service is less than or equal to W is the same as the probability that individual shipper demand is less than or equal to W/n.

$$\phi(W)=\mathrm{Prob}(Q^{d}\le W)=\mathrm{Prob}\left(nq^{d^*}\le W\right) \\ =\mathrm{Prob}\left(q^{d^*}\le\frac{W}{n}\right) \tag{4.15}$$

Substituting the individual shipper demand curve into equation 4.15 yields the cumulative distribution for aggregate shipper conventional service demand shown in equation 4.16.

$$\phi(W)=\mathrm{Prob}(Q^{d}\le W)=\mathrm{prob}\left(\rho\le\tau-y+\frac{W}{n}\right) \tag{4.16}$$

Using equation 4.16 and setting W=0 reveals the probability that shipper aggregate demand equals zero is equal to the probability of ρ being less than or equal to $\rho^{o}=\tau-y$. Similarly, the probability shipper aggregate demand will be less than or equal to the railroad capacity is equal to the probability of ρ being less than or equal to $\rho^{r}=\tau-y+Q^{r}(R)/n$. Equation 4.17 shows the railroad subjective probability about shipper aggregate demand using its belief about the random variable ρ.

$$\begin{aligned} \phi(W)&=H(\rho^{o}(\tau)) && \text{if } W=0 \\ &=H(\rho^{W}(\tau)) && \text{if } W\varepsilon(0,Q^{r}(R)) \\ &=H(\rho^{r}(\tau,R)) && \text{if } W=Q^{r}(R) \end{aligned} \tag{4.17}$$

where:

$H(\rho)$=probability distribution function of ρ.

$\rho^o(\tau)=\tau-y$.

$\rho^r(\tau,R)=\tau-y+(Q^r(R)/n)$.

$\rho^W(\tau)=\tau-y+(W/n)$.

The subjective probability of the entire fleet of cars being active is equal to the probability that the shipper aggregate demand for conventional service is greater than or equal to the railroad capacity of conventional service. The subjective probability the entire rail fleet will be active is denoted as $1-H(\rho^r(\tau,R))$.

In Figure 4.6 the curve UR shows the railroad capacity utilization rate. The railroad reaches full asset utilization whenever shipper aggregate demand for conventional service exceeds the railroad capacity. The railroad, however, has idle equipment whenever demand for conventional service falls short of railroad capacity, i.e. the value of ρ is less than ρ^r.

The curve PF shows the percentage of shipper car orders for conventional service being filled by the railroad. The railroad is able to completely fill all car orders when ρ is less than ρ^r. But for values of ρ greater than ρ^r the railroad is unable to completely fill conventional service car orders, since it is operating at full capacity. The percentage of car orders filled by the railroad decreases as the value of ρ

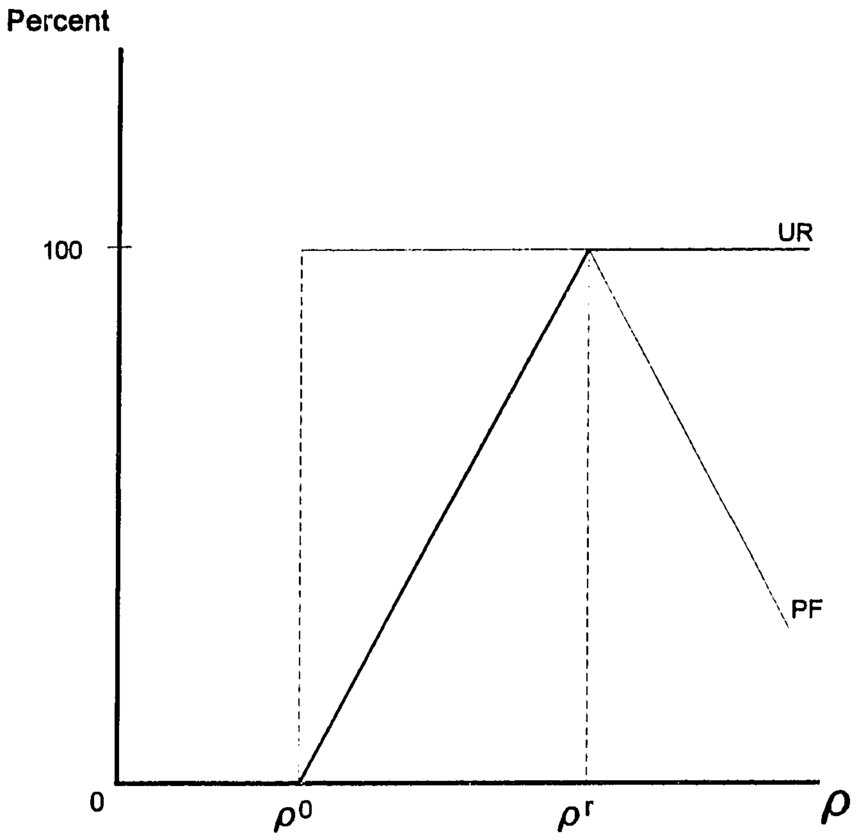


Figure 4.6. Railroad capacity utilization and percent of conventional service orders filled.

rises above ρ^r. Figure 4.6 shows the persistent car shortages and car surpluses inherent in the railroad industry for the movement of grain. These persistent car shortages ($\rho>\rho^r$) and car surpluses ($\rho<\rho^r$) occur because the railroad chooses its tariff rate and capacity before knowing the demand for its conventional tariff service.

Tariff Rate and Fleet Size Decisions

The railroad uses its subjective probability regarding shipper aggregate demand for conventional service to find the fleet size R and normalized tariff rate $\tau=(t/2v)$ which maximizes its expected profit as shown in equation 4.18.

$$\begin{gathered}\underset{\tau,R}{\text{Max}}\ E_\rho\left[\pi=(2v\tau-b)\alpha_n R_n^*-BR\right]\\ \text{where } R_n^*=\min\left[R,\frac{Q^d(\rho,\tau)}{\alpha_n}\right]\end{gathered}\qquad(4.18)$$

The first order condition for the railroad optimization problem with respect to the tariff rate is stated equation 4.19.

$$\frac{\partial E\pi}{\partial \tau}=E_\rho\left[2v\alpha_n R_n^* + (2v\tau-b)\,\alpha_n\frac{\partial R_n^*}{\partial \tau}\right] = 0$$

$$=\int_{\rho^\circ}^{\rho^r}[2vn(\rho-\tau+y)-n(2v\tau-b)]h(\rho)\,d\rho$$

$$+\int_{\rho^r}^{\infty}2v\alpha_n Rh(\rho)\,d\rho=0 \qquad (4.19)$$

where;

$$\frac{\partial R_n^*}{\partial \tau}= \quad 0 \qquad \text{if} \quad \rho>\rho^r(\tau,R) \text{ and } \rho<\rho^\circ(\tau)$$

$$=\frac{\partial Q^d}{\partial \tau}\left(\frac{1}{\alpha_n}\right) \quad \text{if} \quad \rho\epsilon[\rho^\circ(\tau),\rho^r(\tau,R)]$$

Equation 4.19 states that the railroad chooses the optimal tariff rate such that the expected marginal profit with respect to the tariff rate during car shortages plus the expected marginal profit with respect to the tariff rate during car surpluses is equal to zero. Figure 4.7 shows the expected marginal railroad profit during periods of car shortages if ρ is uniformly distributed. In this case, $E\pi_\tau{}^{sh}$ is a linear downward sloping curve $E\pi_\tau{}^{sh}$ in the positive quadrant. The expected marginal railroad profit during car shortages is always positive, since railroad output remains at capacity with tariff rate changes. However, as the tariff rate rises, the probability of operating at full capacity decreases causing the expected marginal profit to decline.

If ρ is uniformly distributed, the expected marginal railroad profit during car surpluses is represented by curve

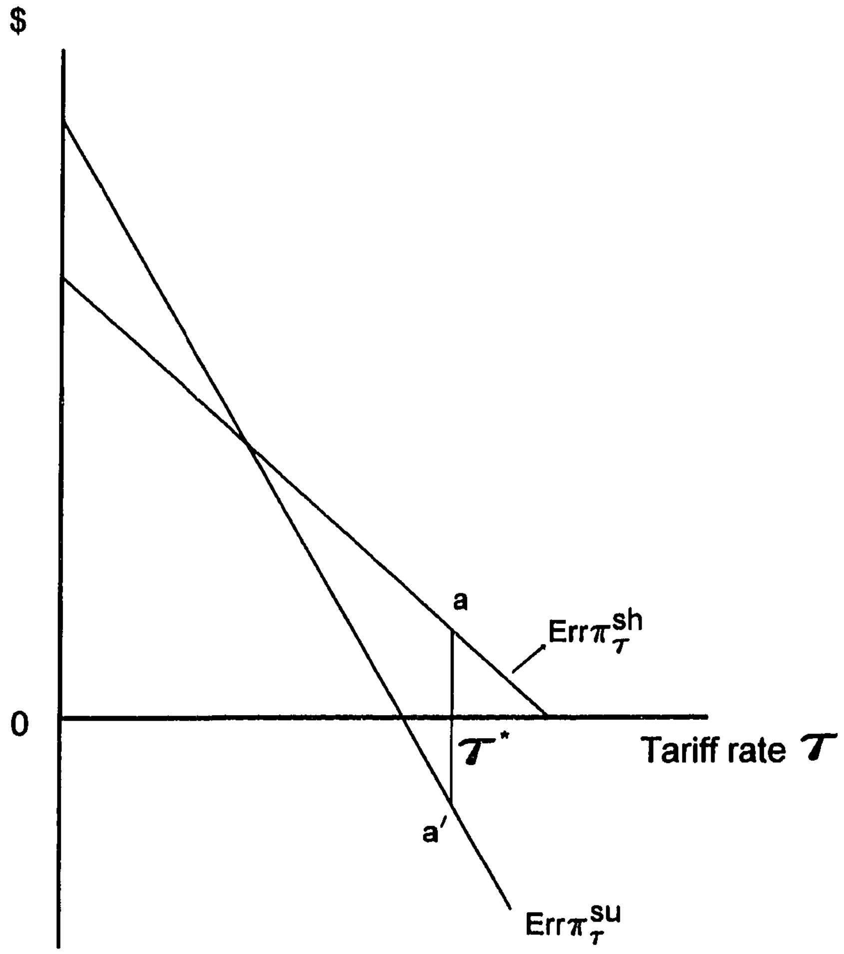


Figure 4.7. Optimal choice of tariff rate.

$E\pi_\tau^{su}$. The expected marginal railroad profit during car surpluses declines as the tariff rate rises and eventually becomes negative. The decrease in expected profits is to due the reduction in rail service demand as a result of a higher tariff. The railroad chooses the tariff rate $\tau*$ such that the expected marginal railroad profit during car shortages balances with the expected marginal railroad profit during car surpluses. In Figure 4.7, the optimal tariff rate τ^* is set such that the distance τ^*a plus τ^*a' is equal to zero.

Equation 4.20 states the railroad acquires a fleet size such that the marginal cost of an additional car is equal to the expected marginal revenue of a car during car shortages. The marginal revenue of an additional car during car surpluses is zero, since the additional car will not be used.

$$\frac{\partial E\pi}{\partial R} = E_\rho\left[(2v\tau - b)\,\alpha_n \frac{\partial R_n^*}{\partial R} - B\right] = 0$$

$$= \int_{\rho^r}^{\infty} [2v\tau - b]\alpha_n\, h(\rho)\, d\rho - B = 0 \qquad (4.20)$$

where:

$$\frac{\partial R_n^*}{\partial R} = 0 \quad \text{if} \quad \rho < \rho^r(\tau, R)$$

$$= 1 \quad \text{if} \quad \rho \geq \rho^r(\tau, R)$$

Figure 4.8 shows the marginal cost of adding an additional car to the fleet as the horizontal line B. If ρ is uniformly distributed, the expected marginal revenue of a car declines as the fleet size increases, since a larger fleet size implies a lower probability of full capacity utilization. The optimal fleet size R^* equates the marginal cost of adding a car to the expected marginal revenue of a car during car shortages as shown in Figure 4.8.

The railroad tariff and fleet size decisions are made simultaneously and are analyzed in (R,τ) space as shown in Figure 4.9. The curve FOC^R represents the combinations of R and τ such that the fleet size first order condition holds. The slope and the rate of change of the slope of FOC^R are shown in equation 4.21.

$$\begin{gathered}
\frac{dR}{d\tau} = -\frac{E\pi_{R\tau}}{E\pi_{RR}} \\
\frac{d^2R}{d\tau^2} = -\left(\frac{1}{E\pi_{RR}}\right)^3 \left[E\pi_{R\tau\tau}E\pi_{RR}^2 - 2E\pi_{RR\tau}E\pi_{R\tau}E\pi_{RR} + E\pi_{RRR}E\pi_{R\tau}^2\right]
\end{gathered} \tag{4.21}$$

Similarly, the curve FOC^τ represents the combinations of R and τ such that the tariff first order condition is satisfied. The slope and the rate of change of the slope of FOC^τ are shown in equation 4.22.

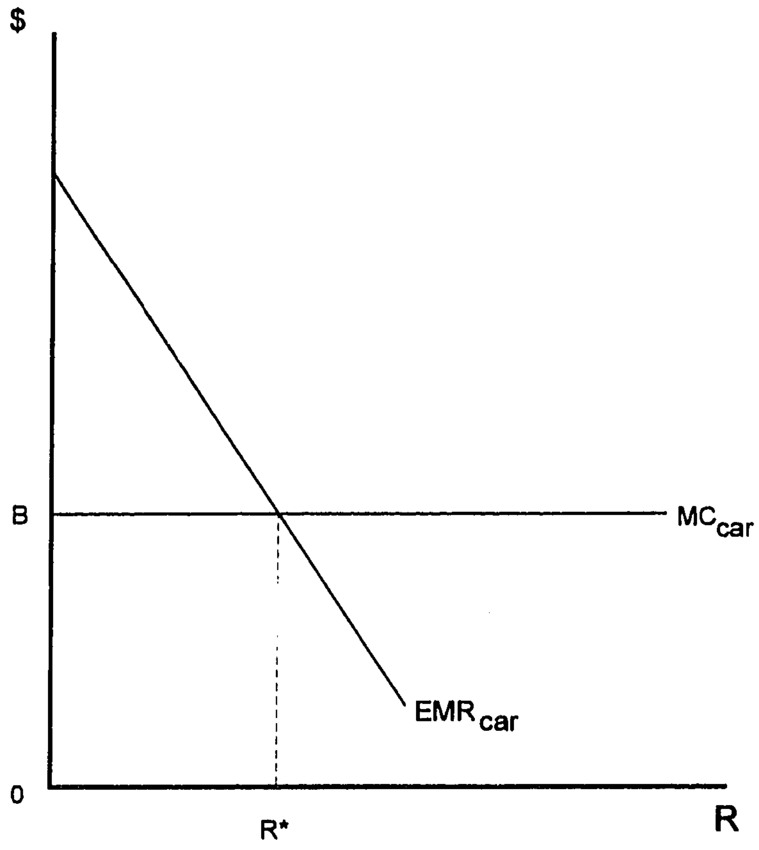


Figure 4.8. Optimal choice of fleet size.

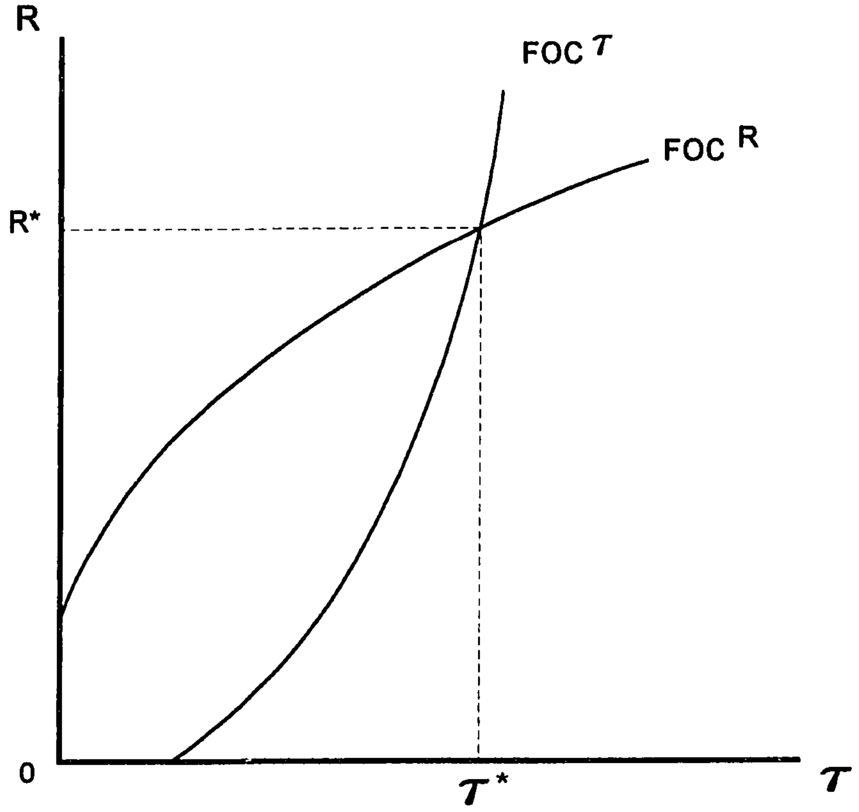


Figure 4.9. Railroad fleet and tariff decisions $E\pi_{R\tau} > 0$.

$$\frac{dR}{d\tau}=-\frac{E\pi_{\tau\tau}}{E\pi_{R\tau}}$$
$$\frac{d^2R}{d\tau^2}=-\left(\frac{1}{E\pi_{R\tau}}\right)^3\left[E\pi_{\tau\tau\tau}E\pi_{R\tau}^2-2E\pi_{\tau\tau R}E\pi_{R\tau}E\pi_{\tau\tau}+E\pi_{\tau RR}E\pi_{\tau\tau}^2\right] \tag{4.22}$$

Equation 4.23 shows the second and third partial derivatives of the first order conditions needed to sign the slope and the rate of change in the slope.

$$E\pi_{RR}=-(2v\tau-b)\left(\frac{\alpha_n^2}{n}\right)h(\rho^r)$$
$$E\pi_{R\tau}=\int_{\rho^r}^{\infty}2v\alpha_n h(\rho)\,d\rho-(2v\tau-b)\alpha_n h(\rho^r)$$
$$E\pi_{\tau\tau}=\int_{\rho^o}^{\rho^r}-4vnh(\rho)\,d\rho-n(2v\tau-b)[h(\rho^r)-h(\rho^o)]$$
$$E\pi_{RR\tau}=-2v\left(\frac{\alpha_n^2}{n}\right)h(\rho^r)-(2v\tau-b)\left(\frac{\alpha_n^2}{n}\right)h'(\rho^r) \tag{4.23}$$
$$E\pi_{\tau\tau\tau}=6vn[h(\rho^o)-h(\rho^r)]-n(2v\tau-b)[h'(\rho^r)-h'(\rho^o)]$$
$$E\pi_{\tau\tau R}=-4v\alpha_n h(\rho^r)-\alpha_n(2v\tau-b)h'(\rho^r)$$
$$E\pi_{RRR}=-(2v\tau-b)\left(\frac{\alpha_n^3}{n^2}\right)h'(\rho^r)$$

If the random variable ρ is assumed to be uniformly distributed, so that $h(\rho^r)=h(\rho^o)$ and $h'(\rho^r)=h'(\rho^o)=0$, then all the partials in equation 4.23 are negative except $E\pi_{RRR}=E\pi_{\tau\tau\tau}=0$ and $E\pi_{R\tau}$ which is indeterminate. Assuming $E\pi_{R\tau}$ is positive, then FOC^{τ} is upward sloping and convex while FOC^{R} is upward sloping and concave. The optimal R and τ are found at the intersection of FOC^{R} and FOC^{τ} as shown in Figure 4.9. The case of $E\pi_{R\tau}=0$ is shown in Figure 4.10. In this case, FOC^{τ} is a vertical line and FOC^{R} is a horizontal line. Finally, if $E\pi_{R\tau}$ is negative both curves are downward sloping but the rate of change of the slope is indeterminate.

The conventional service equilibrium can be characterized in (z,p) space as shown in Figure 4.11. The ray AD in (z,p) space represents the combinations of z and p such that shippers receive all the cars they desire and railroad assets are fully utilized, i.e. the values of p and z such that $\rho=\rho^{r}(\tau,R)$. The combinations of z and p lying below the line result in shippers being rationed but railroad assets are fully utilized. For example, a high grain price and a low salvage value creates a demand for rail service which exceeds the capacity of the railroad, i.e. a value of $\rho>\rho^{r}(\tau,R)$. The combinations of z and p lying above the line result in shippers receiving all the cars they desire but part of the railroad fleet is idle. For example, a low price of grain and a high salvage value creates a demand for rail service which is less than the capacity of the railroad, i.e. a value of $\rho<\rho^{r}(\tau,R)$.

Distribution of Costs on Railroad Decisions

This section examines the effect of the relative size of constant per unit operating costs and constant per unit

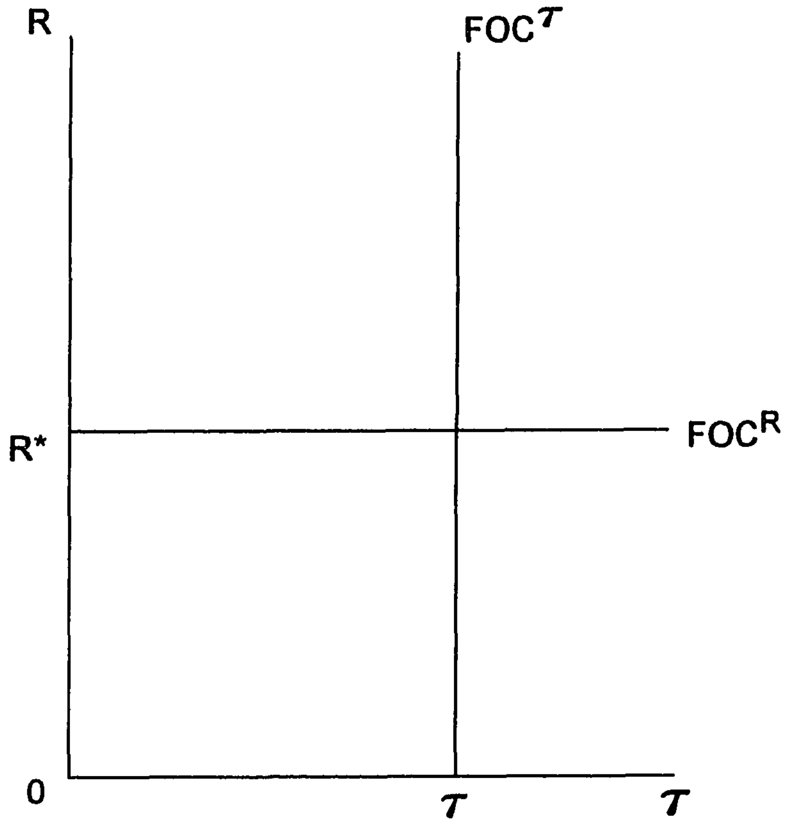


Figure 4.10. Railroad fleet and tariff decisions $E\pi_{R\tau} = 0$.

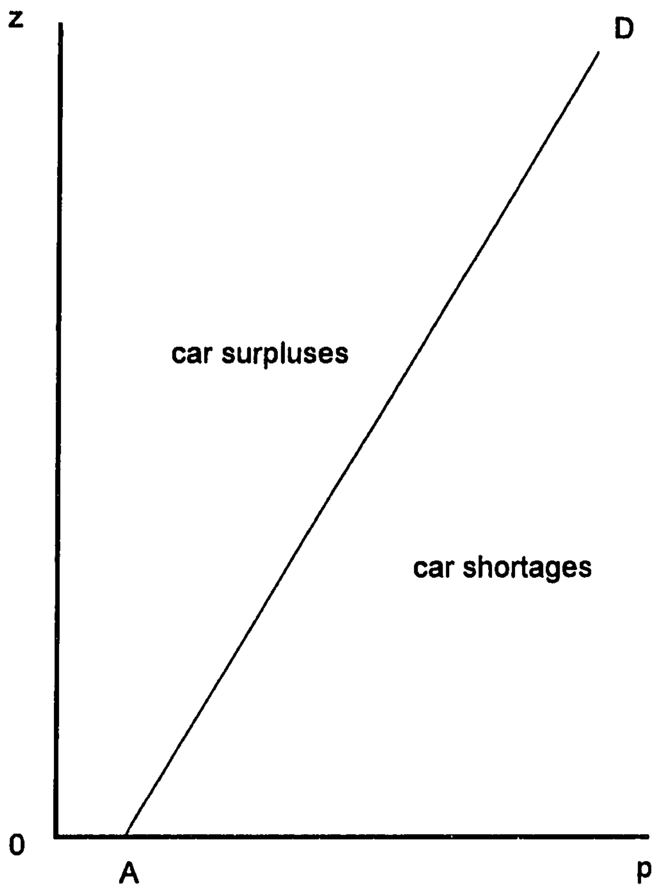


Figure 4.11. Conventional service equilibrium.

capacity costs on the railroad decisions and profits. The total constant per unit cost of producing output is denoted as C. Per unit operating costs, b, are represented by λC and per unit capacity costs, $B' = (B/\alpha_n)$, are represented by $(1-\lambda)C$. Increasing (decreasing) λ increases (decreases) unit operating costs and decreases (increases) unit capacity costs. The effect of changing λ on the tariff rate τ, fleet size R, and profits are examined under deterministic and uncertain demand.

Deterministic Demand

In the deterministic case, the variable ρ is assumed to be equal to its expected value. The demand for the railroad service is denoted as $n(E\rho-\tau+y)$ and the railroad capacity is denoted as $\alpha_n R$. The railroad knowing the demand for its service will acquire a capacity level sufficient to cover demand at the optimal tariff rate. The railroad's optimal capacity given its tariff rate τ is shown in equation 4.24.

$$R^* = \frac{n*(\bar{\rho}-\tau+y)}{\alpha_n}$$

$$\textit{where;} \qquad (4.24)$$

$$\bar{\rho} = E\rho - \frac{Ep-Ez}{2v}$$

The railroad chooses τ to maximize its profit as shown in equation 4.25.

$$\begin{aligned}\max_{\tau}\ r r\pi &= n(\overline{\rho}-\tau+y)(2v\tau-b)-BR^{*}\\ &= n(\overline{\rho}-\tau+y)\left[2v\tau-\lambda C-(1-\lambda)C\alpha_{n}R^{*}\right]\\ &= n(\overline{\rho}-\tau+y)[2v\tau-C]\end{aligned} \tag{4.25}$$

where:

C=total per unit cost of production.

$b=\lambda C$=unit operating costs.

$B'=B/\alpha_n=(1-\lambda)C$=unit capacity costs.

$\lambda\epsilon[0,1]$.

The first order condition, equation 4.26, states the monopolist railroad chooses τ such that the marginal revenue of producing a trip is equal to the total constant marginal cost of producing the trip.

$$2v\tau-2v(\overline{\rho}-\tau+y)=C \tag{4.26}$$

The optimal tariff rate, fleet size, and railroad profit are shown in equations 4.27-4.29.

$$\tau^{*}=\frac{1}{4v}[2v(\overline{\rho}+y)+C] \tag{4.27}$$

$$R^{*}=\frac{n}{4v\alpha_{n}}[2v(\overline{\rho}+y)-C] \tag{4.28}$$

$$rr\pi^{*}=\frac{n}{8v}[2v(\overline{\rho}+y)-C]^{2} \tag{4.29}$$

In the deterministic setting, λ, the distribution of marginal production costs between marginal operating and marginal capacity costs is irrelevant to the railroad normalized tariff and capacity decisions. Only the total constant marginal cost of producing a unit of output is important.

Data for a numerical example are presented in Table 4.1. The optimal values of tariff rate τ, fleet size R, and railroad profit under the deterministic case are shown in equation 4.30.

$$\begin{gathered}\tau^{*}-35.71\\ R^{*}-952.38\\ rr\pi^{*}-\$2,857,143\end{gathered}\qquad(4.30)$$

Table 4.1. Data for the Deterministic Setting.

Shipper grain inventory in cars (y) = 25
Expected shipper grain price per car (Ep) = \$9,450
Expected grain salvage value per car (Ez) = \$5,950
Shipper storage parameter (v) = \$70
Expected value of ρ [Eρ=(Ep-Ez)/2v] = 25
Total railroad cost of producing a trip (C) = \$3,000
Number of trips by a car in conventional service (α_n) = 1.5
Number of shippers (n) = 100

Demand Uncertainty

The optimizing procedure for a railroad facing random demand for its service when choosing its tariff rate and fleet were shown in equations 4.19 and 4.20. To see the effect of λ

on the tariff and fleet size decisions substitute $b=\lambda C$ and $B=(1-\lambda)C\alpha_n$ into the first order conditions. Equation 4.31 shows the system of equations which determine the effect of λ on the tariff rate and fleet size.

$$\begin{bmatrix} E\pi_{\tau\tau} & E\pi_{\tau R} \\ E\pi_{R\tau} & E\pi_{RR} \end{bmatrix} \begin{bmatrix} \frac{d\tau}{d\lambda} \\ \frac{dR}{d\lambda} \end{bmatrix} = \begin{bmatrix} -E\pi_{\tau\lambda} \\ -E\pi_{R\lambda} \end{bmatrix} \tag{4.31}$$

where

$$E\pi_{\tau\lambda} = nC[H(\rho^{r})-H(\rho^{o})] > 0$$

$$E\pi_{R\lambda} = CH(\rho^{r})\alpha_{n} > 0$$

Assuming $E\pi_{\tau R}$ is positive, then an increase in λ increases τ and the fleet size R. Figure 4.12 shows the effects of increasing λ on the curves FOC^R and FOC^τ. Recall FOC^R are the combinations of (R,τ) such that the railroad fleet size is optimal and FOC^τ are the combinations of (R,τ) such that the railroad normalized tariff rate is optimal. The fleet size and tariff rate τ which maximizes railroad expected profit is found at the intersection of these two curves.

When choosing an optimal fleet size, the railroad equates the expected marginal profit from an additional rail car to the marginal capacity costs. Increasing λ increases marginal operating costs and decreases marginal capacity costs by equal amounts. Holding τ constant, an increase in marginal operating costs decreases the marginal profit from an additional rail car by an identical amount. However, the

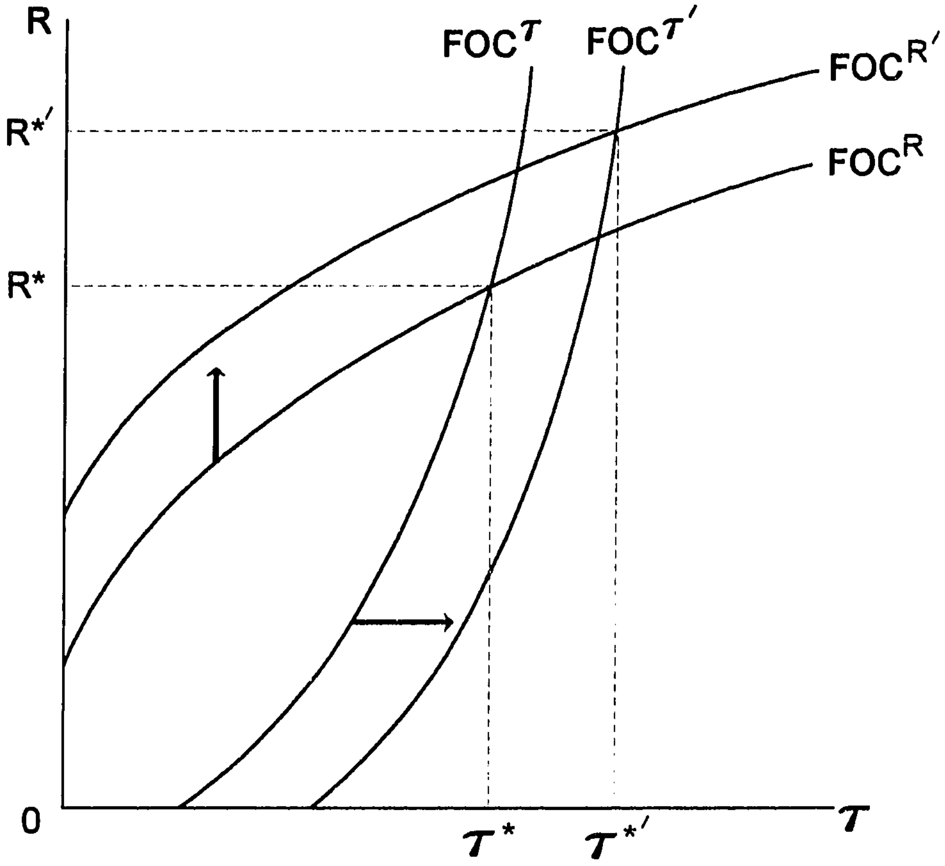


Figure 4.12. The effect of λ on the optimal tariff τ^* and fleet size R*.

expected marginal profit from an additional rail car decreases by a lesser amount, since there is the probability the rail car may not be used. Therefore, increasing λ and holding τ constant decreases the marginal capacity cost by a greater amount than the reduction in expected marginal profit. The railroad will acquire a larger fleet for a given τ when λ increases, indicated by FOC^R shifting upward to $FOC^{R'}$ in Figure 4.12.

Similarly, if λ increases, the railroad increases its tariff rate τ for a given fleet size. Marginal operating costs rise, implying the railroad will increase its tariff rate τ. Figure 4.12 shows FOC^τ shifting to the right when λ increases. Therefore, as λ increases, FOC^R shifts up and FOC^τ shifts to the right, increasing the optimal fleet size and tariff rate.

For illustrative purposes, shipper demand for rail service is assumed to be uniformly and normally distributed. If demand follows a normal distribution, the distribution is arbitrarily truncated in the interval [0,50]. Table 4.2 shows that as λ increases, τ and R also increase when ρ is uniformly distributed over various intervals. Similarly, Table 4.3 shows the increasing effects of λ on τ and R when ρ is normally distributed with different standard deviations.

Table 4.2. The Effect of Costs on Railroad Decisions with a Uniform Distribution over the Intervals [20,30], [10,40], and [0,50], C=$3000.

Interval	λ	τ	Fleet R	Errπ
[20,30]	0.0	34.76	938.11	2,269,102
	0.1	34.84	950.11	2,292,711
	0.2	34.93	964.95	2,319,829
	0.3	35.03	981.89	2,351,259
	0.4	35.13	1,002.02	2,388,058
	0.5	35.24	1,026.26	2,431,638
	0.6	35.35	1,055.88	2,483,929
	0.7	35.47	1,092.77	2,547,629
	0.8	35.58	1,139.75	2,626,625
	0.9	35.67	1,201.38	2,726,734
	1.0	35.71		2,857,143
[10,40]	0.0	32.44	849.49	1,179,570
	0.1	32.73	890.22	1,236,053
	0.2	33.05	938.03	1,303,283
	0.3	33.39	994.55	1,384,014
	0.4	33.76	1,061.79	1,481,850
	0.5	34.15	1,142.42	1,601,535
	0.6	34.54	1,239.97	1,749,394
	0.7	34.93	1,359.40	1,933,984
	0.8	35.44	1,502.30	2,167,722
	0.9	35.89	1,666.67	2,467,634
	1.0	36.96		2,815,848
[0,50]	0.0	35.16	624.49	431,900
	0.1	35.94	701.90	524,487
	0.2	36.68	790.72	637,952
	0.3	37.37	892.76	776,733
	0.4	38.00	1,010.41	946,299
	0.5	38.56	1,146.83	1,153,482
	0.6	39.03	1,306.36	1,406,971
	0.7	39.39	1,495.34	1,718,101
	0.8	39.82	1,666.67	2,100,223
	0.9	40.89	1,666.67	2,518,080
	1.0	41.96		2,952,009

Table 4.3. The Effect of Costs on Railroad Decisions with a Normal Distribution with Standard Deviations of 2,3, and 4, C=$3000.

Sigma	λ	τ	Fleet R	Errπ
2	0.0	35.16	952.21	2,474,968
	0.1	35.20	958.51	2,492,279
	0.2	35.24	965.71	2,511,373
	0.3	35.29	974.06	2,532,623
	0.4	35.34	983.94	2,556,531
	0.5	35.39	995.92	2,583,791
	0.6	35.45	1,010.93	2,615,418
	0.7	35.51	1,030.68	2,652,988
	0.8	35.58	1,058.85	2,699,057
	0.9	35.65	1,106.34	2,759,667
	1.0	35.71		2,857,143
3	0.0	34.87	950.30	2,287,141
	0.1	34.93	959.85	2,312,649
	0.2	35.00	970.76	2,340,839
	0.3	35.07	983.42	2,372,276
	0.4	35.15	998.39	2,407,716
	0.5	35.23	1,016.53	2,448,211
	0.6	35.31	1,039.23	2,495,294
	0.7	35.41	1,069.08	2,551,342
	0.8	35.51	1,111.59	2,620,431
	0.9	35.62	1,183.09	2,710,975
	1.0	35.72		2,857,117
4	0.0	34.58	946.99	2,101,643
	0.1	34.66	959.87	2,135,020
	0.2	34.75	974.59	2,171,985
	0.3	34.85	991.65	2,213,296
	0.4	34.95	1,011.82	2,259,971
	0.5	35.06	1,036.24	2,313,423
	0.6	35.18	1,066.78	2,375,711
	0.7	35.31	1,106.89	2,450,025
	0.8	35.44	1,163.90	2,541,822
	0.9	35.58	1,259.61	2,662,348
	1.0	35.74		2,856,277

Demand Variability on Railroad Decisions

The effects of a mean preserving spread/contraction of the conventional rail service demand on railroad decisions has two important applications. First, the domestic demand for U.S. grain is more stable than the demand for U.S. grain exports. A railroad primarily serving export markets has a more volatile demand for its conventional service than a railroad serving primarily domestic markets. Hence, the effect of market type, domestic versus export, primarily served by the railroad on its decisions are captured by studying the effect of a mean preserving contraction of the random variable ρ characterizing the aggregate demand for conventional rail service.

Second, suppose the noise surrounding the aggregate demand for conventional rail service is reduced by stabilizing either the shipper salvage value z or the future grain price p at its expected value. Further assume, the salvage value is normally distributed with mean z^e and variance σ_z^2 and the future price of grain is normally distributed with mean p^e and variance σ_p^2. The salvage value and the future price of grain are assumed to be independent of each other. Therefore, the random variable $\rho=(p-z)/2v$, which characterizes shipper aggregate demand, is normally distributed with mean $(p^e-z^e)/2v$ and variance $(\sigma_p^2+\sigma_z^2)/(4v^2)$. In this case, the effect of stabilizing the random variable (p or z) at its expected value is comparable to a mean preserving contraction of the random variable ρ.

For instance, suppose the future price of grain becomes stabilized at its expected value. The railroad when making its tariff and fleet size decisions knows the future price of grain to be p^e but remains uncertain about the shipper salvage value z. Under these assumptions, the railroad when making its decisions uses the random variable ρ', defined as $(p^e-z)/2v$, to form its beliefs regarding the future state of shipper aggregate demand for conventional rail service. The random variable ρ' is normally distributed with mean $(p^e-z^e)/2v$ and variance $(\sigma_z^2)/(4v^2)$. The random variable ρ' is a mean preserving contraction of the random variable ρ, since ρ is normally distributed with mean p^e-z^e and variance $(\sigma_p^2+\sigma_z^2)/(4v^2)$.

Similarly, if a government policy stabilized shippers salvage value z at its expected value, then the railroad when making its tariff and fleet size decisions knows the shipper salvage value is z^e. The railroad, however, remains uncertain about the future price of grain. The railroad uses the random variable ρ'', defined as $(p-z^e)/2v$, to form its beliefs regarding the future state of shipper aggregate demand for conventional rail service. The random variable ρ'' is normally distributed with mean $(p^e-z^e)/2v$ and variance $(\sigma_p^2)/(4v^2)$. The random variable ρ'' is a mean preserving contraction of the random variable ρ.

Simulations

Tables 4.4-4.6 show the optimal tariff rate and fleet when the cost level is $3000 and the random variable ρ is uniformly distributed in the intervals [25,25], [20,30], [10,40], [0,50], and [-10,60]. The cost level C represents the total constant per unit cost of production. The tariff rate is represented by tau, fleet by R, and railroad expected profit by Ex-rr profit. The probability aggregate demand for rail service is zero at the optimal tariff is represented by the column prob D=0. The probability shippers want to ship their entire inventory by rail at the optimal tariff is represented by the column prob D=max. The probability aggregate demand exceeds the capacity of the railroad at the optimal tariff and fleet is denoted by the column prob ration. Finally, the column reliability is equal to probability the railroad is able to satisfy shipper aggregate demand and is equal to one minus the probability of rationing. The railroad fleet needed to haul all the grain is represented by 1,666.67 cars.

From Table 4.4 changing the variability of ρ from its expected value of 25 to the interval [20,30] decreases the tariff rate but the fleet size may increase or decrease. The fleet size decreases when capacity costs are high and

Table 4.4. The Effect of a Mean Preserving Spread on Railroad Decisions with a Uniform Distribution, C=$3000 and λ=0.0, 0.1, 0.2, and 0.3

λ	Interval	τ	Fleet R	Errπ	Prob D=0	Prob D=max	Prob Ration	Reliability
0.0	[25,25]	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	[20,30]	34.76	938.11	2,269,102	0.000	0.000	0.6164	0.3836
	[10,40]	32.44	849.49	1,179,570	0.000	0.252	0.6605	0.3395
	[0,50]	35.16	624.49	431,900	0.203	0.297	0.6095	0.3905
	[-10,60]	40.64	496.72	225,596	0.366	0.277	0.5273	0.4727
0.1	[25,25]	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	[20,30]	34.84	950.52	2,292,711	0.000	0.000	0.5897	0.4103
	[10,40]	32.73	890.22	1,236,053	0.000	0.242	0.6304	0.3696
	[0,50]	35.94	701.90	524,487	0.219	0.281	0.5706	0.4294
	[-10,60]	41.26	615.18	333,126	0.375	0.268	0.4930	0.5070
0.2	[25,25]	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	[20,30]	34.93	964.95	2,319,829	0.000	0.000	0.5594	0.4406
	[10,40]	33.05	938.03	1,303,283	0.000	0.232	0.5960	0.4040
	[0,50]	36.68	790.72	637,952	0.234	0.266	0.5292	0.4708
	[-10,60]	41.84	747.07	471,607	0.383	0.259	0.4565	0.5435
0.3	[25,25]	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	[20,30]	35.03	981.89	2,351,259	0.000	0.000	0.5245	0.4755
	[10,40]	33.39	994.55	1,384,014	0.000	0.220	0.5563	0.4437
	[0,50]	37.37	892.76	776,733	0.247	0.253	0.4848	0.5152
	[-10,60]	42.36	894.51	646,888	0.391	0.252	0.4175	0.5825

Table 4.5. The Effect of a Mean Preserving Spread on Railroad Decisions with a Uniform Distribution, C=$3000 and λ=0.4, 0.5, 0.6, and 0.7

λ	Interval	τ	Fleet R	Errπ	Prob D=0	Prob D=max	Prob Ration	Reliability
0.4	[25,25]	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	[20,30]	35.13	1,002.02	2,388,058	0.000	0.000	0.4841	0.5159
	[10,40]	33.76	1,061.79	1,481,850	0.000	0.208	0.5104	0.4896
	[0,50]	38.00	1,010.41	946,299	0.260	0.240	0.4369	0.5631
	[-10,60]	42.81	1,060.26	886,005	0.397	0.246	0.3755	0.6245
0.5	[25,25]	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	[20,30]	35.24	1,026.26	2,431,638	0.000	0.000	0.4369	0.5631
	[10,40]	34.15	1,142.42	1,601,535	0.000	0.195	0.4573	0.5427
	[0,50]	38.56	1,146.83	1,153,482	0.271	0.229	0.3848	0.6152
	[-10,60]	43.18	1,247.97	1,137,566	0.403	0.240	0.3300	0.6700
0.6	[25,25]	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	[20,30]	35.35	1,055.88	2,483,929	0.000	0.000	0.3811	0.6190
	[10,40]	34.54	1,239.97	1,749,394	0.000	0.182	0.3953	0.6047
	[0,50]	39.03	1,306.36	1,406,971	0.281	0.219	0.3275	0.6725
	[-10,60]	43.44	1,462.66	1,472,304	0.406	0.237	0.2802	0.7198
0.7	[25,25]	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	[20,30]	35.47	1,092.77	2,547,629	0.000	0.000	0.3141	0.6859
	[10,40]	34.93	1,359.40	1,933,984	0.000	0.169	0.3225	0.6775
	[0,50]	39.39	1,495.34	1,718,101	0.288	0.212	0.2635	0.7365
	[-10,60]	43.75	1,666.67	1,882,813	0.411	0.232	0.0000	1.0000

Table 4.6. The Effect of a Mean Preserving Spread on Railroad Decisions with a Uniform Distribution, C=$3000 and λ=0.8, 0.9, and 1.0

λ	Interval	τ	Fleet R	Errπ	Prob D=0	Prob D=max	Prob Ration	Reliability
0.8	[25,25]	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	[20,30]	35.58	1,139.75	2,626,625	0.000	0.000	0.2325	0.7675
	[10,40]	35.44	1,502.30	2,167,722	0.015	0.152	0.2343	0.7657
	[0,50]	39.82	1,666.67	2,100,223	0.296	0.204	0.0000	1.0000
	[-10,60]	44.82	1,666.67	2,330,516	0.426	0.217	0.0000	1.0000
0.9	[25,25]	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	[20,30]	35.67	1,201.38	2,726,734	0.000	0.000	0.1308	0.8692
	[10,40]	35.89	1,666.67	2,467,634	0.030	0.137	0.0000	1.0000
	[0,50]	40.89	1,666.67	2,518,080	0.318	0.182	0.0000	1.0000
	[-10,60]	45.89	1,566.67	2,789,700	0.441	0.202	0.0000	1.0000
1.0	[25,25]	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	[20,30]	35.71	1,666.67	2,857,143	0.000	0.000	0.0000	1.0000
	[10,40]	36.96	1,666.67	2,815,848	0.065	0.101	0.0000	1.0000
	[0,50]	41.96	1,666.67	2,952,009	0.339	0.161	0.0000	1.0000
	[-10,60]	46.96	1,666.67	3,260,364	0.457	0.186	0.0000	1.0000

increases when capacity costs are low.

Further increases in the variability of ρ shows both the tariff rate and fleet size may increase or decrease. Holding everything else constant, increasing the interval on which ρ is uniformly distributed places more probability weight at the extremes. If the tariff rate remains the same, increasing the interval will increase the probability demand is zero and the probability demand reaches its maximum. For instance, if the tariff rate is 36 with each shipper having 25 units of grain to sell and ρ is uniformly distributed in the interval [10,40], then the probability shipper aggregate demand is zero is equal to $\text{prob}(\rho \leq \rho^o) = 0.03$ and the probability shippers will want to ship all of their grain by rail is equal to $\text{prob}(\rho \geq \rho^y) = 0.13$, as shown in equation 4.32.

$$\begin{aligned} \text{prob}(\rho \leq \rho^o) &= \int_{10}^{11} \left[\frac{1}{40-10}\right] d\rho = 0.03 \\ \text{prob}(\rho \geq \rho^y) &= \int_{36}^{40} \left[\frac{1}{40-10}\right] d\rho = 0.13 \end{aligned} \tag{4.32}$$

But if ρ is uniformly distributed in the interval [0,50], then the probability shipper aggregate demand is zero is equal to 0.18 and the probability of shipper aggregate reaching its maximum is equal to 0.32, as shown in equation 4.33.

$$\begin{aligned} \text{prob}(\rho \le \rho^{o}) &= \int_{0}^{11} \left[\frac{1}{50-0}\right] d\rho = 0.18 \\ \text{prob}(\rho \ge \rho^{y}) &= \int_{36}^{50} \left[\frac{1}{50-0}\right] d\rho = 0.32 \end{aligned} \tag{4.33}$$

At first, the railroad decreases its tariff rate to recapture the lost expected sales from the lower extreme of the distribution. In this case, a lower tariff rate implies the expected profit from recaptured sales in the lower extreme of the distribution exceeds the reduction in expected profit from sales in the rest of the distribution.

However, holding the tariff rate constant, as the interval on which ρ is uniformly distributed becomes wider and wider, the probability demand is zero and reaches its maximum becomes larger and larger. The expected shipper demand becomes less and less responsive to changes in the tariff rate. A greater reduction in the tariff rate is needed to recapture the same amount of expected sales from the lower extreme of the distribution. Eventually, recapturing these lost expected sales from lower extreme of the distribution becomes too costly. Furthermore, the less responsive shipper expected demand at the upper extreme of the distribution gives the monopolist railroad the incentive to increase its tariff rate.

The effect of a mean preserving spread when ρ is normally distributed are shown in Tables 4.7-4.10. Again the tariff rates fall as sigma, the standard deviation of ρ, increases. Tariff rates eventually increase when sigma gets large enough (σ=7 or 8). The response of the fleet size to a mean preserving spread of ρ is again indeterminate. Finally, a mean preserving spread of ρ decreases expected railroad profits.

The results coincide with the uncertainty literature. In particular, when demand is modeled in an additive fashion, the monopolist's price is lower and its output may be greater or less than the riskless case [Mills, 1962; Karlin and Carr, 1962]. When increases in the variability of ρ are small around the riskless case, the tariff rate falls and the fleet size may increase or decrease agreeing with the past findings. In these instances, when ρ is normally or uniformly distributed, the demand for rail service is also normally or uniformly distributed.

However, if the variability of ρ becomes large enough, the demand for rail service no longer follows the same distribution as ρ. The lower bound of zero and an upper bound in the form of an inventory constraint creates a non-differentiable aggregate demand density function with positive weight at the two extremes. Large increases in the variability of ρ, creates a greater probability that demand will be either zero or its upper limit and lessens the probability demand will be sensitive to changes in the tariff

Table 4.7. The Effect of a Mean Preserving Spread on Railroad Decisions with a Uniform Distribution, C=$3000 and λ=0.0, 0.1, 0.2.

λ	σ	τ	Fleet R	Errπ	Prob D=0	Prob D=max	Prob Ration	Reliability
0.0	0	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	1	35.44	952.87	2,664,999	0.000	0.000	0.6046	0.3954
	2	35.16	952.21	2,474,968	0.000	0.000	0.6094	0.3906
	3	34.87	950.30	2,287,141	0.000	0.000	0.6145	0.3855
	4	34.58	946.99	2,101,643	0.000	0.008	0.6198	0.3802
	5	34.28	941.54	1,919,053	0.001	0.032	0.6250	0.3750
	6	34.02	932.50	1,741,365	0.004	0.066	0.6298	0.3702
	7	33.83	919.05	1,572,135	0.010	0.103	0.6335	0.3665
	8	33.70	901.66	1,415,784	0.020	0.138	0.6358	0.3642
0.1	0	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	1	35.46	956.00	2,673,802	0.000	0.000	0.5788	0.4212
	2	35.20	958.51	2,492,279	0.000	0.000	0.5834	0.4166
	3	34.93	959.85	2,312,649	0.000	0.000	0.5881	0.4119
	4	34.66	959.87	2,135,020	0.000	0.008	0.5931	0.4069
	5	34.39	957.83	1,959,959	0.001	0.030	0.5980	0.4020
	6	34.16	952.31	1,789,440	0.004	0.063	0.6024	0.3976
	7	33.99	942.52	1,626,946	0.011	0.099	0.6056	0.3944
	8	33.89	928.89	1,476,740	0.021	0.133	0.6075	0.3925
0.2	0	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	1	35.48	959.57	2,683,494	0.000	0.000	0.5495	0.4505
	2	35.24	965.71	2,511,373	0.000	0.000	0.5537	0.4463
	3	35.00	970.76	2,340,839	0.000	0.000	0.5581	0.4419
	4	34.75	974.59	2,171,985	0.000	0.007	0.5627	0.4373
	5	34.51	976.45	2,005,366	0.001	0.029	0.5673	0.4327
	6	34.30	974.94	1,842,939	0.004	0.061	0.5712	0.4288
	7	34.16	969.30	1,688,110	0.012	0.095	0.5739	0.4261
	8	34.09	959.93	1,544,981	0.022	0.127	0.5753	0.4247

Table 4.8. The Effect of a Mean Preserving Spread on Railroad Decisions with a Uniform Distribution, C=$3000 and λ=0.3, 0.4, and 0.5.

λ	σ	τ	Fleet R	Errπ	Prob D=0	Prob D=max	Prob Ration	Reliability
0.3	0	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	1	35.50	963.70	2,694,261	0.000	0.000	0.5159	0.4841
	2	35.29	974.06	2,532,623	0.000	0.000	0.5197	0.4803
	3	35.07	983.42	2,372,276	0.000	0.000	0.5237	0.4763
	4	34.85	991.65	2,213,296	0.000	0.007	0.5279	0.4721
	5	34.63	998.03	2,056,229	0.001	0.027	0.5319	0.4681
	6	34.45	1,001.16	1,903,018	0.005	0.058	0.5353	0.4647
	7	34.34	1,000.30	1,756,991	0.012	0.091	0.5375	0.4625
	8	34.29	995.84	1,622,080	0.024	0.122	0.5383	0.4617
0.4	0	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	1	35.53	968.60	2,706,351	0.000	0.000	0.4769	0.5231
	2	35.34	983.94	2,556,531	0.000	0.000	0.4803	0.5197
	3	35.15	998.39	2,407,716	0.000	0.000	0.4838	0.5162
	4	34.95	1,011.82	2,259,971	0.000	0.006	0.4874	0.5126
	5	34.76	1,023.52	2,113,833	0.001	0.025	0.4909	0.5091
	6	34.61	1,032.10	1,971,232	0.005	0.055	0.4937	0.5063
	7	34.53	1,036.85	1,835,418	0.013	0.087	0.4953	0.5047
	8	34.52	1,038.11	1,710,142	0.026	0.116	0.4955	0.5045
0.5	0	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	1	35.56	974.53	2,720,109	0.000	0.000	0.4313	0.5687
	2	35.39	995.92	2,583,791	0.000	0.000	0.4342	0.5658
	3	35.23	1,016.53	2,448,211	0.000	0.000	0.4371	0.5629
	4	35.06	1,036.24	2,313,423	0.000	0.006	0.4401	0.5599
	5	34.90	1,054.34	2,179,960	0.001	0.024	0.4430	0.5570
	6	34.79	1,069.49	2,049,739	0.006	0.051	0.4451	0.5549
	7	34.73	1,080.97	1,925,928	0.014	0.082	0.4460	0.5540
	8	34.75	1,089.08	1,812,082	0.028	0.111	0.4457	0.5543

Table 4.9. The Effect of a Mean Preserving Spread on Railroad Decisions with a Uniform Distribution, C=$3000 and λ=0.6, 0.7, and 0.8.

λ	σ	τ	Fleet R	Errπ	Prob D=0	Prob D=max	Prob Ration	Reliability
0.6	0	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	1	35.58	981.98	2,736,038	0.000	0.000	0.3772	0.6228
	2	35.45	1,010.93	2,615,418	0.000	0.000	0.3794	0.6206
	3	35.31	1,039.23	2,495,294	0.000	0.000	0.3817	0.6183
	4	35.18	1,066.78	2,375,711	0.000	0.005	0.3840	0.6160
	5	35.05	1,092.87	2,257,202	0.001	0.022	0.3862	0.6138
	6	34.97	1,116.16	2,141,672	0.006	0.048	0.3876	0.6124
	7	34.95	1,135.96	2,032,196	0.016	0.077	0.3879	0.6121
	8	35.01	1,152.49	1,932,120	0.030	0.105	0.3870	0.6130
0.7	0	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	1	35.61	991.71	2,754,923	0.000	0.000	0.3119	0.6881
	2	35.51	1,030.68	2,652,988	0.000	0.000	0.3134	0.6866
	3	35.41	1,069.08	2,551,342	0.000	0.000	0.3150	0.6850
	4	35.31	1,106.89	2,450,025	0.000	0.005	0.3166	0.6834
	5	35.22	1,143.39	2,349,570	0.002	0.021	0.3180	0.6820
	6	35.17	1,177.27	2,251,869	0.007	0.045	0.3188	0.6812
	7	35.18	1,207.83	2,159,893	0.017	0.073	0.3185	0.6815
	8	35.27	1,235.20	2,076,748	0.032	0.099	0.3171	0.6829
0.8	0	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	1	35.65	1,005.78	2,778,110	0.000	0.000	0.2316	0.7684
	2	35.58	1,058.85	2,699,057	0.000	0.000	0.2325	0.7675
	3	35.51	1,111.59	2,620,431	0.000	0.000	0.2333	0.7667
	4	35.44	1,163.90	2,541,822	0.000	0.005	0.2342	0.7658
	5	35.39	1,215.08	2,463,916	0.002	0.019	0.2349	0.7651
	6	35.38	1,263.83	2,388,582	0.007	0.042	0.2350	0.7650
	7	35.43	1,309.41	2,318,668	0.019	0.068	0.2344	1.0000
	8	35.55	1,351.76	2,256,983	0.035	0.093	0.2329	0.7671

Table 4.10. The Effect of a Mean Preserving Spread on Railroad Decisions with a Uniform Distribution, C=$3000 and λ=0.9 and 1.0.

λ	σ	τ	Fleet R	Errπ	Prob D=0	Prob D=max	Prob Ration	Reliability
0.9	0	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	1	35.68	1,029.44	2,808,390	0.000	0.000	0.1307	0.8693
	2	35.65	1,106.34	2,759,667	0.000	0.000	0.1310	0.8690
	3	35.62	1,183.09	2,710,975	0.000	0.000	0.1312	0.8688
	4	35.58	1,259.61	2,662,348	0.000	0.004	0.1315	0.8685
	5	35.57	1,335.17	2,614,324	0.002	0.017	0.1316	0.8684
	6	35.59	1,408.46	2,568,737	0.008	0.039	0.1314	0.8686
	7	35.68	1,478.63	2,528,260	0.020	0.063	0.1307	1.0000
	8	35.83	1,545.15	2,495,295	0.037	0.087	0.1296	0.8704
1.0	0	35.71	952.38	2,857,143	-	-	0.0000	1.0000
	1	35.71	1,666.67	2,857,143	0.000	0.000	0.0000	1.0000
	2	35.71	1,666.67	2,857,143	0.000	0.000	0.0000	1.0000
	3	35.72	1,666.67	2,857,117	0.000	0.000	0.0000	1.0000
	4	35.74	1,666.67	2,856,277	0.000	0.004	0.0000	1.0000
	5	35.83	1,666.67	2,852,215	0.002	0.015	0.0000	1.0000
	6	36.00	1,666.67	2,844,012	0.010	0.033	0.0000	1.0000
	7	36.25	1,666.67	2,833,580	0.025	0.054	0.0000	1.0000
	8	36.56	1,666.67	2,823,742	0.046	0.073	0.0000	1.0000

rate.

Therefore, the effects of either market type served by the railroad or policies to stabilize rail demand on the railroad tariff and capacity decisions is indeterminate. However, a railroad serving primarily domestic markets versus a railroad serving primarily export markets will have higher expected profits. Similarly, policies to stabilize rail demand will lead to higher expected profits for the monopolist railroad.

Symmetric Information

This section examines the effects of the railroad having the same grain market information as the grain shippers. The symmetric information could occur through government regulation or by the railroad developing closer working relations with grain shippers. Four decades into the computer age reveal that the very nature of business is information [Coates, 1993]. Recent developments of American business to develop a closer working relationship between customers and suppliers include a just-in-time inventory (JIT II) system [Dysart, 1993; Burke, 1991; McClenahen, 1991] and the organizational structure of a virtual corporation [Davidow, 1992; Byrne et al., 1993; Malone and Davidow, 1992]. In the JIT II system, a representative of the supplier is employed full time at the customer's location. This "in-plant" learns the needs and the business of the customers. Similarly, a virtual corporation is defined as a temporary network of independent companies - suppliers, and customers - linked by information technology to share skills, costs, and access to one another's markets [Byrne et al., 1993].

These concepts which share information between customers and suppliers would allow the railroad to learn the shipper's information regarding its salvage value. In this section, the railroad is assumed to learn the shippers salvage value z simultaneously with shippers, i.e., before making its fleet size decision but after the tariff decision.

In this section and in the next chapter, the grain price p is assumed to be normally distributed in the interval [7700, 11200] with an expected value of 9450. The salvage value z is assumed to be trinomially distributed with 1/3 probability assigned to each of the following values $Ez-\epsilon$, Ez, and $Ez+\epsilon$, where $Ez=5950$ and ϵ represents the spread of the distribution. With these assumptions, the expected value of ρ $(p-z/2v)$ continues to be 25. The remaining data used in the numerical analysis are unaltered and are shown in Table 4.1.

The welfare impact of the railroad and shippers sharing information as well as its affect on the railroad tariff rate and capacity decisions are the focus of this section. Perfect information shows the maximum amount of total welfare obtainable. The optimal tariff rate t ($=2v\tau^*$), railroad conventional service capacity, railroad profit, shipper profit, and total welfare under deterministic demand with $z=Ez=5950$ and $p=Ep=9450$ are shown in equation 4.34. Railroad conventional service capacity is defined as the fleet size R multiplied by the number of trips a car in conventional service completes, $\alpha_n=1.5$. Total welfare (TW) is defined as the sum of railroad and shipper profits.

$$\begin{aligned} t^* &= \$5000/car \qquad \alpha_n R^* = 1{,}428{,}571.57 \\ rr\pi^* &= \$2{,}857{,}143 \\ s\pi^* &= \$\ \ 119{,}286 \\ TW^* &= \$2{,}976{,}429 \end{aligned} \tag{4.34}$$

Table 4.11 shows the optimal tariff rate t, railroad conventional service capacity, and total expected welfare with asymmetric information under the pre-Staggers car allocation system. The results of the previous section concerning the effects of λ and a mean preserving spread on railroad decisions and expected profits continue to hold under the new distributional assumptions of p and z.

Tables 4.12 and 4.13 show the expected railroad profit, expected shipper profit, and expected total welfare. The informational gain by the monopolist railroad increases expected railroad profit and expected total welfare. Expected shipper profit is only slightly less under symmetric information. Expected total welfare increases, since the

Table 4.11. The Pre-Staggers Program with Asymmetric Information, with C=$3,000.

λ	ε	Tariff t	RR Capacity	Errπ	Esπ	Total Eπ
0.0	100	4,802	1,412.22	1,942,197	122,545	2,064,742
	200	4,797	1,411.41	1,923,545	122,626	2,046,171
	300	4,790	1,409.91	1,892,971	122,759	2,015,730
0.1	100	4,817	1,436.51	1,981,791	122,444	2,104,235
	200	4,813	1,436.19	1,963,895	122,524	2,086,419
	300	4,806	1,435.59	1,934,539	122,658	2,057,197
0.2	100	4,833	1,464.27	2,025,860	122,333	2,148,193
	200	4,829	1,464.60	2,008,122	122,415	2,130,537
	300	4,823	1,464.99	1,980,831	122,548	2,103,379
0.3	100	4,850	1,496.46	2,075,354	122,211	2,197,565
	200	4,846	1,497.47	2,059,269	122,292	2,181,561
	300	4,841	1,499.09	2,032,854	122,426	2,155,280
0.4	100	4,868	1,534.52	2,131,552	122,076	2,253,628
	200	4,865	1,536.36	2,116,571	122,157	2,238,728
	300	4,860	1,539.30	2,091,960	122,289	2,214,249
0.5	100	4,887	1,580.51	2,196,229	121,926	2,318,155
	200	4,885	1,583.34	2,182,529	122,007	2,304,536
	300	4,881	1,587.99	2,160,025	122,138	2,282,163
0.6	100	4,908	1,637.94	2,271,956	121,758	2,393,714
	200	4,096	1,641.96	2,259,771	121,836	2,381,607
	300	4,903	1,648.73	2,239,768	121,968	2,361,736
0.7	100	4,931	1,713.09	2,362,707	121,569	2,484,276
	200	4,929	1,718.75	2,352,353	121,647	2,474,000
	300	4,927	1,728.20	2,335,384	121,777	2,457,161
0.8	100	4,955	1,819.46	2,475,237	121,359	2,596,596
	200	4,954	1,827.39	2,467,170	121,437	2,588,607
	300	4,952	1,840.47	2,453,997	121,562	2,575,559
0.9	100	4,979	1,995.99	2,623,288	121,129	2,744,417
	200	4,979	2,007.42	2,618,239	121,202	2,739,441
	300	4,978	2,026.28	2,610,071	121,322	2,731,393
1.0	100	5,009		2,855,393	120,768	2,976,161
	200	5,011		2,854,559	120,819	2,975,378
	300	5,014		2,853,160	120,887	2,974,047

Table 4.12. The Welfare Effect of Symmetric Information Under the Pre-Staggers Car Ordering System for $0.0 \leq \lambda \leq 0.4$.

		Symmetric Information			Asymmetric Information		
λ	ϵ	$Err\pi$	$Es\pi$	Total $E\pi$	$Err\pi$	$Es\pi$	Total $E\pi$
0.0	100	1,948,467	122,541	2,071,008	1,942,197	122,545	2,064,742
	200	1,948,467	122,612	2,071,079	1,923,545	122,626	2,046,171
	300	1,948,467	122,731	2,071,198	1,892,971	122,759	2,015,730
0.1	100	1,987,805	122,440	2,110,245	1,981,791	122,444	2,104,235
	200	1,987,805	122,512	2,110,317	1,963,895	122,524	2,086,419
	300	1,987,805	122,631	2,110,436	1,934,539	122,658	2,057,197
0.2	100	2,031,586	122,330	2,153,916	2,025,860	122,333	2,148,193
	200	2,031,586	122,401	2,153,987	2,008,122	122,415	2,130,537
	300	2,031,586	122,521	2,154,107	1,980,831	122,548	2,103,379
0.3	100	2,080,755	122,208	2,202,963	2,075,354	122,211	2,197,565
	200	2,080,755	122,279	2,203,034	2,059,269	122,292	2,181,561
	300	2,080,755	122,398	2,203,153	2,032,854	122,426	2,155,280
0.4	100	2,136,583	122,072	2,950,879	2,131,552	122,076	2,253,628
	200	2,136,583	122,143	2,950,950	2,116,571	122,157	2,238,728
	300	2,136,583	122,262	2,951,059	2,091,960	122,289	2,214,249

Table 4.13. The Welfare Effect of Symmetric Information under the Pre-Staggers Car Ordering System for 0.5 ≤ λ ≤ 1.0.

		Symmetric Information			Asymmetric Information		
λ	ε	Errπ	Esπ	Total Eπ	Errπ	Esπ	Total Eπ
	100	2,200,829	121,923	2,322,752	2,196,229	121,926	2,318,155
0.5	200	2,200,829	121,995	2,322,824	2,182,529	122,007	2,304,536
	300	2,200,829	122,114	2,322,943	2,160,025	122,138	2,282,163
	100	2,276,049	121,756	2,397,805	2,271,956	121,758	2,393,714
0.6	200	2,276,049	121,827	2,397,876	2,259,771	121,836	2,381,607
	300	2,276,049	121,946	2,397,995	2,239,768	121,968	2,361,736
	100	2,366,187	121,567	2,487,754	2,362,707	121,569	2,484,276
0.7	200	2,366,187	121,638	2,487,825	2,352,353	121,647	2,474,000
	300	2,366,187	121,757	2,487,944	2,335,384	121,777	2,457,161
	100	2,477,954	121,359	2,599,313	2,475,237	121,359	2,596,596
0.8	200	2,477,954	121,430	2,599,384	2,467,170	121,437	2,588,607
	300	2,477,955	121,547	2,599,502	2,453,997	121,562	2,575,559
	100	2,624,997	121,127	2,746,124	2,623,288	121,129	2,744,417
0.9	200	2,624,997	121,198	2,746,195	2,618,239	121,202	2,739,441
	300	2,625,003	121,313	2,746,316	2,610,071	121,322	2,731,393
	100	2,855,393	120,768	2,976,161	2,855,393	120,768	2,976,161
1.0	200	2,854,559	120,819	2,975,378	2,854,559	120,819	2,975,378
	300	2,853,160	120,887	2,974,047	2,853,160	120,887	2,974,047

increase in expected railroad profit exceeds the slight decrease in expected shipper profits.

The decrease in expected shipper profit is due to a very slight increase in the tariff rate as shown in Table 4.14. The railroad obtains the shipper information after making its tariff decision but before its fleet size decision. Hence, the tariff is relatively unaffected by the sharing of information.

The increase in expected railroad profits and total welfare is due mainly to the railroad making a more informed fleet size decisions. Tables 4.15-4.18 present the railroad's conventional service capacity under symmetric and asymmetric information. The capacity level of the railroad at the expected value of z is relatively unchanged between the symmetric and asymmetric cases. However, with the sharing of information the railroad expands its capacity fleet when the shipper salvage value is low and decrease its capacity when the salvage value is high. A low (high) salvage value indicates to the railroad that shipper demand for conventional will be higher (lower) than average.

The monopolist railroad uses the shipper information to increase its expected profits by acquiring a more appropriate capacity level. The more appropriate capacity level reduces the probability of car shortages and decreases the probability of idle rail cars. Expected shipper profit decreases slightly

Table 4.14. The Effect of Symmetric Information on the Pre-Staggers Tariff Rate, C=$3000.

λ	ϵ	Symmetric Tariff	Asymmetric Tariff
0.0	100	4,803	4,802
	200	4,803	4,797
	300	4,803	4,790
0.1	100	4,818	4,817
	200	4,818	4,813
	300	4,818	4,806
0.2	100	4,834	4,833
	200	4,834	4,829
	300	4,834	4,823
0.3	100	4,851	4,850
	200	4,851	4,846
	300	4,851	4,841
0.4	100	4,869	4,868
	200	4,869	4,865
	300	4,869	4,860
0.5	100	4,888	4,887
	200	4,888	4,885
	300	4,888	4,881
0.6	100	4,909	4,908
	200	4,909	4,096
	300	4,909	4,903
0.7	100	4,932	4,931
	200	4,932	4,929
	300	4,932	4,927
0.8	100	4,955	4,955
	200	4,955	4,954
	300	4,955	4,952
0.9	100	4,979	4,979
	200	4,979	4,979
	300	4,980	4,978
1.0	100	5,009	5,009
	200	5,011	5,011
	300	5,014	5,014

and total welfare increases with the sharing of information. To persuade shippers to share their grain market information, the railroad could agree to transfer a portion of its increased welfare to shippers.

Total welfare with symmetric information is lower than under perfect information. If the monopolist railroad knows the value of z and p before making its tariff and fleet decisions, welfare losses due to car shortages and idle equipment is zero. The monopolist railroad, however, will use the additional information and increase its tariff rate in order to maximize its expected profits.

Table 4.15. The Effect of Symmetric Information on Railroad Capacity under the Pre-Staggers Car Allocation System for λ=0.0, 0.1, and 0.2.

			Symmetric Information	Asymmetric Information
λ	ϵ	z	Conventional Capacity	Conventional Capacity
0.0	100	5850	1,483.88	1,412.22
		5950	1,412.45	
		6050	1,341.03	
	200	5750	1,555.31	1,411.41
		5950	1,412.45	
		6150	1,269.60	
	300	5650	1,626.74	1,409.91
		5950	1,412.45	
		6250	1,198.17	
0.1	100	5850	1,508.01	1,436.51
		5950	1,436.58	
		6050	1,365.15	
	200	5750	1,579.43	1,436.19
		5950	1,436.58	
		6150	1,293.72	
	300	5650	1,650.86	1,435.59
		5950	1,436.58	
		6250	1,222.29	
0.2	100	5850	1,535.58	1,464.27
		5950	1,464.15	
		6050	1,392.72	
	200	5750	1,607.01	1,464.60
		5950	1,464.15	
		6150	1,321.29	
	300	5650	1,678.44	1,464.99
		5950	1,464.15	
		6250	1,249.87	

Table 4.16. The Effect of Symmetric Information on Railroad Capacity under the Pre-Staggers Car Allocation System for λ=0.3, 0.4, and 0.5.

λ	ϵ	z	Symmetric Information	Asymmetric Information
			Conventional Capacity	Conventional Capacity
0.3	100	5850	1,567.54	1,496.46
		5950	1,496.11	
		6050	1,424.68	
	200	5750	1,638.97	1,497.47
		5950	1,496.11	
		6150	1,353.25	
	300	5650	1,710.40	1,499.09
		5950	1,496.11	
		6250	1,281.83	
0.4	100	5850	1,605.26	1,534.52
		5950	1,533.83	
		6050	1,462.40	
	200	5750	1,676.68	1,536.36
		5950	1,533.83	
		6150	1,390.97	
	300	5650	1,748.11	1,539.30
		5950	1,533.83	
		6250	1,319.54	
0.5	100	5850	1,650.98	1,580.51
		5950	1,579.55	
		6050	1,508.12	
	200	5750	1,722.41	1,583.34
		5950	1,579.55	
		6150	1,436.70	
	300	5650	1,793.84	1,587.99
		5950	1,579.55	
		6250	1,365.27	

Table 4.17. The Effect of Symmetric Information on Railroad Capacity under the Pre-Staggers Car Allocation System for $\lambda=0.6$, 0.7, and 0.8.

			Symmetric Information	Asymmetric Information
λ	ϵ	z	Conventional Capacity	Conventional Capacity
0.6	100	5850	1,708.01	1,637.94
		5950	1,636.58	
		6050	1,565.15	
	200	5750	1,779.43	1,641.96
		5950	1,636.58	
		6150	1,493.72	
	300	5650	1,850.86	1,648.73
		5950	1,636.58	
		6250	1,422.29	
0.7	100	5850	1,782.62	1,713.09
		5950	1,711.19	
		6050	1,639.76	
	200	5750	1,854.05	1,718.75
		5950	1,711.19	
		6150	1,568.33	
	300	5650	1,925.47	1,728.20
		5950	1,711.19	
		6250	1,496.90	
0.8	100	5850	1,888.30	1,819.46
		5950	1,816.87	
		6050	1,745.44	
	200	5750	1,959.73	1,827.39
		5950	1,816.87	
		6150	1,674.02	
	300	5650	2,301.08	1,840.47
		5950	1,816.79	
		6250	1,602.51	

Table 4.18. The Effect of Symmetric Information on Railroad Capacity under the Pre-Staggers Car Allocation System for λ=0.9.

			Symmetric Information	Asymmetric Information
λ	ε	z	Conventional Capacity	Conventional Capacity
		5850	2,063.53	
	100	5950	1,992.10	1,955.99
		6050	1,920.67	
		5750	2,134.96	
0.9	200	5950	1,992.10	2,007.42
		6150	1,849.24	
		5650	2,206.22	
	300	5950	1,991.94	2,026.28
		6250	1,777.65	

CHAPTER 5

GUARANTEED SERVICE

In 1987 railroads began offering guaranteed service to shippers as an alternative to conventional tariff service. The purpose of this chapter is examine the affects of guaranteed service on the welfare of the railroad and shippers.

The analysis assumes a characteristic of the Union Pacific Railroad grain car allocation system in that the railroad charges the same transportation rate for guaranteed service and conventional tariff service. Figure 5.1 shows the sequence of railroad and shipper decisions under guaranteed service.

In this chapter, the review of the relevant literature on the public utilities dilemma of choosing price and capacity before knowing demand is extended. Second, the aspects surrounding the shipper choices of conventional service and guaranteed service are examined. Similarly, the issues facing a railroad offering both conventional tariff service and guaranteed service is discussed. Next, three ways guaranteed service affects the welfare of shippers and railroad are revealed. Each effect is isolated and studied, i.e., the effect of the shipper externality, the informational effect,

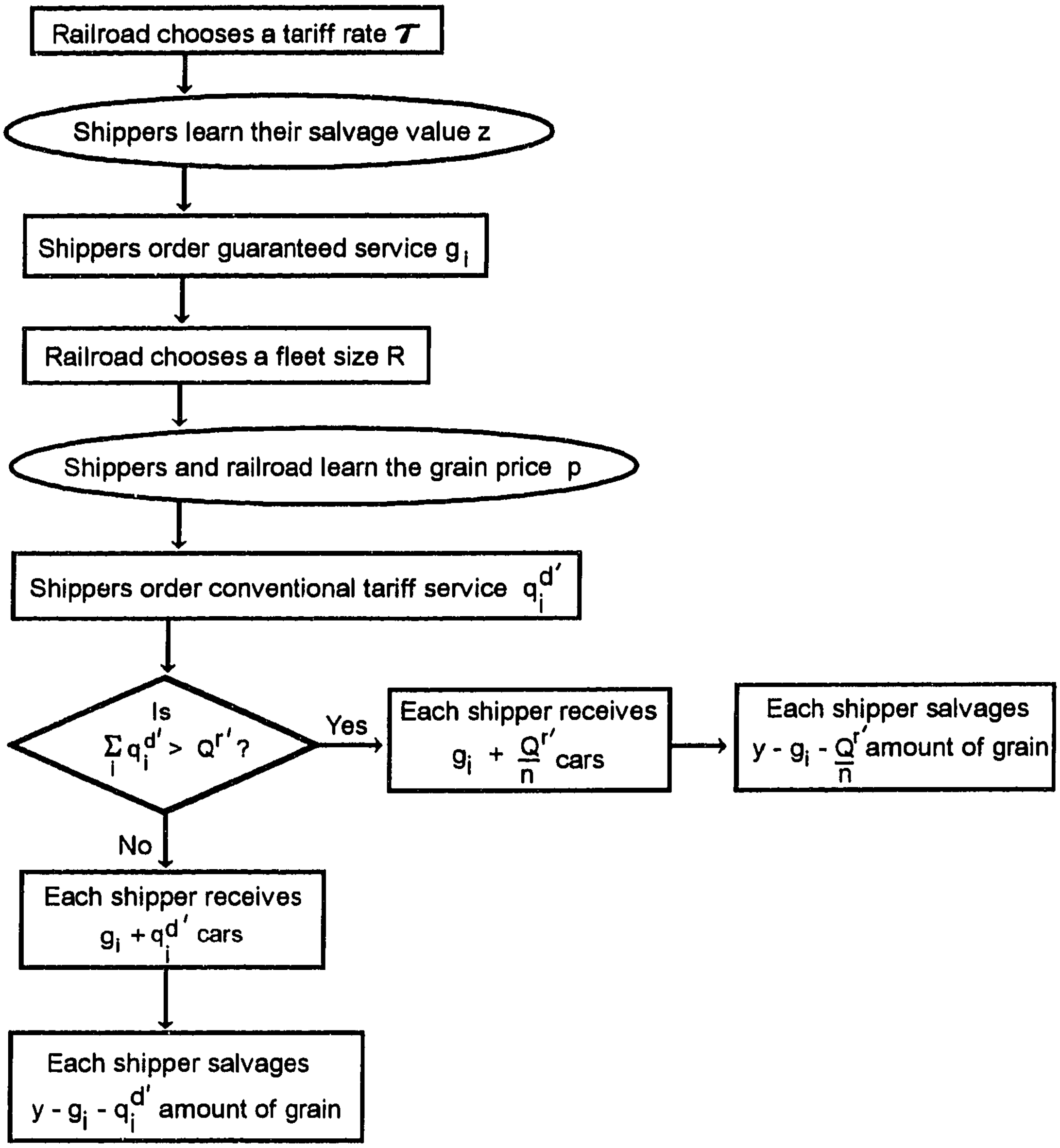


Figure 5.1. Sequence of decisions with guaranteed service.

and railcar productivity effect. Finally, the effects of limiting the amount of guaranteed service offered to shippers is examined.

Literature Review

Firms choosing price and capacity before knowing demand creates periods of large surpluses and shortages. One method to alleviate the adverse effects of shortages is for a regulatory agency to impose a reliability of service constraint. The firm when choosing price and capacity must adhere to the exogenously imposed constraint. The effect of a reliability (or quality) of service standard on the pricing and investment behavior of a firm has been investigated [Meyer, 1975]. The reliability of service constraint states that the probability of demand exceeding capacity must be less than or equal to some exogenously specified level set by a regulatory agency. Each customer faces the same service quality and price from the utility. Optimal prices are higher, choking off demand and allowing the reliability constraint to be met. Also, the optimal choice of such reliability constraints for either a welfare maximizing or for a regulated profit maximizing monopolist has been studied [Crew and Kleindorfer, 1978].

The reliability of service approach assumes customers can be costlessly ranked according to their willingness to pay. In practice a firm's ability to rank customers according to their willingness to pay is very limited. Interruptible service establishes an order to ration service to customers during periods of excess demand. The monopolist or utility divides customers into classes based on some observable characteristics. For example, a utility may divide its customers into residential, commercial, and industrial classes. The price charged to each class and the order in which service is interrupted is decided by the utility. When demand exceeds capacity, the group with the lowest reliability of service is cut off first [Tschirhart and Jen 1979].

An alternative framework of interruptible service allows customers rather than the utility to choose their ranking. In the analysis, customers are free to give the utility the right to cut their supply when demand exceeds supply in return for a reduction in their electricity rates [Marchland, 1973].

Another framework, called ripple control service, the utility chooses price and capacity before knowing demand [Dansby, 1979]. All customers, however, are limited to a prespecified level of usage chosen by the utility whenever demand exceeds capacity. The probability of being interrupted is the same for all customers.

A model similar to interruptible service where consumers ration themselves, called the self-rationing model, was developed [Panzar and Sibley, 1978]. The utility chooses a usage price and a fuse price to maximize social welfare. The utility must choose a capacity to meet the total demanded by consumers. Consumers reserve a particular level of capacity before the state of demand is known at a stated fuse price. The consumer may not use all of its reserved capacity but they cannot use more capacity than their reserved level. For each unit of capacity actually used, the consumer pays the additional usage price. The optimal usage price is equal to the constant marginal operating costs, b, and the fuse price (the price to reserve capacity) is equal to the constant marginal capacity costs, B. Hence, the utility makes zero profit in all states of demand. No specific assumptions were made concerning how uncertainty enters the demand function. The previous results of zero profit were dependent on the assumptions of additive or multiplicative uncertainty and the type of the rationing scheme imposed.

This self rationing scheme generally leads to a lower level of welfare compared to the costless ex post rationing to those with the greatest willingness to pay. The model does not allow consumers to trade capacity rights. Hence, if one consumer wants more than its reserved capacity and another consumer uses less, welfare improvement is lost. Similarly, if all consumers want more than their reserved amount, welfare improvement could be made, since the marginal willingness to pay is not equated across consumers. However, if consumers are similar, the self rationing approach leads to optimal welfare levels.

The self rationing model was later extended in two ways. First, individual customer demands were allowed to vary within the billing period and customer demands were assumed to be imperfectly correlated rather than identically correlated [Schwarz and Taylor, 1987]. Second, the usage and fuse prices were allowed to be nonlinear rather than linear [Oren et al., 1985].

A similar approach to interruptible service and self-rationing is the literature on priority pricing [Chao and Wilson, 1987; Wilson, 1989 and 1991; Tse, 1989]. The monopolist or utility states a price and reliability of service for a menu of service offerings. Consumers then select the type of service most desired. The firm ranks customers according to the reliability levels chosen. Available capacity is first allocated to the highest reliability class and the remaining capacity is allocated to the second highest priority class. This continues until the entire capacity is used or all customers are served.

Consumers are offered a more diverse set of products differentiated by the quality of service. Consumers are able to choose the price and reliability level is best suited for them. Consumers with high valuations for the service pay the higher price for better reliability. Thus, in periods of shortages, the available supply is rationed to the consumers with the highest evaluation of the service (i.e., those with the greater costs of interruption) satisfying the condition for allocative efficiency.

Priority service can also be interpreted as insurance against supply shortages. Consumers pay a higher premium for a greater reliability of service and a lower probability of receiving interrupted service.

Priority service gives the supplier firm an informational benefit by allowing consumers to reveal their willingness to pay for quality improvements provided by additional capacity. The information aids the firm in capacity planning. The greater the number of customers acquiring higher priority service, the greater the incentive to expand capacity. Customers are paying higher prices causing the marginal revenue of used capacity to increase.

Recently, the airline use of advanced purchase discounts has been studied [Gale and Holmes, 1992 and 1993]. The airline industry is characterized by a peak demand that faces capacity constraints and an off peak period where capacity is not a factor. In order for the airline to increase output, it must divert demand from the peak period to the off peak period. The purpose of the advanced purchase discounts is to shift demand from the peak to the off-peak period. Differing qualities of service is not an issue.

The research presented in this chapter is related more to priority pricing literature than to the literature on advance purchase discounts. There are two types of rail service - guaranteed and conventional tariff service. Guaranteed service is never interrupted and therefore has the highest possible quality of service. Conventional tariff service is spot service and is the lower priority service. The analysis allows customers to purchase various quantities of both types of service.

The sequence of decisions in which the services are purchased characterizes the railroad industry. The higher priority service is purchased with customers uncertain as to its value, while conventional service is acquired with full information. Private information is passed from customers to the firm when purchasing guaranteed service. The informational gain allows the firm to better predict the demand for conventional service. Finally, the analysis allows different production technologies to be used for the two types of service.

Shipper Environment

This section examines the shipper choices of conventional tariff service and guaranteed service. First, the shippers choice of conventional tariff service given their precommitted quantity of guaranteed service is studied. In Figure 5.1, shippers choose guaranteed service after learning the value of their salvage value z but before learning the price of grain. Shippers must use the guaranteed service previously ordered regardless of the realized grain price. The choice of conventional tariff service comes after learning the price of grain. Therefore, the shipper's demand for guaranteed service affects its conventional tariff service demand.

Second, the affects of guaranteed service on the ration quantity of conventional service received by a shipper during car shortages is investigated. During car shortages, each shipper receives an equal amount of the railroad's conventional service capacity called the ration quantity. The railroad fleet is used to produce either conventional service or guaranteed service. Therefore, for a given fleet size, as the aggregate amount of guaranteed service changes, the railroad conventional service capacity and the ration quantity change.

Third, shippers purchase guaranteed service based on their expectations of having their conventional tariff service car order rationed. Hence, shipper beliefs regarding the possibility of having their conventional tariff service car order rationed is also examined.

Finally, the shipper choice of guaranteed service is characterized. Shippers order guaranteed service to insure themselves of moving grain by rail when the marginal revenue from selling grain delivered by rail is more attractive than the salvage value.

Shipper Choice of Conventional Tariff Service

Shippers have the same complete information as under the pre-Staggers car allocation system when deciding the amount of conventional service to order. Shippers know their grain salvage value, storage costs, the rail rate, the railroad's conventional service capacity, and the current price of grain. Shippers also know the amount of guaranteed service they previously purchased.

Shippers are assumed to know if their car order for conventional service will be rationed and the ration quantity they will receive from the railroad. Hence, shippers know they are unable to influence the amount of conventional service received by over-ordering rail cars. Consequently, shippers order only the desired amount of conventional service.

The shipper profit optimization problem for the amount of conventional service to order is the same as under the pre-Staggers car allocation system except the shipper must load all the guaranteed cars previously acquired as shown in equation 5.1.

$$\max_{q_i^{d'}} s\pi_i(p,t,z) = (p-t)(g_i+q_i^{d'}) + z_i(y-g_i-q_i^{d'}) - v(y-g_i-q_i^{d'})^2 \qquad (5.1)$$

where:

g_i= guaranteed service previously ordered by the ith shipper.

$q_i^{d'}$= conventional service ordered by shipper i.

p= grain price.

t= railroad tariff rate.

z= shipper grain salvage value.

v= shipper storage cost parameter.

y= initial shipper grain inventory.

$s\pi_i$= ith shipper profit.

The first order condition, shown in equation 5.2, implies the shipper equates the marginal revenue from selling grain delivered by conventional rail service [p-t] to its opportunity cost which is the marginal revenue from salvaging grain.

$$[p-t] - [z-2v(y-g_i-q_i^{d'})] = 0 \qquad (5.2)$$

Guaranteed service causes the opportunity cost of selling grain delivered by conventional rail service to increase from $[z-2v(y-q_i^{d'})]$ to $[z-(2v(y-g_i-q_i^{d'})]$ as shown by the shift from MC_{Rail} to MC'_{Rail} in Figure 5.2. The increase is due to the shipper previously acquiring g_i amount of guaranteed rail service.

The ith shipper demand for conventional service with and

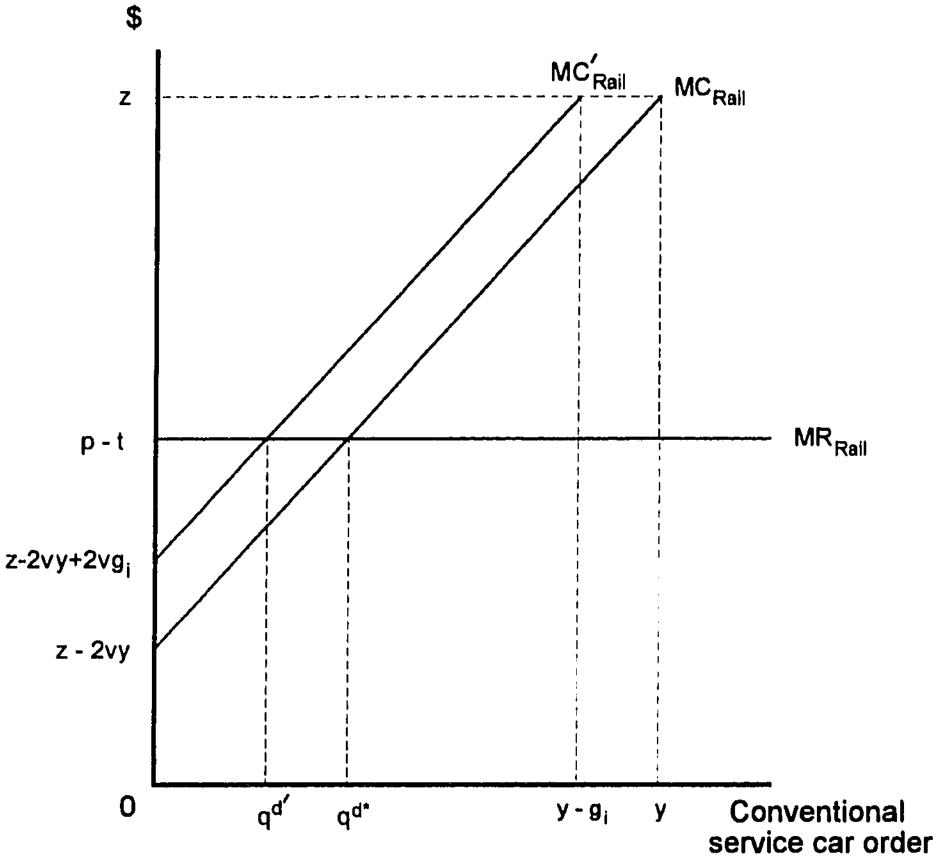


Figure 5.2. Shipper optimal choice of conventional service with and without guaranteed service.

without guaranteed service as a function of the marginal revenue from selling grain delivered by conventional rail service is shown in Figure 5.3. The shipper's choice of conventional service given g_i amount of guaranteed service was previously acquired is denoted as $q_i^{d'}$. The shippers conventional service car order without guaranteed service is denoted as q^d. The ith shipper demand for conventional rail service is shifted to the left by the amount of guaranteed service previously acquired. Hence, the ith shipper demand for conventional service having precommitted to guaranteed service is written as $q^{d'}=\max[0,q^d-g_i]$.

A shipper previously acquiring guaranteed service decreases its conventional service car order by g_i when the marginal revenue from selling grain delivered by conventional rail service, $[p-t]$, is above $[z-2v(y-g_i)]$. The shipper does not order conventional service when the marginal revenue from selling grain delivered by conventional rail service is below $[z-2v(y-g_i)]$. In this region, the marginal revenue from selling grain delivered by conventional rail service is less than or equal to the marginal revenue from salvaging the last bushel of uncommitted grain. The shipper only uses its guaranteed service to move grain by rail. Finally, if the marginal revenue from selling grain delivered by conventional rail service is greater than or equal to the marginal revenue from salvaging its first bushel of uncommitted grain (z), the

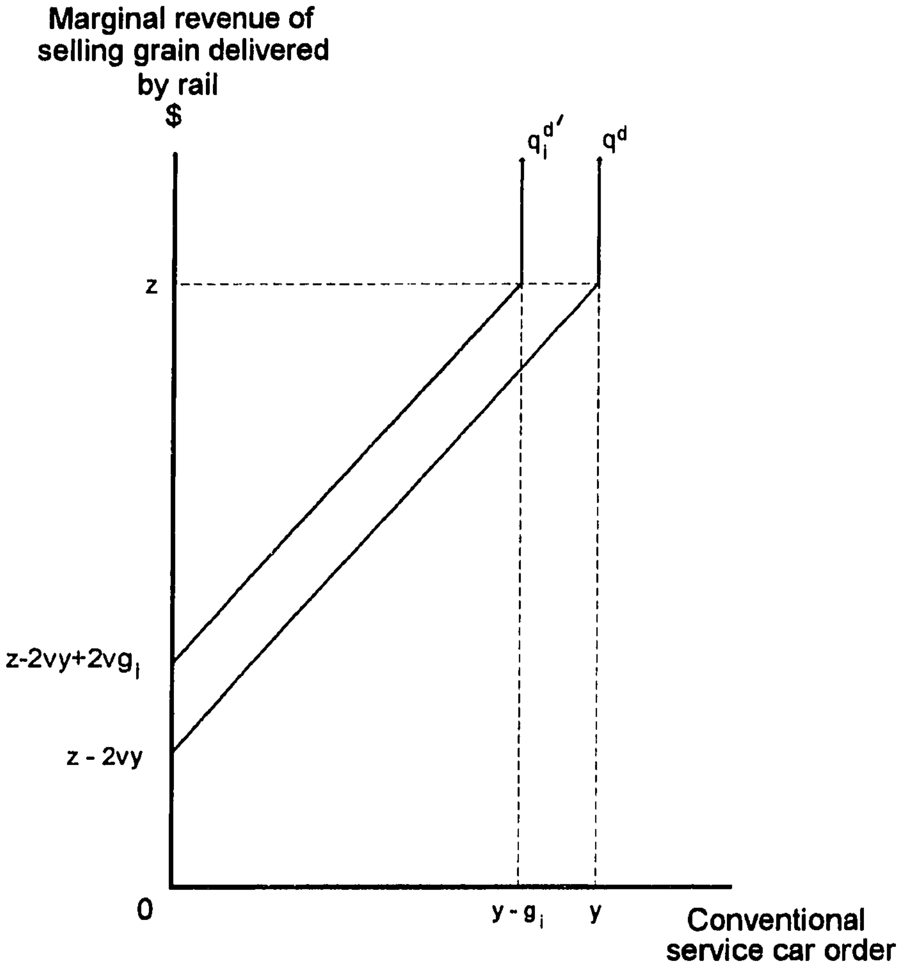


Figure 5.3. Shipper demand for conventional service with and without guaranteed service.

shipper desires to use conventional rail service to move its entire uncommitted grain inventory.

The shipper's demand for conventional rail service under a car allocation system with guaranteed service is shown in equation 5.3.

$$
\begin{aligned}
q_i^{d'} &= 0 && \text{if } p-t \leq z-2vy+2vg_i \\
&= \frac{p-t-z+2v(y-g_i)}{2v} && \text{if } z-2vy+2vg_i \leq p-t \leq z \\
&= y-g_i && \text{if } p-t \geq z
\end{aligned}
\tag{5.3}
$$

Using the notation from the previous chapter, $\tau=(t/2v)$ and $\rho=(p-z)/2v$, the shipper demand for conventional service is rewritten as equation 5.4.

$$
\begin{aligned}
&q_i^{d'} = \min[\max[\rho-\tau+y-g_i, 0], y-g_i] \\
&\text{where;} \\
&q_i^{d'} = 0 \quad \text{if } \rho < \tau-y+g_i \\
&\quad = \rho-\tau+y-g_i \quad \text{if } \rho \in [\tau-y+g_i, \tau] \\
&\quad = y-g_i \quad \text{if } \rho > \tau
\end{aligned}
\tag{5.4}
$$

The aggregate demand for conventional service, $Q^{d'}$, is equal to the sum of the individual shipper demand curves. The aggregate demand for conventional service, $Q^{d'}$, can be expressed as the aggregate conventional service demand under the pre-Staggers system minus the aggregate quantity of guaranteed service ordered as shown in equation 5.5.

$$Q^{d'}(\rho,\tau,G)=\sum_{i=1}^{n} q_i^{d'}(\rho,\tau,g_i) \\ =\sum_{i=1}^{n} \max[0,q^{d}(\rho,\tau)-g_i] \tag{5.5}$$

where:

G=aggregate quantity of guaranteed service ordered.

Conventional Service Received by Shippers

The conventional service capacity of the railroad offering guaranteed service is represented by $Q^{r'}$. A conventional service car shortage (surplus) occurs when the aggregate demand for conventional service is greater (less) than the conventional service capacity of the railroad. During a car surplus, the shipper receives all of the conventional service it orders. However, during car shortages, each shipper receives the ration quantity of conventional rail service, denoted as $Q^{r'}/n$. Equation 5.6 shows the amount of conventional service a shipper receives from a railroad offering guaranteed service.

$$k_i'=\min\left[q_i^{d'}(\rho,\tau,g_i),\frac{Q^{r'}}{n}\right] \tag{5.6}$$

where:

k'_i= conventional service the ith shipper receives from a railroad offering guaranteed service.

$q_i^{d'}$= conventional service ordered by the ith shipper.

$Q^{r'}/n$= ration quantity of conventional rail service.

Shipper Rationing Beliefs

Shippers order guaranteed service to insure against the possibility of having their conventional car service orders rationed. Shippers are assumed to believe they are small enough relative to the aggregate that they do not have a significant affect on the aggregate demand for guaranteed service. When ordering guaranteed service shippers know the rail rate, the probability distribution of the future grain price, their salvage value z, and their storage costs.

The salvage value z reveals to the shipper both the aggregate demand for guaranteed service and the railroad fleet size. First, a low salvage value implies shippers place a high value on rail transportation, indicating the possibility of a large demand for conventional service when the price of grain is revealed. Shippers believe there exists a large probability that conventional service will be rationed. Consequently, the aggregate demand for guaranteed service increases. The aggregate amount of guaranteed service desired by shippers is assumed to be a monotonically decreasing function of z. For example, in Figure 5.4, if the salvage value is z^a, the aggregate guaranteed service orders will be G^a. But, if the salvage value falls to z^b, the value of rail service rises and shippers increase the aggregate quantity of guaranteed service orders to G^b.

Second, the railroad determines fleet size based on the

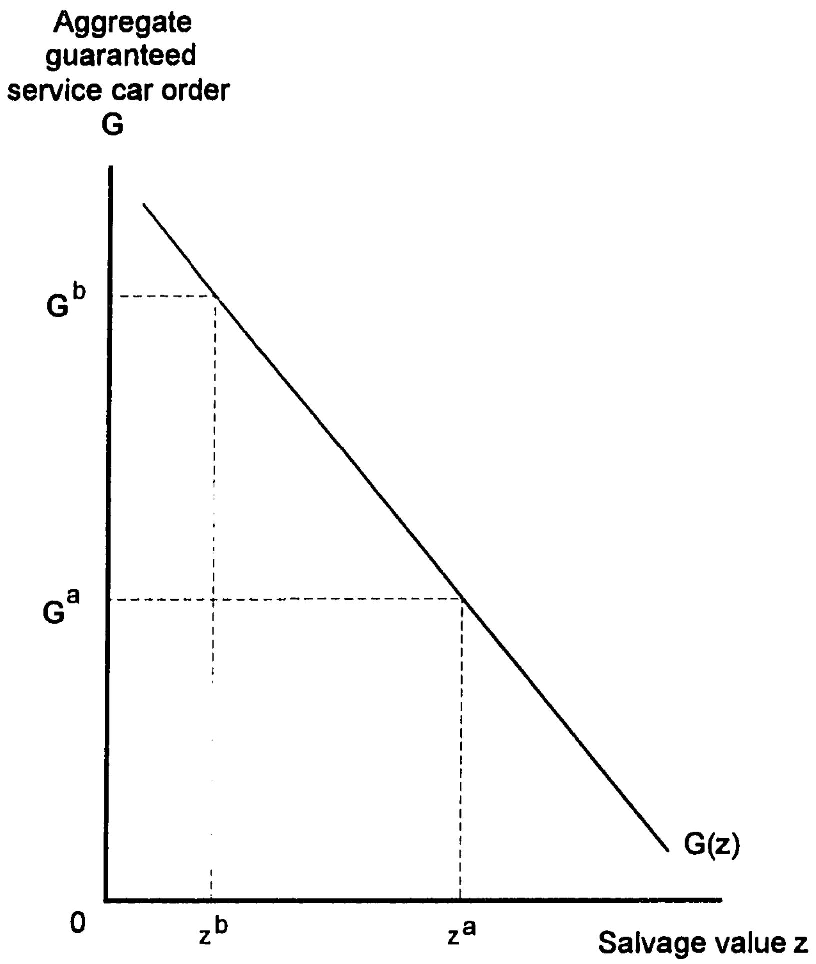


Figure 5.4. The relationship between the salvage value z and aggregate guaranteed service car orders G.

aggregate amount of guaranteed service ordered. If the railroad receives a large number of guaranteed service orders, the railroad knows shippers do not have an attractive alternative to rail service and expect a larger than average demand for conventional service. The railroad accumulates a larger fleet of rail cars to serve the larger than average expected conventional service demand. Hence, railroad fleet size is a monotonically increasing function of the aggregate amount of guaranteed service ordered as shown in Figure 5.5. If shippers order G^a amount of guaranteed service the railroad responds with a fleet of R^a. But if the amount of guaranteed service ordered rises to G^b, the railroad increases its fleet to R^b. Shippers are therefore assumed to know the railroad's fleet response to the aggregate amount of guaranteed service ordered.

The shipper upon learning its salvage value z, infers both the aggregate demand for guaranteed service and the railroad fleet size. Therefore, the shipper is able to determine the probability of being rationed.

The probability of conventional service being rationed is equal to the probability of the grain price being above some critical level. Let the price, p_i^r, denote the critical price of grain given τ and z at which the ith shipper conventional service demand is equal to the ration quantity of conventional service. Grain prices below (above) the critical price, p_i^r,

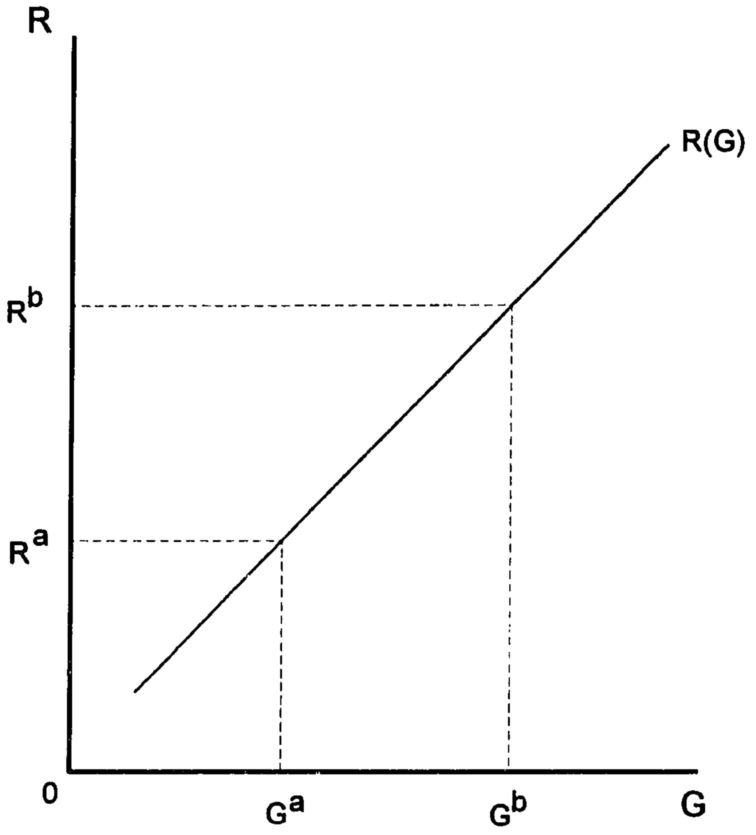


Figure 5.5. The relationship between fleet size R and aggregate guaranteed service car order G.

indicate shippers (do not) receive their entire conventional service car order.

Let $\phi(Q^{r'}/n)$ denote the shipper's subjective probability that its demand for conventional service is less than or equal to its rationed share of the conventional service capacity. Hence, $1-\phi(Q^{r'}/n)$ denotes the shipper's subjective probability its conventional service car order will be rationed as shown in equation 5.7.

$$
\begin{aligned}
1-\phi\left(\frac{Q^{r'}}{n}\right) &= \text{prob}\left(q_i^{d'} \geq \frac{Q^{r'}}{n}\right) \\
&= \text{prob}\left(\frac{p-t-z+2v(y-g_i)}{2v} \geq \frac{Q^{r'}}{n}\right) \\
&= \text{prob}\left(p \geq z+2v\tau-2vy+2vg_i+\frac{2v}{n}[Q^{r'}]\right) \qquad (5.7) \\
&= \text{prob}(p \geq p_i^{r}) \\
&= \int_{p_i^{r}}^{\infty} m(p)\,dp
\end{aligned}
$$

where:

$t=2v\tau=$tariff rate.

$p_i^r=$ grain price at which the ith shipper demand for conventional service equals its ration quantity.

$m(p)=$grain price density function.

Shipper Choice of Guaranteed Service

Shipper profit depends on the amount of guaranteed and conventional service received from the railroad. Recall k'_i denotes the total amount of conventional service the ith shipper receives from the railroad and g_i denotes the amount of guaranteed service the ith shipper orders. The railroad is assumed to fill all guaranteed car orders. Therefore, the ith shipper receives $g_i+k'_i$ amount of rail service. The profit of the ith shipper, $s\pi_i$, from shipping $g_i+k'_i$ by rail and salvaging the remaining $y-g_i-k'_i$ grain is shown in equation 5.8.

$$s\pi_i=(p-2v\tau)(g_i+k'_i)+z(y-g_i-k'_i)-v(y-g_i-k'_i)^2 \qquad (5.8)$$

Shippers, however, choose guaranteed service before knowing the price of grain p. Hence, shippers choose the amount of guaranteed service which maximizes their expected profits as shown in equation 5.9.

$$\begin{aligned}&\mathrm{Max}_{g_i}\ E_p\left[(p-2v\tau)(g_i+k'_i)+z(y-g_i-k'_i)-v(y-g_i-k'_i)^2\right]\\&\text{where}\\&k'_i=\min\left[q_i^{d'}(\rho,\tau,g_i),\frac{Q^{r'}}{n}\right] \qquad (5.9)\\&\rho=\frac{p-z}{2v}\end{aligned}$$

The first order condition, equation 5.10, states that shippers equate the marginal expected benefits from guaranteed service during car shortages to the marginal expected loss from using guaranteed service when salvaging grain is a more attractive alternative.

$$E_p\left[[p-2v\tau-z+2v(y-g_i-k'_i)]\left(1+\frac{\partial k'_i}{\partial g_i}\right)\right]=0 \tag{5.10}$$

where

$$\frac{\partial k_i}{\partial g_i}=0 \text{ if } k'_i=0 \text{ or } \frac{Q^{r'}}{n}$$

$$=-1 \text{ otherwise}$$

The amount of conventional service received by a shipper is zero ($k'_i=0$) when the shipper fails to order conventional service. If the grain price is below p_i^o, the shipper will not order conventional service. In this case, the amount of conventional service received by the shipper is unaffected by its choice of guaranteed service.

Also, shippers believe the ration quantity of conventional service is unaffected by the size of its guaranteed service order. If the grain price is above p_i^r, the shipper will receive its ration quantity. Hence, during car shortages, shippers believe the amount of conventional service it receives ($k'_i=Q^{r'}/n$) is unaffected by its choice of guaranteed service.

If the grain price is the interval $[p_i^o,p_i^r]$, an increase in the guaranteed service order decreases the conventional service order by the same amount. Previously, Figure 5.3 showed the conventional service order decreasing by the guaranteed service order. The first order condition is rewritten as equation 5.11.

$$\int_{0}^{p_i^o}[p-p_i^o]m(p)\,dp+\int_{p_i^r}^{\infty}[p-p_i^r]m(p)\,dp=0$$

where (5.11)

$$p_i^o=z+2v\tau-2vy+2vg_i$$

$$p_i^r=z+2v\tau-2vy+2vg_i+2v\left[\frac{Q^{r'}}{n}\right]$$

Shippers must use all the guaranteed service ordered. The cost of guaranteed service to a shipper is the reduced flexibility to market its grain once the price of grain is revealed. The shipper prefers to salvage grain when the grain price falls below p_i^o. The shipper, however, must use the guaranteed rail service which reduces its expected profits.

Conventional service car shortages occur when the price of grain exceeds p_i^r. During car shortages, shippers receive their ration quantity plus the amount of guaranteed service ordered. Shippers believe the size of their guaranteed car order has no affect on their ration quantity of conventional tariff service. Hence, shippers believe guaranteed service increases the amount of grain it moves by rail during conventional car service shortages, thereby increasing its expected profits.

Railroad Environment

This section discusses the conventional service capacity of the railroad, the optimal production of conventional service, and the railroad's beliefs about conventional service demand.

Conventional Service Capacity

The railroad fleet is divided into the production of guaranteed service and the production of conventional service. The number of cars used to produce guaranteed service is equal to the guaranteed service shippers previously ordered divided by the number of trips a rail car in guaranteed service completes. The remaining cars are used in the production of conventional service. The conventional service capacity of the railroad is defined as the conventional service fleet multiplied by the number of trips a car in conventional service completes. Equation 5.12 shows the conventional service capacity, $Q^{r'}$, of the railroad offering guaranteed service.

$$\begin{aligned} Q^{r'} - \alpha_n \left[R - \frac{G}{\alpha_g} \right] \\ - \alpha_n R - \theta G \end{aligned} \tag{5.12}$$

where:

$Q^{r'}$= railroad conventional service capacity.

R= fleet size.

G= aggregate quantity of guaranteed service car orders.

α_n= marginal product of a rail car in conventional service.

α_g= marginal product of a car in guaranteed service.

$\theta=(\alpha_{ng}/\alpha_g)$= ratio of the marginal product of a car in conventional service to a car in guaranteed service.

The ratio of the marginal product of a car in conventional service to a car in guaranteed service (θ) is assumed to be in the interval (0,1]. If $\theta=1$, there are no rail car productivity gains from guaranteeing service. In this case, the marginal product of a car in conventional service is equal to the marginal product of a car in guaranteed service. However, if $\theta<1$ the railroad is assumed to use the additional information it receives from guaranteed service car orders to increase the productivity of its cars.

Traditionally, conventional service car orders do not provide the railroad with the commodity to be shipped, the corridor the shipment travels, or even if there is a firm intent to move grain. Conventional car service orders could be canceled without penalty up to 15 days prior to the movement (Sperry, 1991). However, with guaranteed service the railroad receives certain information as to the commodity volume to be shipped, the corridor on which it moves, and the future point in time of the movement. The railroad uses this additional information to reduce empty mileage and increase the efficiency of its cars.

Railroad Production of Conventional Service

The production of conventional service by a railroad offering guaranteed service is similar to the production under the pre-Staggers car allocation system discussed in chapter 4. The tariff decision ensures the marginal revenue of a car in conventional service continues to exceed its marginal cost. Hence, the railroad desires an infinite amount of cars in conventional service. However, the cars actually placed into service is constrained either by the railroad conventional service fleet or shipper demand. The conventional service fleet, $R-G/\alpha_g$, is the maximum number of cars available for the production of conventional service, while the minimum number of cars needed to satisfy shipper demand for conventional service is $Q^{d'}/\alpha_n$. Therefore, the optimal number of rail cars placed in conventional service is denoted as $R_n^{*'}$ and is equal to $\min[R-G/\alpha_g,Q^{d'}/\alpha_n]$.

Railroad Subjective Probability When Deciding Fleet Size

In the pre-Staggers car allocation system, the railroad did not know the shipper salvage value z when deciding its fleet size. Figure 5.3 showed the aggregate amount of guaranteed service ordered by shippers (G) to be a monotonically decreasing function of their salvage value z.

Hence, by offering guaranteed service the railroad is assumed to learn the shipper salvage value from the aggregate quantity of guaranteed service car orders. The grain price, however, continues to be unknown to the railroad when deciding its fleet. Equation 5.13 shows the railroad subjective probability that shipper aggregate conventional service demand is less than or equal to W is equivalent to the probability that the grain price is less than or equal to some critical level, p^W.

$$\begin{aligned}\phi(W)=\mathrm{Prob}(Q^{d'}\leq W)=\mathrm{prob}\left(p\leq z+2v\tau-2vy+2vG+\frac{2vW}{n}\right) \\ =\mathrm{prob}(p\leq p^{W})\end{aligned} \qquad (5.13)$$

Similarly, the railroad's subjective probability that aggregate demand for conventional service is zero (W=0) is equal to the probability that the grain price is less than or equal to $p^o(\tau,z)=z+2v\tau-2vy+2vG$. The railroad's subjective probability that its entire fleet will be active ($W=Q^{r'}$) is equal to the probability the grain price is greater than or equal to $p^r(\tau,z,R)=z+2v\tau-2vy+2vG+[2vQ^{r'}(R,G,\theta)]/n$.

Railroad Subjective Probability When Deciding Tariff Rate

The railroad chooses its tariff rate before learning the shipper salvage value z. The railroad knows the probability distributions of the future price of grain p and the shipper salvage value z. The railroad uses the joint probability distribution to form its subjective beliefs regarding aggregate guaranteed service and aggregate conventional service demand.

Full Model of Guaranteed Service

The sequence of decisions between the railroad and shippers under guaranteed service was shown in Figure 5.1. The railroad first chooses the rail rate r. Shippers learn their grain salvage value z. From this information shippers learn the aggregate demand for guaranteed service and the fleet size response of the railroad before ordering guaranteed service. Simultaneously, the railroad extracts the shipper salvage value z from the aggregate guaranteed service orders before choosing its fleet size.

The aforementioned sequence of decisions is altered to simplify the analysis. Figure 5.6 shows the sequence of railroad and shipper decisions used to study guaranteed service. First, the railroad determines the rail rate r. Next, the railroad and shippers learn the shipper salvage value. The railroad simultaneously chooses R with the n shippers choosing their optimal guaranteed service car order g_i. The railroad chooses a fleet given the aggregate guaranteed orders, while shippers order guaranteed service given the railroad fleet. This new sequence of decisions simplifies the analysis and maintains the mathematical and

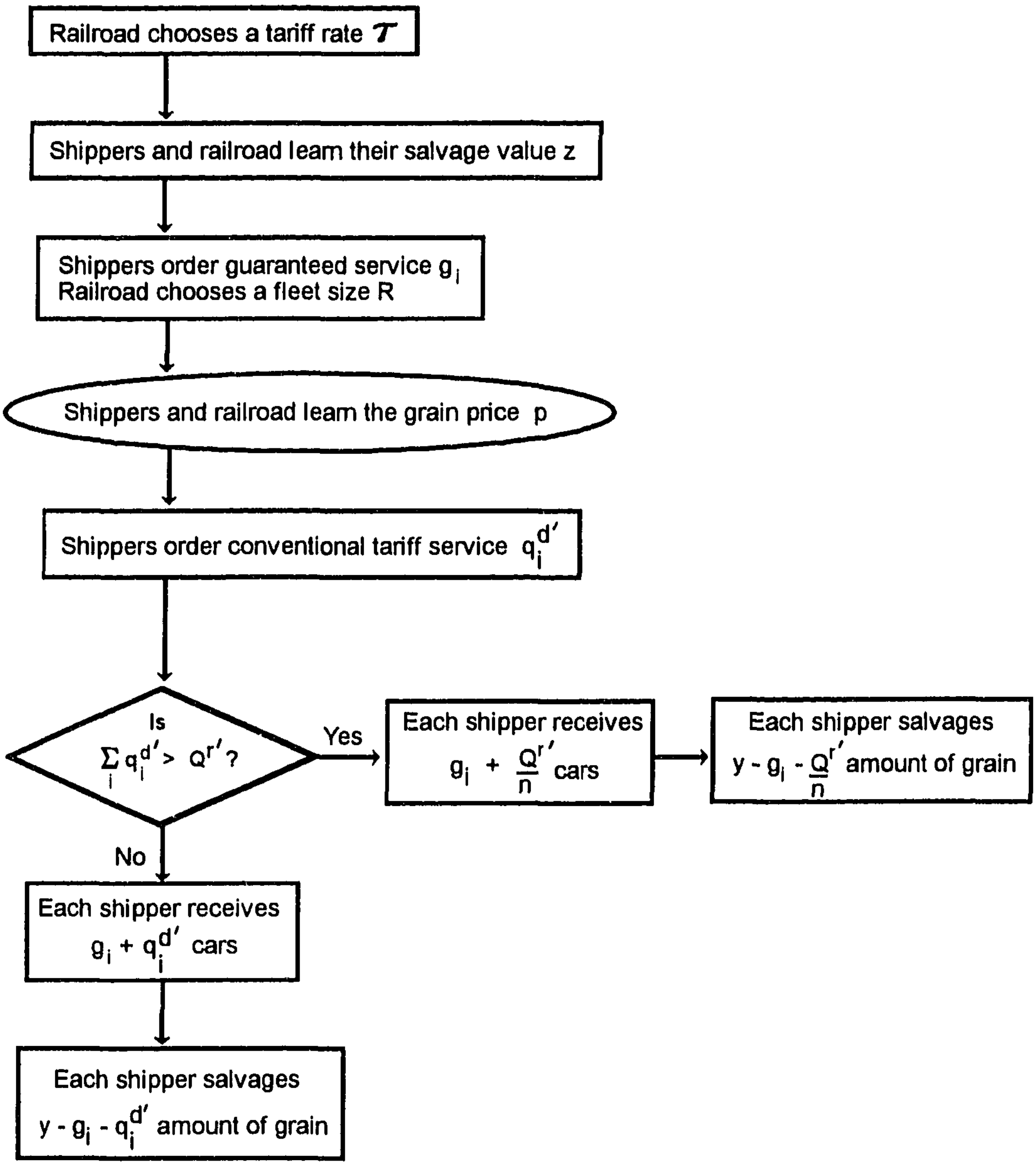


Figure 5.6. Modified sequence of decisions with guaranteed service.

informational structure of the problem.

The shipper's choice of guaranteed service given a fleet size was characterized in equation 5.11. The railroad choice of a fleet which maximizes its expected profits given the aggregate guaranteed car orders is shown in equation 5.14.

$$\begin{aligned} &Max_R\ Err\pi = E_p\Big[(2v\tau-b)\,(\alpha_n R_n^* + G) - BR\Big] \\ &\text{where}\quad R_n^* = \min\left[R - \frac{G}{\alpha_g},\ \frac{Q^{d'}(p,z,\tau)}{\alpha_n}\right] \end{aligned} \qquad (5.14)$$

The first order condition is shown in equation 5.15.

$$\begin{aligned} &\frac{\partial Err\pi}{\partial R} = E_p\left[(2v\tau-b)\,\alpha_n \frac{\partial R_n^*}{\partial R} - B\right] = 0 \\ &\qquad = \int_{p^r(\tau,R,G)}^{\infty} (2v\tau-b)\,\alpha_n m(p)\,dp - B = 0 \\ &\text{where} \\ &\qquad p^r = 2v\tau + z - 2vy + \frac{2v\alpha_n R + 2v(1-\theta)G}{n} \\ &\qquad \theta = \frac{\alpha_n}{\alpha_g} \\ &\qquad m(p) = \text{density function of } p \end{aligned} \qquad (5.15)$$

The fleet is fully utilized if the grain price is at least p^r, while a portion of the fleet remains idle if the grain price is below p^r. If the fleet is fully utilized, adding an extra car increases the number of cars used in conventional rail service, R_n^*, by the extra unit. The marginal revenue of a car used in the production of conventional service is equal to the marginal revenue per trip

$(2v\tau\text{-}b)$ multiplied by the number of trips the extra car completes (α_n). If a portion of the fleet is idle, the marginal revenue of an additional car is zero. In this case, the rail car is not used and the number of cars used in the production of conventional service remains unchanged. The optimizing condition states the railroad equates the expected marginal revenue of a car to the marginal cost of acquiring a car (B).

The railroad optimal fleet condition and the n shipper guaranteed car order conditions are solved simultaneously. The optimal railroad fleet size and the aggregate guaranteed car orders are dependent on the grain salvage value z. The railroad, however, chooses its tariff rate to maximize its expected profits before knowing z as shown in equation 5.16.

$$\begin{aligned} &\mathrm{Max}_{\tau}\ \mathrm{Err}\pi\text{-}E_{p,z}\Big[(2v\tau-b)\big(\alpha_n R_n^{*}+G(\tau,z)\big)-BR\Big] \\ &\text{where}\quad R_n^{*}\text{-}\min\left[R-\frac{G(\tau,z)}{\alpha_g},\ \frac{Q^{d'}(p,z,\tau)}{\alpha_n}\right] \end{aligned} \tag{5.16}$$

The first order condition is stated in equation 5.17.

$$\frac{\partial Err\pi}{\partial\tau}=E_{p,z}\left[2v(\alpha_n R_n^*+G)+\left(\alpha_n\frac{\partial R_n^*}{\partial\tau}+\frac{\partial G}{\partial\tau}\right)(2v\tau-b)\right]=0$$

where

$$\begin{aligned}\frac{\partial R_n^*}{\partial\tau}=&\quad 0 &&\text{if}\quad R_n^*=0\\ =&\ \frac{1}{\alpha_n}\left(\frac{\partial Q^d}{\partial\tau}-\frac{\partial G}{\partial\tau}\right) &&\text{if}\quad R_n^*=\frac{Q^{d'}}{\alpha_n}\\ =&\ -\frac{1}{\alpha_g}\left(\frac{\partial G}{\partial\tau}\right) &&\text{if}\quad R_n^*=R-\frac{G}{\alpha_g}\end{aligned} \tag{5.17}$$

The railroad chooses the tariff rate such that the expected marginal profit with respect to the tariff rate during car shortages plus the expected marginal profit with respect to the tariff rate during car surpluses is equal to zero.

If the grain price is below p^o, the demand for conventional service is zero. Hence, there will not be any cars in the production of conventional service. Any infinitesimal change in the tariff will not change conventional service demand and the number of rail cars in the production of conventional service remains at zero.

If the grain is above p^r, the demand for conventional service exceeds the conventional service fleet. In this case, the entire conventional service fleet is used in the production of conventional service. An infintesimial change in the tariff rate affects the conventional service fleet only through the amount of guaranteed service. The railroad fleet size decision is optimized after the tariff decision. Hence, the change in the fleet size (R) due to a change in the tariff rate is eliminated by the envelope theorem.

If the grain price is in the interval $[p^o, p^r]$, only a portion of the conventional service fleet is used to satisfy conventional service demand. In this interval, guaranteed service demand replaces conventional service demand. The shipper demand for conventional under guaranteed service ($Q^{d'}$) is equal to the shipper demand for conventional service under the pre-Staggers system (Q^d) minus the shipper demand for guaranteed service (G).

The first order condition is rewritten in terms of the individual random variables p and z as shown in equation 5.18.

$$
\begin{aligned}
\frac{\partial Err\pi}{\partial \tau} = & \int_{0}^{p^{o}}\int_{-\infty}^{\infty}\left[2vG(z)+\frac{\partial G}{\partial \tau}(2v\tau-b)\right]\gamma(z)m(p)\,dzdp \\
& +\int_{p^{o}}^{p^{r}}\int_{-\infty}^{\infty}\left[2vQ^{d}(p,z)+(2v\tau-b)\frac{\partial Q^{d}}{\partial \tau}\right]\gamma(z)m(p)\,dzdp \\
& +\int_{p^{r}}^{\infty}\int_{-\infty}^{\infty} 2v[\alpha_{n}R+(1-\theta)G(z)]\gamma(z)m(p)\,dzdp \\
& +\int_{p^{r}}^{\infty}\int_{-\infty}^{\infty}\left[(2v\tau-b)(1-\theta)\frac{\partial G}{\partial \tau}\right]\gamma(z)m(p)\,dzdp=0
\end{aligned}
\qquad (5.18)
$$

where

$$p^{o}=z+2v\tau-2vy+\frac{2vG}{n}$$

$$p^{r}=z+2v\tau-2vy+\frac{2v\alpha_{n}R+(1-\theta)G}{n}$$

$\gamma(z)$ = density function of z

Railroad Decisions With and Without Guaranteed Service

The differences in the optimizing conditions for the railroad with and without guaranteed service will be discussed briefly. The railroad fleet size and tariff decisions under the pre-Staggers system (Chapter 4) are restated in terms of the individual random variables p and z as shown in equations 5.19 and 5.20.

$$
\begin{aligned}
\frac{\partial rr\pi}{\partial R} & = E_{p,z}\left[(2v\tau-b)\alpha_{n}\frac{\partial R_{n}^{*}}{\partial R}-B\right]=0 \\
& =\int_{p^{r}}^{\infty}\int_{-\infty}^{\infty}[(2v\tau-b)\alpha_{n}]\gamma(z)m(p)\,dzdp-B=0
\end{aligned}
\qquad (5.19)
$$

$$\frac{\partial r r \pi}{\partial \tau} = E_{p,z}\left[2v\alpha_n R_n^* + (2v\tau - b)\alpha_n \frac{\partial R_n^*}{\partial \tau}\right] = 0$$

$$= \int_{p^o}^{p^r}\int_{-\infty}^{\infty}\left[2vQ^d(p,z) + (2v\tau - b)\frac{\partial Q^d}{\partial \tau}\right]\gamma(z)m(p)\,dz\,dp$$

$$+ \int_{p^r}^{\infty}\int_{-\infty}^{\infty}[2v\alpha_n R]\gamma(z)m(p)\,dz\,dp = 0 \tag{5.20}$$

where

$p^o = z + 2v\tau - 2vy$

$p^r = z + 2v\tau - 2vy + \frac{2v\alpha_n R}{n}$

The railroad tariff rate optimizing conditions with guaranteed service (equation 5.18) and without guaranteed service (equation 5.20) are different in two ways. First, with guaranteed service the railroad takes into account the responsiveness of guaranteed service demand to changes in the tariff rate. Secondly, railroad capacity and the probability the railroad fleet is fully utilized are affected by the rail car productivity gains associated with guaranteed service.

The railroad fleet size optimizing conditions with guaranteed service (equation 5.15) and without guaranteed service (equation 5.19) are different in three ways. First, with guaranteed service, the railroad learns the salvage value z of the shipper before choosing a fleet size. The uncertainty surrounding the demand for conventional service is reduced through the informational gain associated with guaranteed service. Second, the probability of the fleet size being fully utilized is affected by the improvements made in rail car productivity through guaranteed service. The critical grain price at which a given fleet size is fully utilized increases with rail car productivity gains. If there are no productivity gains from guaranteeing service, $\theta=1$, the critical grain price at which a given fleet size is fully utilized is not changed from guaranteeing service. Finally, any elements of guaranteed service affecting the tariff rate also influences the fleet size.

The following three sections isolate the impacts of guaranteed service on the railroad and shipper welfare. The three effects of guaranteed service are the shipper externality, informational gains, and rail car productivity gains.

Shipper Externality

Each shipper believes it is small enough that when ordering guaranteed service, the aggregate amount of guaranteed service ordered is not significantly affected by its individual guaranteed car order. As a result, shippers believe their ration quantity of conventional tariff service is not affected by their individual guaranteed car orders. In reality, however, a one unit increase in a guaranteed service order does not imply one more unit will be shipped. The increase in an individual guaranteed service order may be provided partly at the expense of conventional service. Moreover, the decrease in conventional service capacity may be large enough to offset the increase in guaranteed service, so the total amount of grain hauled remains unchanged during periods of high rail demand. Shippers fail to realize the affect of their order on the conventional service ration quantity available to themselves and all other shippers.

For example, assume away rail car productivity gains and informational effects from guaranteeing service. Hence, $\theta=1$ and the fleet size remains constant regardless of the amount of guaranteed service ordered. In this case, individual shippers ordering guaranteed service are worse off than under the pre-Staggers program. The shipper believes the expected benefits from ordering guaranteed service is the increased profits during conventional service car shortages. However, in a symmetric equilibrium each shipper increasing g_i does nothing to decrease the aggregate probability of being rationed. In fact, guaranteed service is produced at the expense of conventional service. The expected benefits from ordering guaranteed service is actually zero. The costs of guaranteed service continue to be the flexibility loss in marketing grain once the grain price is revealed. Hence, shipper expected profit actually falls with guaranteed service.

Informational Effects

This section focuses on the informational aspects from guaranteeing service. It has been discussed that railroads through guaranteeing service are able to extract the additional market information held by shippers regarding their grain salvage value z. Consequently, the railroad is better informed about future shipper demand for conventional tariff service and acquires a more suitable fleet.

To examine the informational impact of guaranteeing service, rail car productivity effects are eliminated by assuming $\theta=1$. This section is organized in the following fashion. First, the relationship between the shipper salvage value z and the aggregate guaranteed service order G is investigated. For the numerical example, the relationship will be shown to be linear, so the railroad observing the aggregate amount of guaranteed service ordered learns the shipper salvage value. Next, the railroad fleet size response to the amount of guaranteed service ordered will also be shown to be linear for the numerical example. Hence, shippers upon learning their grain salvage value know the railroad fleet and calculate the probability of having their conventional car service order rationed. Third, the effect of increased demand variability on the tariff rate under guaranteed service ($\theta=1$) is examined. It will be shown for the numerical that guaranteeing service has a stabilizing effect on the tariff rate and expected railroad profits. The stabilization is due to the linearity of expected railroad profits with respect to the shipper salvage value. Fourth, the guaranteed service informational impacts on railroad decisions and total welfare are examined by comparing the guaranteed service model with only informational gains, $\theta=1$, to the pre-Staggers car allocation system. Finally, the effect of λ, distribution of total constant per unit cost of production between operating and capacity costs, on railroad and shipper decisions is studied.

<u>Relationship Between Decisions</u>

Tables 5.1 through 5.7 show the relationship between the shipper salvage value z, the railroad fleet, and the amount of guaranteed service ordered by shippers for a given tariff rate. For example, Table 5.4 shows 1,391.78 units of guaranteed service are purchased when the salvage value is \$5950 and the tariff rate t=\$4862. Equation 5.21 shows the negative linear relationship between salvage value z and the amount of guaranteed service purchased G. The negative relationship shows that the greater the salvage value the less attractive rail service will be. Due to rounding, equation 5.21 does not precisely replicate Table 5.4.

$$G=5{,}641.27-0.7142*z \tag{5.21}$$

Table 5.1. Expected Railroad and Shipper Profit under Guaranteed Service with $0.0 \le \lambda \le 0.3$, t=\$5000, C=\$3000, and $\theta=1$.

Shipper Salvage Parameter z	Railroad Fleet R	Guaranteed Service G	Railroad Expected Profit $Err\pi$	Shipper Expected Profit $Es\pi$
\$5650	1,095.26	1,642.89	\$3,285,706	\$116,394
5750	1,047.64	1,571.46	3,142,851	117,286
5850	1,000.02	1,500.03	2,999,997	118,251
5950	952.40	1,428.60	2,857,143	119,286
6050	904.78	1,357.17	2,714,289	120,393
6150	857.16	1,285.74	2,571,434	121,572
6250	809.54	1,214.31	2,428,580	122,822

Similarly, the railroad fleet size response to the amount of guaranteed service ordered for Table 5.4 is shown in equation 5.22. The greater the amount of guaranteed service ordered, the lower the shipper salvage value, and the greater likelihood of high conventional service demand. Hence, the railroad acquires a large fleet when the aggregate guaranteed service order is large.

$$R=180.4282 + 0.6668*G \tag{5.22}$$

Finally, plugging equation 5.22 into equation 5.21 gives the relationship between railroad fleet size and the shipper salvage value as shown in equation 5.23.

$$R=3942.027 - 0.4762*z \tag{5.23}$$

Table 5.2. Expected Railroad and Shipper Profit under Guaranteed Service with $\lambda=0.4$, $t=\$4800$, $C=\$3000$, and $\theta=1$.

Shipper Salvage Parameter z	Railroad Fleet R	Guaranteed Service G	Railroad Expected Profit Errπ	Shipper Expected Profit Esπ
\$5650	1,190.46	1,785.68	\$3,214,205	\$119,821
5750	1,142.84	1,714.25	3,085,719	120,571
5850	1,095.22	1,642.82	2,957,145	121,392
5950	1,047.60	1,571.39	2,828,570	122,285
6050	999.99	1,499.96	2,699,996	123,249
6150	952.37	1,428.54	2,571,422	124,285
6250	904.75	1,357.11	2,442,819	125,392

Table 5.3. Expected Railroad and Shipper Profit under Guaranteed Service with $\lambda=0.5$, $t=\$4822$, $C=\$3000$, and $\theta=1$.

Shipper Salvage Parameter z	Railroad Fleet R	Guaranteed Service G	Railroad Expected Profit Errπ	Shipper Expected Profit Esπ
\$5650	1,220.08	1,709.85	\$3,134,746	\$119,731
5750	1,172.46	1,638.42	3,004,602	120,496
5850	1,124.84	1,566.99	2,874,458	121,333
5950	1,077.22	1,495.56	2,744,314	122,242
6050	1,029.60	1,424.14	2,614,169	123,222
6150	981.99	1,352.71	2,484,025	124,274
6250	934.37	1,281.28	2,353,881	125,396

Table 5.4. Expected Railroad and Shipper Profit under Guaranteed Service with $\lambda=0.6$, t=$4862, C=$3000, and $\theta=1$.

Shipper Salvage Parameter z	Railroad Fleet R	Guaranteed Service G	Railroad Expected Profit $Er\pi$	Shipper Expected Profit $Es\pi$
$5650	1,251.27	1,606.06	$3,079,997	$119,343
5750	1,203.65	1,534.63	2,947,003	120,137
5850	1,156.09	1,463.20	2,813,999	121,002
5950	1,108.47	1,391.78	2,681,014	121,940
6050	1,060.85	1,320.35	2,548,030	122,948
6150	1,013.18	1,248.92	2,415,026	124,028
6250	965.56	1,177.49	2,282,032	125,179

Table 5.5. Expected Railroad and Shipper Profit under Guaranteed Service with $\lambda=0.7$, t=$4901, C=$3000, and $\theta=1$.

Shipper Salvage Parameter z	Railroad Fleet R	Guaranteed Service G	Railroad Expected Profit $Er\pi$	Shipper Expected Profit $Es\pi$
$5650	1,295.11	1,484.91	$3,051,406	$118,975
5750	1,247.49	1,413.48	2,915,642	119,797
5850	1,199.87	1,342.05	2,779,878	120,690
5950	1,152.25	1,270.63	2,644,113	121,655
6050	1,104.63	1,199.20	2,508,349	122,691
6150	1,057.01	1,127.77	2,372,585	123,799
6250	1,009.39	1,056.34	2,236,820	124,978

Table 5.6. Expected Railroad and Shipper Profit under Guaranteed Service with $\lambda=0.8$, t=\$4938, C=\$3000, and $\theta=1$.

Shipper Salvage Parameter z	Railroad Fleet R	Guaranteed Service G	Railroad Expected Profit $Er\pi$	Shipper Expected Profit $Es\pi$
\$5650	1,360.61	1,333.65	\$3,057,441	\$118,628
5750	1,313.00	1,262.22	2,919,026	119,476
5850	1,265.38	1,190.79	2,780,612	120,396
5950	1,217.76	1,119.36	2,642,198	121,388
6050	1,170.14	1,047.94	2,503,783	122,450
6150	1,122.52	976.51	2,365,369	123,584
6250	1,074.90	905.08	2,226,955	124,790

Table 5.7. Expected Railroad and Shipper Profit under Guaranteed Service with $\lambda=0.9$, t=\$4973, C=\$3000, and $\theta=1$.

Shipper Salvage Parameter z	Railroad Fleet R	Guaranteed Service G	Railroad Expected Profit $Er\pi$	Shipper Expected Profit $Es\pi$
\$5650	1,473.59	1,114.58	\$3,114,916	\$118,294
5750	1,425.97	1,043.15	2,974,021	119,167
5850	1,378.35	971.73	2,833,127	120,112
5950	1,330.74	900.30	2,692,233	121,128
6050	1,283.12	828.87	2,551,339	122,215
6150	1,235.50	757.44	2,410,444	123,374
6250	1,187.88	686.01	2,269,550	124,605

Equation 5.21 shows how the railroad is able to extract the shipper salvage value from the guaranteed service orders. Equation 5.22 shows the railroad fleet size response to the aggregate amount of guaranteed service ordered. The railroad uses the shipper salvage information in making capacity decisions. Hence, the shipper upon learning its salvage value z also knows the railroad fleet size as shown in equation 5.23.

The Demand Variability Effects Without Productivity Gains

Under the pre-Staggers system, an increase in demand variability through the shipper salvage value decreased the tariff rate and expected railroad profit but the direction of the change in the fleet size was indeterminate. The numerical example shows that in a rail car ordering system offering conventional tariff service and guaranteed service, the variability of demand has no affect on the tariff rate and expected railroad profits. Hence, offering guaranteed service not only allows shippers to insure against rationing but also stabilizes the railroad tariff rate and railroad expected profit.

Table 5.8 shows the value of τ and expected railroad profit for various values of λ and salvage value spreads. The spread (ϵ) indicates the three shipper salvage values to be $Ez-\epsilon$, Ez, and $Ez+\epsilon$, where the expected value of z (Ez) is equal to \$5950. The tariff rate and expected railroad profit

Table 5.8. The Effect of a Mean Preserving Spread on Expected Railroad and Shipper Profit, C=\$3000 and $\theta=1$.

Ratio of Costs λ	Spread ϵ	Tariff Rate t	$\text{Err}\pi$	$\text{Es}\pi$	Total $E\pi$
0.0	100	5,000	2,857,143	119,310	2,976,453
	200	5,000	2,857,143	119,382	2,976,525
	300	5,000	2,857,143	119,501	2,976,644
0.1	100	5,000	2,857,143	119,310	2,976,453
	200	5,000	2,857,143	119,382	2,976,525
	300	5,000	2,857,143	119,501	2,976,644
0.2	100	5,000	2,857,143	119,310	2,976,453
	200	5,000	2,857,143	119,382	2,976,525
	300	5,000	2,857,143	119,501	2,976,644
0.3	100	5,000	2,857,143	119,310	2,976,453
	200	5,000	2,857,143	119,382	2,976,453
	300	5,000	2,857,143	119,501	2,976,644
0.4	100	4,800	2,828,570	122,309	2,950,879
	200	4,800	2,828,570	122,380	2,950,950
	300	4,800	2,828,570	122,499	2,951,059
0.5	100	4,822	2,744,314	122,266	2,866,580
	200	4,822	2,744,314	122,337	2,866,651
	300	4,822	2,744,314	122,456	2,866,770
0.6	100	4,862	2,681,014	121,963	2,802,977
	200	4,862	2,681,014	122,035	2,803,049
	300	4,862	2,681,014	122,154	2,803,168
0.7	100	4,901	2,644,113	121,679	2,765,792
	200	4,901	2,644,113	121,750	2,765,863
	300	4,901	2,644,113	121,869	2,765,982
0.8	100	4,938	2,642,198	121,411	2,763,609
	200	4,938	2,642,198	121,483	2,763,681
	300	4,938	2,642,198	121,602	2,763,800
0.9	100	4,973	2,692,233	121,152	2,813,385
	200	4,973	2,692,233	121,223	2,813,456
	300	4,973	2,692,233	121,342	2,813,575

are constant regardless of the salvage value spread. There exists, however, an ϵ^* large enough such that the tariff rate and expected railroad profits increase. In this case, the railroad increases its tariff rate and expected profit by selling services only during periods very high demand, i.e. the shipper salvage value is extremely low.

The stabilization of railroad tariff rate and expected profit is due to the linearity existing in the numerical example. The relationships between guaranteed service orders and shipper salvage value (equation 5.21) and between railroad fleet size and shipper salvage value (equation 5.23) are linear. Using Table 5.4 the relationship between expected railroad profit and shipper salvage value is shown in equation 5.24.

$$Err\pi=10{,}594{,}174.458-(1{,}329.943*z) \qquad (5.24)$$

The implications of this linearity is that the optimal tariff rate and maximum expected profits will remain unchanged given a mean preserving spread of the salvage value z, as shown in equation 5.25.

$$E_p[rr\pi|_{Ez}]=E_{p,z}[rr\pi] \qquad (5.25)$$

Simulation Results of Informational Effects

Tables 5.9 and 5.10 show the expected railroad and shipper profit for a car allocation system with guaranteed service and the pre-Staggers system. The informational effect of guaranteed service is to increase expected railroad profit. The increase in expected railroad profits is due to tariff rate changes, the ability to lock in business, and the ability to acquire a more appropriate conventional service fleet.

In Table 5.11, when capacity costs are relatively high ($\lambda \leq 0.3$) the tariff rate is greater with guaranteed service than in the pre-Staggers system. In these instances, conventional service demand at the pre-Staggers tariff rate is insufficient for the railroad to acquire a conventional service fleet. Also, the guaranteed service demand at the pre-Staggers rate is too high for the railroad to maximize profits. The choice of a tariff rate for a scheduled carrier automatically implies a fleet size, since the railroad must acquire enough capacity to satisfy all guaranteed service demand. To increase its profits beyond the pre-Staggers level, the railroad increases the tariff rate to choke off demand for guaranteed service.

When capacity costs are lower and the fear of rationing is decreased, the railroad produces guaranteed and conventional service. In order to lock in business and encourage shippers to purchase guaranteed service without full knowledge of grain market conditions, the railroad decreases its tariff rate. In these cases, the tariff rate with guaranteed service is lower than in the pre-Staggers system.

Table 5.9. The Informational Effects of Guaranteed Service on Railroad and Shipper Expected Profits for $0.0 \le \lambda \le 0.4$.

		Guaranteed Service			Pre-Staggers		
λ	ϵ	Errπ	Esπ	Total Eπ	Errπ	Esπ	Total Eπ
0.0	100	2,857,143	119,310	2,976,453	1,942,197	122,545	2,064,742
	200	2,857,143	119,382	2,976,525	1,923,545	122,626	2,046,171
	300	2,857,143	119,501	2,976,644	1,892,971	122,759	2,015,730
0.1	100	2,857,143	119,310	2,976,453	1,981,791	122,444	2,104,235
	200	2,857,143	119,382	2,976,525	1,963,895	122,524	2,086,419
	300	2,857,143	119,501	2,976,644	1,934,539	122,658	2,057,197
0.2	100	2,857,143	119,310	2,976,453	2,025,860	122,333	2,148,193
	200	2,857,143	119,382	2,976,525	2,008,122	122,415	2,130,537
	300	2,857,143	119,501	2,976,644	1,980,831	122,548	2,103,379
0.3	100	2,857,143	119,310	2,976,453	2,075,354	122,211	2,197,565
	200	2,857,143	119,382	2,976,525	2,059,269	122,292	2,181,561
	300	2,857,143	119,501	2,976,644	2,032,854	122,426	2,155,280
0.4	100	2,828,570	122,309	2,950,879	2,131,552	122,076	2,253,628
	200	2,828,570	122,380	2,950,950	2,116,571	122,157	2,238,728
	300	2,828,570	122,499	2,951,059	2,091,960	122,289	2,214,249

Table 5.10. The Informational Effects of Guaranteed Service on Railroad and Shipper Expected Profits for $0.5 \le \lambda \le 0.9$.

		Guaranteed Service			Pre-Staggers		
λ	ϵ	$Err\pi$	$Es\pi$	Total $E\pi$	$Err\pi$	$Es\pi$	Total $E\pi$
0.5	100	2,744,314	122,266	2,866,580	2,196,229	121,926	2,318,155
	200	2,744,314	122,337	2,866,651	2,182,529	122,007	2,304,536
	300	2,744,314	122,456	2,866,770	2,160,025	122,138	2,282,163
0.6	100	2,681,014	121,963	2,802,977	2,271,956	121,758	2,393,714
	200	2,681,014	122,035	2,803,049	2,259,771	121,836	2,381,607
	300	2,681,014	122,154	2,803,168	2,239,768	121,968	2,361,736
0.7	100	2,644,113	121,679	2,765,792	2,362,707	121,569	2,484,276
	200	2,644,113	121,750	2,765,863	2,352,353	121,647	2,474,000
	300	2,644,113	121,869	2,765,982	2,335,384	121,777	2,457,161
0.8	100	2,642,198	121,411	2,763,609	2,475,237	121,359	2,596,596
	200	2,642,198	121,483	2,763,681	2,467,170	121,437	2,588,607
	300	2,642,198	121,602	2,763,800	2,453,997	121,562	2,575,559
0.9	100	2,692,233	121,152	2,813,385	2,623,288	121,129	2,744,417
	200	2,692,233	121,223	2,813,456	2,618,239	121,202	2,739,441
	300	2,692,233	121,342	2,813,575	2,610,071	121,322	2,731,393

Table 5.11. The Informational Effect of Guaranteed Service on the Tariff Rate, C=$3000.

		Guaranteed Service	Pre-Staggers
λ	ϵ	Tariff t	Tariff t
0.0	100	5,000	4,802
	200	5,000	4,797
	300	5,000	4,790
0.1	100	5,000	4,817
	200	5,000	4,813
	300	5,000	4,806
0.2	100	5,000	4,833
	200	5,000	4,829
	300	5,000	4,823
0.3	100	5,000	4,850
	200	5,000	4,846
	300	5,000	4,841
0.4	100	4,800	4,868
	200	4,800	4,865
	300	4,800	4,860
0.5	100	4,822	4,887
	200	4,822	4,885
	300	4,822	4,881
0.6	100	4,862	4,908
	200	4,862	4,096
	300	4,862	4,903
0.7	100	4,901	4,931
	200	4,901	4,929
	300	4,901	4,927
0.8	100	4,938	4,955
	200	4,938	4,954
	300	4,938	4,952
0.9	100	4,973	4,979
	200	4,973	4,979
	300	4,973	4,978

The informational effect on railroad capacity is shown in Tables 5.12 through 5.15. The railroad acquires a more appropriate capacity level with the additional information provided by guaranteed service. Total railroad capacity is allowed to decrease (increase) when the shipper salvage value is higher (lower) than average. Also, conventional tariff service capacity decreases with the introduction of guaranteed service as shippers substitute guaranteed service for tariff service. In this manner, the lost sales from insufficient capacity and investments in idle equipment are reduced. Hence, expected railroad profit always increases from the informational effect on railroad capacity.

The informational effect of guaranteed service on expected shipper profits depends on whether unit capacity costs are high or low relative to unit operating costs. If unit capacity costs are relatively high ($\lambda<0.4$), shippers are worse off with guaranteed service than under the pre-Staggers system. In these cases, expected shipper profit with guaranteed service is lower than the pre-Staggers level because guaranteed service is offered totally at the expense of conventional tariff service. Shippers lose marketing flexibility when only guaranteed service is produced. Also, in some instances, the tariff rate is higher with guaranteed service than the pre-Staggers tariff rate. This further decreases the expected shipper profit.

Table 5.12. The Informational Effects of Guaranteed Service on Railroad Capacity for λ=0.0, 0.1, and 0.2.

			Guaranteed Service			Pre-Stag.
λ	ϵ	z	Conv. Capacity	Guar. Capacity	Total Capacity	Conv. Capacity
0.0	100	5850	0.0	1,500.03	1,500.03	1,412.22
		5950	0.0	1,428.60	1,428.60	
		6050	0.0	1,357.17	1,357.17	
	200	5750	0.0	1,571.46	1,571.46	1,411.41
		5950	0.0	1,428.60	1,428.60	
		6150	0.0	1,285.74	1,285.74	
	300	5650	0.0	1,642.89	1,642.89	1,409.91
		5950	0.0	1,428.60	1,428.60	
		6250	0.0	1,214.31	1,214.31	
0.1	100	5850	0.0	1,500.03	1,500.03	1,436.51
		5950	0.0	1,428.60	1,428.60	
		6050	0.0	1,357.17	1,357.17	
	200	5750	0.0	1,571.46	1,571.46	1,436.19
		5950	0.0	1,428.60	1,428.60	
		6150	0.0	1,285.74	1,285.74	
	300	5650	0.0	1,642.89	1,642.89	1,435.59
		5950	0.0	1,428.60	1,428.60	
		6250	0.0	1,214.31	1,214.31	
0.2	100	5850	0.0	1,500.03	1,500.03	1,464.27
		5950	0.0	1,428.60	1,428.60	
		6050	0.0	1,357.17	1,357.17	
	200	5750	0.0	1,571.46	1,571.46	1,464.60
		5950	0.0	1,428.60	1,428.60	
		6150	0.0	1,285.74	1,285.74	
	300	5650	0.0	1,642.89	1,642.89	1,464.99
		5950	0.0	1,428.60	1,428.60	
		6250	0.0	1,214.31	1,214.31	

Table 5.13. The Informational Effects of Guaranteed Service on Railroad Capacity for λ=0.3, 0.4, and 0.5.

			Guaranteed Service			Pre-Stag.
λ	ε	z	Conv. Capacity	Guar. Capacity	Total Capacity	Conv. Capacity
0.3	100	5850	0.0	1,500.03	1,500.03	1,496.46
		5950	0.0	1,428.60	1,428.60	
		6050	0.0	1,357.17	1,357.17	
	200	5750	0.0	1,571.46	1,571.46	1,497.47
		5950	0.0	1,428.60	1,428.60	
		6150	0.0	1,285.74	1,285.74	
	300	5650	0.0	1,642.89	1,642.89	1,499.09
		5950	0.0	1,428.60	1,428.60	
		6250	0.0	1,214.31	1,214.31	
0.4	100	5850	0.0	1,642.82	1,642.83	1,534.52
		5950	0.0	1,571.39	1,571.40	
		6050	0.0	1,499.96	1,499.97	
	200	5750	0.0	1,714.25	1,714.26	1,536.36
		5950	0.0	1,571.39	1,571.40	
		6150	0.0	1,428.54	1,428.55	
	300	5650	0.0	1,785.68	1,785.69	1,539.30
		5950	0.0	1,571.39	1,571.40	
		6250	0.0	1,357.11	1,357.12	
0.5	100	5850	120.27	1,566.99	1,687.26	1,580.51
		5950	120.27	1,495.56	1,615.83	
		6050	120.27	1,424.14	1,544.41	
	200	5750	120.27	1,638.42	1,758.69	1,583.34
		5950	120.27	1,495.56	1,615.83	
		6150	120.27	1,352.71	1,472.98	
	300	5650	120.27	1,709.85	1,830.12	1,587.99
		5950	120.27	1,495.56	1,615.83	
		6250	120.27	1,281.28	1,401.55	

Table 5.14. The Informational Effects of Guaranteed Service on Railroad Capacity for λ=0.6, 0.7, and 0.8.

			Guaranteed Service			Pre-Stag.
λ	ϵ	z	Conv. Capacity	Guar. Capacity	Total Capacity	Conv. Capacity
0.6	100	5850	270.85	1,463.20	1,734.05	1,637.94
		5950	270.85	1,391.78	1,662.63	
		6050	270.85	1,320.35	1,591.20	
	200	5750	270.85	1,534.63	1,805.48	1,641.96
		5950	270.85	1,391.78	1,662.63	
		6150	270.85	1,248.92	1,519.77	
	300	5650	270.85	1,606.06	1,876.91	1,648.73
		5950	270.85	1,391.78	1,662.63	
		6250	270.85	1,177.49	1,448.34	
0.7	100	5850	457.75	1,342.05	1,799.80	1,713.09
		5950	457.75	1,270.63	1,728.38	
		6050	457.75	1,199.20	1,656.95	
	200	5750	457.75	1,413.48	1,871.23	1,718.75
		5950	457.75	1,270.63	1,728.38	
		6150	457.75	1,127.77	1,585.52	
	300	5650	457.75	1,484.91	1,942.66	1,728.20
		5950	457.75	1,270.63	1,728.38	
		6250	457.75	1,056.34	1,514.09	
0.8	100	5850	707.27	1,190.79	1,898.06	1,819.46
		5950	707.27	1,119.36	1,826.63	
		6050	707.27	1,047.94	1,755.21	
	200	5750	707.27	1,262.22	1,969.49	1,827.39
		5950	707.27	1,119.36	1,826.63	
		6150	707.27	976.51	1,683.78	
	300	5650	707.27	1,333.65	2,040.92	1,840.47
		5950	707.27	1,119.36	1,826.63	
		6250	707.27	905.08	1,612.35	

Table 5.15. The Informational Effects of Guaranteed Service on Railroad Capacity for $\lambda=0.9$.

			Guaranteed Service			Pre-Stag.
λ	ϵ	z	Conv. Capacity	Guar. Capacity	Total Capacity	Conv. Capacity
0.9	100	5850	1,095.80	971.73	2,067.53	1,995.99
		5950	1,095.80	900.30	1,996.10	
		6050	1,095.80	828.87	1,924.67	
	200	5750	1,095.80	1,043.15	2,138.95	2,007.42
		5950	1,095.80	900.30	1,996.10	
		6150	1,095.80	757.44	1,853.24	
	300	5650	1,095.80	1,114.58	2,210.38	2,026.28
		5950	1,095.80	900.30	1,996.10	
		6250	1,095.80	686.01	1,781.81	

Shippers, however, are better off with guaranteed service when the railroad offers guaranteed service as well as conventional tariff service. In these cases, capacity costs are relatively lower ($\lambda>0.4$) and the railroad decreases its tariff rate from the pre-Staggers rate. Both the lower tariff rate and increased service offerings cause expected shipper profit to increase beyond the pre-Staggers level.

Total welfare and expected railroad profits are higher with guaranteed service than under the pre-Staggers system, regardless of the distribution of capacity and operating costs. If a portion of the railroad gains are transferred to shippers to offset their losses, all parties are made better off with guaranteed service.

Effect of λ with the Tariff Rate and Salvage Value Constant

This section presents the effects of increasing λ on the railroad capacity decision and the shipper choice of guaranteed service holding the tariff rate and shipper salvage value constant. The railroad capacity decision and the shipper choice of guaranteed service are made simultaneously. The railroad and shippers choose a best response given the others' decision. Recall, that with $\lambda=0$, the unit operating cost is zero and the unit capacity cost is the entire unit cost of production. Assume the tariff rate is at a level such that at $\lambda=0$, only guaranteed service is produced. In other words, the tariff rate is assumed to be at a level where there is no incentive for the railroad to acquire a conventional service fleet. Hence, at the given tariff rate, conventional service demand is insufficient and the high capacity costs overwhelm the large expected operating profit from producing conventional service.

As λ increases, the rise in unit operating costs equals the fall in unit capacity costs. The decrease in expected marginal operating profit from producing conventional service is less than the decrease in unit capacity costs, since the probability of producing conventional service is less than one. Hence, holding the tariff rate and shipper salvage value constant, an increase in λ serves to increase the incentive for the railroad to acquire a conventional service fleet.

Assume there exists some λ_0, such that the railroad begins to acquire a conventional service fleet at the assumed tariff rate and shipper salvage value. Hence, when $\lambda \epsilon [0,\lambda_0]$, there is no incentive to a acquire a conventional service fleet, the probability of having a conventional service order rationed is equal to 1, the amount guaranteed service produced remains constant, and the railroad profit is also constant. The railroad is a scheduled carrier.

As λ increases beyond λ_0, the railroad acquires a conventional service fleet, which decreases the probability of having a conventional service order rationed, causing the amount of guaranteed service purchased to decrease. The increase in conventional service capacity is larger than the decrease in the amount of guaranteed service purchased, so that total railroad capacity rises. The loss in profit from reduced guaranteed service sales exceeds the gain in expected profit from increased conventional service sales. Hence, expected railroad profit decreases.

However, as λ increases to some λ_1, the increase in conventional service capacity is large enough such that expected railroad profit increases. In these cases, the gain in expected profit from conventional service exceeds the loss in profit from guaranteed sales. In this interval $[\lambda_1,1]$, the cost of adding conventional service capacity is low enough allowing the railroad to add capacity and gain sales when the grain price is high. The additional conventional service capacity, however, decreases the amount of guaranteed service purchased causing the railroad to lose sales when the grain price is low. The increase in expected conventional service sales exceeds the expected loss in guaranteed service sales.

In Figure 5.7, the loss in railroad profit from reduced guaranteed sales occurs when the resulting grain price is in the interval $[0, p^o]$, where $p^o=z+2v\tau-2vy+2vG/n$. If guaranteed sales decrease from G to G', the loss in sales is (G-G') when the grain price is in the interval $[0,p^{o'}]$ and $[G-G'-Q^{d'}(p)]$ when the grain price is in the interval $[p^{o'},p^o]$, where $p^{o'}=z+2v\tau-2vy+2vG'/n$ and $Q^{d'}$ is the corresponding conventional service demand. For grain prices in the interval $[p^o,p^r]$, where $p^r=z+2v\tau-2vy+2v\alpha_nR/n$, the decrease in guaranteed service produced equals the increase in the amount of conventional service produced.

The gain in railroad profit from increased conventional service capacity (i.e. increasing fleet size R) occurs when the resulting grain price is high. If the fleet size increases from R to R', sales increase $[Q^{d'}(p)-\alpha_nR]$ when the grain price is the interval $[p^r,p^{r'}]$ and increase $\alpha_n(R'-R)$ whenever the grain price is greater than $p^{r'}$, where $p^{r'}=z+2v\tau-2vy+2v\alpha_nR'/n$.

Table 5.16 reviews the effect of increasing λ on the railroad capacity decision and shipper choice of guaranteed

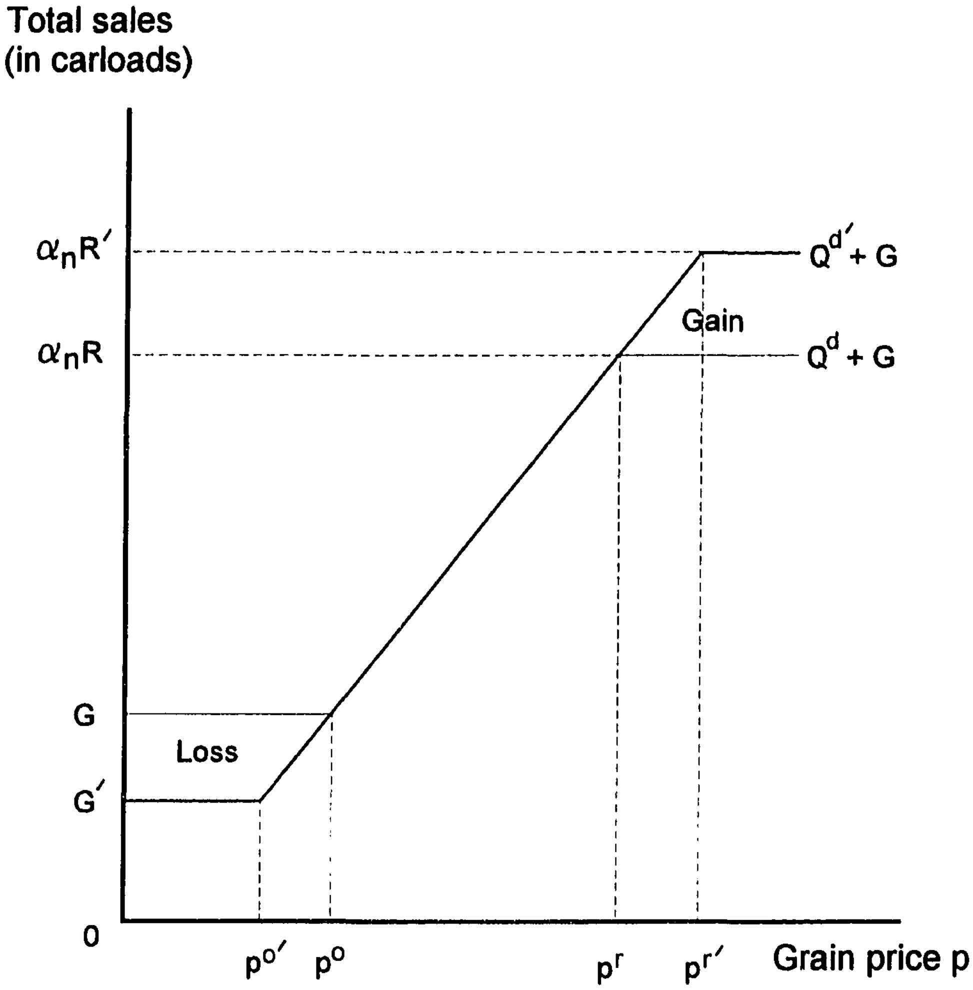


Figure 5.7. The effect of increasing R to R′ and decreasing G to G′ on total sales.

service holding the tariff rate and shipper salvage parameter constant. For $\lambda=0$, it is assumed there is no incentive to acquire a conventional service fleet. At first, increasing unit operating costs and decreasing unit capacity costs leaves all the variables unchanged. The "NC" in Table 5.16 means no change in the variable and a "0" implies the variable is equal to zero when λ is in the corresponding interval. Eventually, at $\lambda=\lambda_0$, the incentive to acquire a conventional service fleet appears. Conventional service capacity increases, the probability of having a conventional service order rationed decreases, the amount of guaranteed service decreases, total railroad capacity increases, and expected railroad profit decreases. However, at $\lambda=\lambda_1$, expected railroad profit begins to increase.

Table 5.16. Effect of λ Holding Tariff Rate and Shipper Salvage Value Constant.

Lambda	Conv. Capacity	Ration Prob.	Guar. Service	Total Capacity	$E\pi$
$[0, \lambda_0]$	0	NC	NC	NC	NC
$[\lambda_0, \lambda_1]$	+	-	-	+	-
$[\lambda_1, 1]$	+	-	-	+	+

The Effect of λ on Optimal Railroad and Shipper Decisions

In Table 5.17, the numerical results indicate that when λ is less than or equal 0.33, the railroad is a scheduled carrier. All grain is moved using guaranteed service and the railroad does not acquire a fleet for conventional tariff service. In this case, the profit margin for a car producing a conventional service trip is large, but the probability of the car being used in conventional service is too small to offset the high costs of acquiring a car.

Table 5.17. Relationship Between Optimal Decisions and λ.

				Shipper Salvage Value=$5950		
Range λ	Tau	Errπ	Esπ	Guar. Cap.	Conv. Cap.	Total Cap.
0.00 to 0.33	NC	NC	NC	NC	0	NC
0.34 to 0.40	-	-	+	+	0	+
0.41 to 0.76	+	-	-	-	+	+
0.77 to 0.99	+	+	-	-	+	+

The distribution of total costs between operating costs and capacity costs, for $\lambda \epsilon [0,0.33]$, has no affect on the decisions of the railroad. The railroad sets the tariff rate knowing it will acquire a fleet large enough to satisfy the demand for guaranteed service in each of the three states of demand. The problem is similar to the deterministic pre-

Staggers case of the railroad choosing its tariff rate knowing it will acquire a fleet large enough to satisfy shipper conventional service demand. In each case, the choice of a fleet is determined by the tariff rate. Therefore, the total constant cost of producing a unit of output is important, not the breakdown between operating and capacity costs.

For $\lambda \epsilon [0, 0.33]$, the probability of having a conventional service order rationed is equal to one, since the tariff rate remains constant and there is not an incentive to acquire a conventional service fleet. Therefore, the amount of guaranteed service purchased by shippers and the expected shipper profit remains constant.

From the discussion in the previous section, as λ increases beyond 0.33 and holding the tariff rate constant, the railroad begins to acquire a conventional service fleet. The larger conventional service fleet decreases the probability shippers are rationed. The amount of guaranteed service purchased decreases and expected railroad profit decreases. In response, the railroad decreases its tariff rate to recapture the lost sales of guaranteed service.

The lower tariff rate causes three reactions to the incentive of acquiring a conventional service fleet. First, the reduction in the tariff rate decreases the marginal revenue of a car, which reduces the incentive to acquire a conventional service fleet. Second, a lower tariff rate increases guaranteed service orders which decreases the probability a car is used in conventional service, since conventional service demand is reduced. This also reduces the incentive to acquire a conventional service fleet. Third, the lower tariff rate also increases conventional service demand which increases the probability a car is used in conventional service. This final reaction increases the incentive to acquire a conventional service fleet. These conflicting reactions cause the affect on the probability a car is used in conventional service to be indeterminate.

The results, however, indicate for values of $\lambda \in [0.34, 0.40]$, as the tariff rate falls, the incentive for the railroad to acquire a conventional service fleet disappears. In these instances, the railroad lowers it tariff rate in order to continue operating as a scheduled carrier. The lower tariff rate increases the amount of guaranteed service purchased. The railroad profit from increased guaranteed service sales is greater than the loss in expected profit from decreased conventional service sales. Hence, railroad profit is maximized by lowering its tariff rate and operating as a scheduled carrier.

For the interval $\lambda \in [0.34, 0.40]$, expected railroad profit decreases as λ increases. The lower tariff rate increases guaranteed sales, but total railroad profit decreases. Expected shipper profit, on the other hand, increases as the lower tariff rate more than offsets the loss in marketing flexibility due to increased guaranteed service sales.

As λ continues to increase beyond 0.4, the incentive to recapture lost guaranteed service sales by lowering the tariff rate disappears because of shrinking profit margins on guaranteed service. The railroad begins to increase its tariff rate. The effect of an increased tariff on the incentive to acquire a conventional service fleet is again indeterminate. The results indicate that the lower capacity costs and higher profit margins give the railroad the incentive to acquire a larger conventional service capacity. The higher tariff rate and larger conventional service capacity decreases guaranteed service sales. The total railroad capacity increases, since the increase in conventional service capacity more than offsets the decrease in guaranteed service sales.

For $\lambda \epsilon [0.41, 0.76]$, expected railroad and expected shipper profit decrease as λ increases. In these cases, the loss in expected profit from decreased guaranteed service sales is greater than the gain in expected profit from increased conventional service sales. However, when λ is greater than or equal to 0.77, expected railroad profit increases. In these instances, capacity costs are very low. The railroad acquires an even larger conventional service fleet, enabling the gain in expected profit from increased conventional service sales to be larger than the loss in expected profit from the decreased guaranteed service sales.

Rail Car Productivity Effects

This section examines the effect of rail car productivity improvements from guaranteeing service. Guaranteeing service provides railroads with new information concerning the specific origins and destinations of future movements. With the exact origin and destination of guaranteed future movements, the railroad moves empty cars directly to the next point of origin. Conventional tariff service does not provide the railroad with future origins or destinations and the railroad does not know if the movement will actually occur. Empty cars in conventional service are moved to where the railroad believes will be the next point of origin. Since, the railroad may receive wrong or clouded signals from shippers with conventional service, guaranteed service enhances the productivity of rail cars by reducing empty mileage.

Rail car productivity effects are examined by using the guaranteed model in the previous section and assuming the trips completed by a car in guaranteed service are 10 percent greater than the trips completed by a car in conventional tariff service, $\theta=(\alpha_n/\alpha_g)=(1.5/1.65)=0.91$. The previous model assumed the number of trips completed by a car in conventional service equals the number of trips completed by a car in guaranteed service, $\alpha_n=\alpha_g=1.5$ and $\theta=1$. Next, the analysis examines the effects of demand variability on railroad expected profits and tariff rates under guaranteed service with productivity gains. Finally, the effects of λ on railroad and shipper decisions is examined in the presence of productivity gains.

Simulation Results for Rail Car Productivity Gains

Tables 5.18 and 5.19 show expected railroad profit, expected shipper profit, and total welfare in the absence of productivity gains and in the presence of a 10 percent increase in rail car productivity from guaranteeing service. Expected railroad profits increase and expected shipper profits do not decrease as a result of the productivity gains. Hence, for all values of λ, total welfare increases due to the productivity gains.

Tables 5.20 and 5.21 show the railroad tariff rate with and without rail car productivity gains. The railroad decreases its tariff rate except in a few cases. The railroad decreases the tariff rate in order to attract more guaranteed service. Productivity gains implies the capacity costs per unit of guaranteed service is reduced. Consequently, a unit of guaranteed service is cheaper to produce than a unit of conventional service.

Table 5.18. The Productivity Effects of Guaranteed Service on Railroad and Shipper Expected Profits for $0.0 \le \lambda \le 0.4$.

		Guaranteed Service No Productivity Gain			Guaranteed Service Productivity Gain - 10%		
λ	ϵ	$Err\pi$	$Es\pi$	Total $E\pi$	$Err\pi$	$Es\pi$	Total $E\pi$
0.0	100	2,857,143	119,310	2,976,453	3,260,035	121,325	3,381,360
	200	2,857,143	119,382	2,976,525	3,260,035	121,396	3,381,431
	300	2,857,143	119,501	2,976,644	3,260,035	121,515	3,381,550
0.1	100	2,857,143	119,310	2,976,453	3,218,551	121,116	3,339,667
	200	2,857,143	119,382	2,976,525	3,218,551	121,187	3,339,738
	300	2,857,143	119,501	2,976,644	3,218,551	121,306	3,339,857
0.2	100	2,857,143	119,310	2,976,453	3,177,332	120,911	3,298,243
	200	2,857,143	119,382	2,976,525	3,177,332	120,982	3,298,314
	300	2,857,143	119,501	2,976,644	3,177,332	121,101	3,298,433
0.3	100	2,857,143	119,310	2,976,453	3,136,378	120,707	3,257,085
	200	2,857,143	119,382	2,976,525	3,136,378	120,778	3,257,156
	300	2,857,143	119,501	2,976,644	3,136,378	120,897	3,257,275
0.4	100	2,828,570	122,309	2,950,879	3,085,707	122,309	3,208,016
	200	2,828,570	122,380	2,950,950	3,085,707	122,380	3,208,087
	300	2,828,570	122,499	2,951,059	3,085,707	122,499	3,208,206

Table 5.19. The Productivity Effects of Guaranteed Service on Railroad and Shipper Expected Profits for $0.5 \le \lambda \le 0.9$.

		Guaranteed Service No Productivity Gain			Guaranteed Service Productivity Gain - 10%		
λ	ϵ	Errπ	Esπ	Total Eπ	Errπ	Esπ	Total Eπ
0.5	100	2,744,314	122,266	2,866,580	2,953,975	123,701	3,077,676
	200	2,744,314	122,337	2,866,651	2,953,975	123,773	3,077,748
	300	2,744,314	122,456	2,866,770	2,953,975	123,892	3,077,867
0.6	100	2,681,014	121,963	2,802,977	2,836,363	123,058	2,959,421
	200	2,681,014	122,035	2,803,049	2,836,363	123,130	2,959,493
	300	2,681,014	122,154	2,803,168	2,836,363	123,249	2,959,612
0.7	100	2,644,113	121,679	2,765,792	2,749,978	122,465	2,872,443
	200	2,644,113	121,750	2,765,863	2,749,978	122,536	2,872,514
	300	2,644,113	121,869	2,765,982	2,749,978	122,655	2,872,633
0.8	100	2,642,198	121,411	2,763,609	2,704,060	121,911	2,825,971
	200	2,642,198	121,483	2,763,681	2,704,060	121,983	2,826,043
	300	2,642,198	121,602	2,763,800	2,704,060	122,102	2,826,162
0.9	100	2,692,233	121,152	2,813,385	2,716,977	121,390	2,838,367
	200	2,692,233	121,223	2,813,456	2,716,977	121,461	2,838,438
	300	2,692,233	121,342	2,813,575	2,716,977	121,581	2,838,558

Table 5.20. The Productivity Effect of Guaranteed Service on the Tariff Rate, C=$3000.

		Productivity Gain - 0%	Productivity Gain - 10%
λ	ϵ	Tariff t	Tariff t
0.0	100	5,000	4,858
	200	5,000	4,858
	300	5,000	4,858
0.1	100	5,000	4,877
	200	5,000	4,877
	300	5,000	4,877
0.2	100	5,000	4,891
	200	5,000	4,891
	300	5,000	4,891
0.3	100	5,000	4,904
	200	5,000	4,904
	300	5,000	4,904
0.4	100	4,800	4,800
	200	4,800	4,800
	300	4,800	4,800
0.5	100	4,822	4,727
	200	4,822	4,727
	300	4,822	4,727
0.6	100	4,862	4,788
	200	4,862	4,788
	300	4,862	4,788
0.7	100	4,901	4,847
	200	4,901	4,847
	300	4,901	4,847
0.8	100	4,938	4,904
	200	4,938	4,904
	300	4,938	4,904
0.9	100	4,973	4,956
	200	4,973	4,956
	300	4,973	4,956

Table 5.21. The Productivity Effect of Guaranteed Service on the Tariff Rate, C=$3000, and ϵ=100.

	Productivity Gain - 0%	Productivity Gain - 10%
λ	Tariff t	Tariff t
0.30	5,000	4,904
0.31	5,000	4,906
0.32	5,000	4,907
0.33	5,000	4,909
0.34	4,980	4,910
0.35	4,950	4,911
0.36	4,920	4,913
0.37	4,890	4,802
0.38	4,860	4,860
0.39	4,830	4,830
0.40	4,800	4,800
0.41	4,785	4,770
0.42	4,790	4,740
0.43	4,793	4,710
0.44	4,798	4,687
0.45	4,802	4,695
0.46	4,805	4,701
0.47	4,810	4,708
0.48	4,814	4,714
0.49	4,818	4,721
0.50	4,822	4,727

In a few cases, the railroad leaves the tariff rate unaltered. The railroad produces the same guaranteed output at the same tariff but at a lower cost. The railroad absorbs the entire efficiency gains from the increased productivity of rail cars in guaranteed service.

Tables 5.22 through 5.25 shows the conventional service and guaranteed service capacity of the railroad with and without the 10 percent productivity gain. The guaranteed service capacity with productivity gains is always greater than or equal to the case without productivity gains. The increase in guaranteed service capacity is greatest when capacity costs are relatively high, e.g., λ=0.0, 0.1, and 0.2. In these cases, all of the grain hauled by the railroad is through guaranteed service. Once again, the productivity gains implies a reduction in the per unit costs of acquiring a car for guaranteed service. The railroad increases the amount of guaranteed service demanded by decreasing its tariff rate and acquires a larger guaranteed service capacity.

Simulation results also indicate guaranteed service productivity gains reduces the incentive for the railroad to acquire conventional service capacity. Tables 5.22 through 5.25 show the conventional service capacity decreasing and the guaranteed service capacity increasing. The increase in guaranteed service capacity more than offsets the decrease in conventional service capacity, so total railroad capacity

Table 5.22. The Productivity Effects of Guaranteed Service on Railroad Capacity for $0.0 \le \lambda \le 0.2$.

		Guaranteed Service Productivity Gain - 10%			Guaranteed Service No Productivity Gain		
λ	z	Conv. Capacity	Guar Capacity	Total Capacity	Conv Capacity	Guar. Capacity	Total Capacity
0.0	5650	0.0	1,740.29	1,740.29	0.0	1,642.89	1,642.89
	5750	0.0	1,668.86	1,668.87	0.0	1,571.46	1,571.46
	5850	0.0	1,597.43	1,597.43	0.0	1,500.03	1,500.03
	5950	0.0	1,526.00	1,526.00	0.0	1,428.60	1,428.60
	6050	0.0	1,454.57	1,454.57	0.0	1,357.17	1,357.17
	6150	0.0	1,383.14	1,383.14	0.0	1,285.74	1,285.74
	6250	0.0	1,311.71	1,311.71	0.0	1,214.31	1,214.31
0.1	5650	0.0	1,730.49	1,730.49	0.0	1,642.89	1,642.89
	5750	0.0	1,659.06	1,659.06	0.0	1,571.46	1,571.46
	5850	0.0	1,587.63	1,587.63	0.0	1,500.03	1,500.03
	5950	0.0	1,516.20	1,516.20	0.0	1,428.60	1,428.60
	6050	0.0	1,444.77	1,444.77	0.0	1,357.17	1,357.17
	6150	0.0	1,373.34	1,373.34	0.0	1,285.74	1,285.74
	6250	0.0	1,301.91	1,301.91	0.0	1,214.31	1,214.31
0.2	5650	0.0	1,720.79	1,720.79	0.0	1,642.89	1,642.89
	5750	0.0	1,649.36	1,649.36	0.0	1,571.46	1,571.46
	5850	0.0	1,577.93	1,577.93	0.0	1,500.03	1,500.03
	5950	0.0	1,506.50	1,506.50	0.0	1,428.60	1,428.60
	6050	0.0	1,435.07	1,435.07	0.0	1,357.17	1,357.17
	6150	0.0	1,363.64	1,363.64	0.0	1,285.74	1,285.74
	6250	0.0	1,292.21	1,292.21	0.0	1,214.31	1,214.31

Table 5.23. The Productivity Effects of Guaranteed Service on Railroad Capacity for $0.3 \leq \lambda \leq 0.5$.

		Guaranteed Service Productivity Gain - 10%			Guaranteed Service No Productivity Gain		
λ	z	Conv. Capacity	Guar Capacity	Total Capacity	Conv Capacity	Guar. Capacity	Total Capacity
	5650	0.0	1,711.09	1,711.09	0.0	1,642.89	1,642.89
	5750	0.0	1,639.66	1,639.66	0.0	1,571.46	1,571.46
	5850	0.0	1,577.93	1,577.93	0.0	1,500.03	1,500.03
0.3	5950	0.0	1,506.50	1,506.50	0.0	1,428.60	1,428.60
	6050	0.0	1,435.07	1,435.07	0.0	1,357.17	1,357.17
	6150	0.0	1,363.64	1,363.64	0.0	1,285.74	1,285.74
	6250	0.0	1,292.21	1,292.21	0.0	1,214.31	1,214.31
	5650	0.0	1,785.68	1,785.69	0.0	1,785.68	1,785.69
	5750	0.0	1,714.25	1,714.26	0.0	1,714.25	1,714.26
	5850	0.0	1,642.82	1,642.83	0.0	1,642.82	1,642.83
0.4	5950	0.0	1,571.39	1,571.40	0.0	1,571.39	1,571.40
	6050	0.0	1,499.96	1,499.97	0.0	1,499.96	1,499.97
	6150	0.0	1,428.54	1,428.55	0.0	1,428.54	1,428.55
	6250	0.0	1,357.11	1,357.12	0.0	1,357.11	1,357.12
	5650	87.11	1,794.43	1,881.54	120.27	1,709.85	1,830.12
	5750	87.11	1,723.00	1,810.11	120.27	1,638.42	1,758.69
	5850	87.11	1,651.57	1,738.68	120.27	1,566.99	1,687.26
0.5	5950	87.11	1,580.14	1,667.25	120.27	1,495.56	1,615.83
	6050	87.11	1,508.71	1,595.82	120.27	1,424.14	1,544.41
	6150	87.11	1,437.29	1,524.40	120.27	1,352.71	1,472.98
	6250	87.11	1,365.86	1,452.97	120.27	1,281.28	1,401.55

Table 5.24. The Productivity Effects of Guaranteed Service on Railroad Capacity for $0.6 \leq \lambda \leq 0.8$.

		Guaranteed Service Productivity Gain - 10%			Guaranteed Service No Productivity Gain		
λ	z	Conv. Capacity	Guar Capacity	Total Capacity	Conv Capacity	Guar. Capacity	Total Capacity
0.6	5650	246.18	1,670.90	1,917.08	270.85	1,606.06	1,876.91
	5750	246.18	1,599.47	1,845.65	270.85	1,534.63	1,805.48
	5850	246.18	1,528.04	1,774.22	270.85	1,463.20	1,734.05
	5950	246.18	1,456.61	1,702.79	270.85	1,391.78	1,662.63
	6050	246.18	1,385.18	1,631.36	270.85	1,320.35	1,591.20
	6150	246.18	1,313.75	1,559.93	270.85	1,248.92	1,519.77
	6250	246.18	1,242.33	1,488.51	270.85	1,177.49	1,448.34
0.7	5650	440.66	1,531.55	1,972.21	457.75	1,484.91	1,942.66
	5750	440.66	1,460.13	1,900.79	457.75	1,413.48	1,871.23
	5850	440.66	1,388.70	1,829.36	457.75	1,342.05	1,799.80
	5950	440.66	1,317.27	1,757.93	457.75	1,270.63	1,728.38
	6050	440.66	1,245.84	1,686.50	457.75	1,199.20	1,656.95
	6150	440.66	1,174.41	1,615.07	457.75	1,127.77	1,585.52
	6250	440.66	1,102.98	1,543.64	457.75	1,056.34	1,514.09
0.8	5650	697.01	1,363.28	2,060.29	707.27	1,333.65	2,040.92
	5750	697.01	1,291.85	1,988.86	707.27	1,262.22	1,969.49
	5850	697.01	1,220.42	1,917.43	707.27	1,190.79	1,898.06
	5950	697.01	1,148.99	1,846.00	707.27	1,119.36	1,826.63
	6050	697.01	1,077.57	1,774.58	707.27	1,047.94	1,755.21
	6150	697.01	1,006.14	1,703.15	707.27	976.51	1,683.78
	6250	697.01	934.71	1,631.72	707.27	905.08	1,612.35

Table 5.25. The Productivity Effects of Guaranteed Service on Railroad Capacity for $\lambda = 0.9$.

		Guaranteed Service Productivity Gain - 10%			Guaranteed Service No Productivity Gain		
λ	z	Conv. Capacity	Guar Capacity	Total Capacity	Conv Capacity	Guar. Capacity	Total Capacity
0.9	5650	1,091.45	1,128.56	2,220.01	1,095.80	1,114.58	2,210.38
	5750	1,091.45	1,057.13	2,148.58	1,095.80	1,043.15	2,138.95
	5850	1,091.45	985.70	2,077.15	1,095.80	971.73	2,067.53
	5950	1,091.45	914.27	2,005.72	1,095.80	900.30	1,996.10
	6050	1,091.45	842.84	1,934.29	1,095.80	828.87	1,924.67
	6150	1,091.45	771.42	1,862.87	1,095.80	757.44	1,853.24
	6250	1,091.45	699.99	1,791.44	1,095.80	686.01	1,781.81

increases.

Recall from Table 5.21, that in a few cases (λ=0.38, 0.39, and 0.40), productivity gains from guaranteeing service had no affect on the railroad tariff rate, leaving shipper demand unchanged. In these instances, railroad capacity also remains unchanged. The railroad uses the productivity gains from guaranteeing service to decrease its fleet but leave total railroad capacity unchanged.

Total railroad capacity is the total amount of grain the railroad is capable of hauling with conventional and guaranteed service. The conventional service capacity is defined as the conventional service fleet multiplied by the number of trips a car in conventional service completes (α_n). Similarly, the guaranteed service capacity is defined as the guaranteed service fleet multiplied by the number of trips a car in conventional service completes (α_g). The guaranteed service and conventional service fleet are defined as the number of cars available to produce guaranteed and conventional service, respectively. The sum of the guaranteed service fleet and conventional service fleet is the total railroad fleet (R).

Since, the railroad must serve all requests for guaranteed service, guaranteed service capacity is also represented by guaranteed service demand (G) and the guaranteed service fleet can be represented by (G/α_g).

Therefore, the conventional service fleet consists of the remaining cars $[R-G/\alpha_g]$ and the conventional service capacity is denoted as $\alpha_n[R-G/\alpha_g]=\alpha_nR-\theta G$.

Total capacity of the railroad never decreases with rail car productivity gains but the total fleet size may decrease. The total railroad fleet may be reduced for two reasons. First, the increased rail car productivity allows the amount of cars in guaranteed service to be reduced even though the total amount of guaranteed service capacity increases. Second, the conventional service fleet is reduced, since rail car productivity gains decreases the conventional service capacity.

For example, in Table 5.24 with $\lambda=0.8$ and $z=5650$, the guaranteed service capacity is 1333.65 and 1363.28 units without and with a 10 percent productivity gain from guaranteeing service, i.e., $\theta=1.0$ and 0.91, respectively. The fleet needed to provide these guaranteed service capacities are 889.10 (1333.65/1.5) and 826.23 (1363.28/1.65) cars. The guaranteed service fleet decreased 62.87 cars even though guaranteed service capacity increased 29.63 trips. Furthermore, the conventional service fleet also decreases from 471.51 to 464.67 cars. Hence, total railroad capacity increases 19.36 trips from 2,040.92 to 2,060.28, while the fleet is reduced 70 cars from 1,361 cars to 1,291 cars. Rail car productivity gains allows the railroad increase the capacity of an existing fleet or increase its capacity while reducing its fleet.

The Demand Variability Effects With Productivity Effects

The effect of a mean preserving spread on the tariff rate and expected railroad and shipper profits with a 10 percent increase in rail car productivity is shown in Table 5.26. For the numerical example, the effects of a mean preserving spread has no affect on the tariff rate and expected railroad profits. Rail car productivity gains leave the stabilizing effect of guaranteed service unchanged.

The Effect of λ With Productivity Effects

The effect of λ on railroad and shipper decisions in the presence of productivity gains is the same as without the productivity gains except in one instance. Without productivity gains the tariff rate was either constant or decreasing. However, Table 5.27 shows the tariff rate increasing in the interval $\theta\epsilon[0.0,0.36]$. In this interval, only guaranteed service is produced. An increase in λ increases the per unit cost of producing guaranteed service. In response to this slight increase in cost the railroad increases its tariff rate slightly and shippers decrease the amount of guaranteed service purchased.

For example, with the total unit cost of production C=\$3,000, if $\lambda=0.2$, then unit operating costs $b=\lambda C=600$ and unit capacity costs $B=(1-\lambda)C=2400$. Similarly, if $\lambda=0.3$, then

Table 5.26. The Effect of a Mean Preserving Spread on Expected Railroad and Shipper Profit, C=$3000 and θ=0.91.

Ratio of Costs λ	Spread ϵ	Tariff Rate t	$Err\pi$	$Es\pi$	Total $E\pi$
0.0	100	4,858	3,260,035	121,325	3,381,218
	200	4,858	3,260,035	121,396	3,381,431
	300	4,858	3,260,035	121,515	3,381,550
0.1	100	4,877	3,218,551	121,116	3,339,667
	200	4,877	3,218,551	121,187	3,339,738
	300	4,877	3,218,551	121,306	3,339,857
0.2	100	4,891	3,177,332	120,911	3,298,243
	200	4,891	3,177,332	120,982	3,298,314
	300	4,891	3,177,332	121,101	3,298,433
0.3	100	4,904	3,136,378	120,707	3,257,085
	200	4,904	3,136,378	120,778	3,257,156
	300	4,904	3,136,378	120,897	3,257,275
0.4	100	4,800	3,085,707	122,309	3,208,016
	200	4,800	3,085,707	122,380	3,208,087
	300	4,800	3,085,707	122,499	3,208,206
0.5	100	4,727	2,953,975	123,701	3,077,676
	200	4,727	2,953,975	123,773	3,077,748
	300	4,727	2,953,975	123,892	3,077,867
0.6	100	4,788	2,836,363	123,058	2,959,421
	200	4,788	2,836,363	123,130	2,959,493
	300	4,788	2,836,363	123,249	2,959,612
0.7	100	4,847	2,749,978	122,465	2,872,443
	200	4,847	2,749,978	122,536	2,872,514
	300	4,847	2,749,978	122,655	2,872,633
0.8	100	4,904	2,704,060	121,911	2,825,971
	200	4,904	2,704,060	121,983	2,826,043
	300	4,904	2,704,060	122,102	2,826,162
0.9	100	4,956	2,716,977	121,390	2,838,367
	200	4,956	2,716,977	121,461	2,838,438
	300	4,956	2,716,977	121,581	2,838,558

b=900 and B=2100. But these values are unit costs for conventional service. With a 10 percent increase in productivity of cars in guaranteed service, the unit capacity costs for guaranteed service are 2182 (2400/1.1) and 1909 (2100/1.1) for $\lambda=0.2$ and 0.3, respectively. Hence, as λ increases from 0.2 to 0.3, the per unit cost of guaranteed service increases from 2782 to 2809.

Table 5.27. Relationship Between Optimal Decisions and λ With Productivity Gains.

				Shipper Salvage Value=$5950		
Range λ	Tau	Errπ	Esπ	Guar. Cap.	Conv. Cap.	Total Cap.
0.00 to 0.36	+	-	-	-	0	-
0.37 to 0.43	-	-	+	+	0	+
0.44 to 0.83	+	-	-	-	+	+
0.84 to 0.99	+	+	-	-	+	+

The remaining phenomenon of Table 5.17 are replicated in Table 5.27, but at larger values of λ. For example, in the interval $\lambda \epsilon [0.37,0.43]$ the railroad reduces its tariff to attract guaranteed service in order to remain as a scheduled carrier. Without productivity gains the interval was [0.34,0.40].

The incentive for the railroad to remain a scheduled carrier disappears occurred in the interval $\lambda \epsilon [0.44,0.83]$ with productivity gains and the interval [0.41,0.76] without the gains. The railroad increases its tariff rate and begins to acquire a conventional service fleet. Expected decreases in the interval, as the increased expected profit from conventional sales is less than the decreased profit from the lost guaranteed sales.

Eventually, railroad expected profit increases, when $\lambda \epsilon [0.84,0.99]$ with productivity gains and [0.77,0.99] without the gains. In these instances, the increased expected profit from conventional sales is greater than the decreased profit from the lost guaranteed sales.

Guaranteed Service Limit

Currently, railroads limit the amount of guaranteed service offered to shippers. The BN limits the amount of COTs to 40 percent of its projected fleet, while the Soo PERX limit is 25 percent. An auction is used by these railroads to distribute the guaranteed service among shippers. Limiting the supply of guaranteed service increases shipper bids and contributes to the restricted supply. The UP, which offers guaranteed service at the same rate as conventional service, also restricts the amount of guaranteed service. Each shipper is given an upper limit on the amount of guaranteed service it can acquire. The upper limit is based on a four year historical average of railroad provided cars. The upper limit gives the shippers the incentive to use more rail service (guaranteed and conventional service) to protect their future allocations of guaranteed service. The UP reasoning for such a system is to increase the equity in the distribution of guaranteed service [Machalaba, 1990].

The constraints on guaranteed service appear to be more political than institutional. The Staggers Act stated (in regards to contract service) that a railroad is prohibited from entering into contracts for the transportation of agricultural commodities which utilizes more than 40 percent of its fleet [Goldstein, 1991]. The ICC, however, found the BN COT program not to be a form of contract service and therefore is not bound by such a constraint [Brown, 1992; Cawthorne, 1992]. The purpose of the contracting constraint was to ensure railroads could fulfill their common carrier obligation of providing adequate conventional tariff service to shippers on reasonable request.

Railroads may limit guaranteed service in order to maintain a good working relationship with shippers. Railroads are usually perceived as giant enterprises enjoying a high degree of monopoly power, while small farmers and grain shippers operate in highly competitive markets. Consequently, railroad actions attract a great deal of public and political concern and rail executives may well avoid any negative attention [USDOT, 1994]. The self-imposed limit may serve as public relations device to ensure shippers there is enough rail capacity for the railroad to satisfy its common carrier obligation. A smaller guaranteed fleet is perceived by shippers to imply a larger conventional fleet. The railroad is then perceived as providing adequate conventional tariff service on reasonable request.

The purpose of this section is to analyze the effects of railroads limiting the amount of guaranteed service to shippers. The guaranteed service limit will be shown to inhibit the railroad fleet sizing decision. The limit serves to restrict the grain market information flowing from shippers to the railroad when acquiring guaranteed service. The guaranteed service limit causes the conventional service fleet to increase, but the expected railroad and shipper profit decrease.

Simulation Results for Guaranteed Service Limit

The two situations studied are shown in Table 5.28 with $\epsilon=300$, and $\lambda=0.3$ and 0.5. The shipper salvage value is either \$5650, \$5950, or \$6250. Suppose the amount of guaranteed service each shipper can purchase is limited to 13 units.

Table 5.28. The Effect of Limiting Guaranteed Service On Railroad and Shipper Expected Profit and Decisions.

λ	Guar. Limit	Tariff Rate t	$Err\pi$	$Es\pi$	z	Guar. Capacity	Conv. Capacity	Total Capacity
0.3	1,300	5,167	2,692,985	117,413	5650	1,300.00	233.54	1,533.54
					5950	1,299.94	19.31	1,319.25
					6250	1,085.66	19.31	1,104.97
	None	5,000	2,857,143	119,501	5650	1,642.89	0.0	1,642.89
					5950	1,428.60	0.0	1,428.60
					6250	1,214.31	0.0	1,214.31
0.5	1,300	5,046	2,625,367	119,418	5650	1,300.00	405.94	1,705.94
					5950	1,299.94	191.72	1,491.66
					6250	1,085.66	191.72	1,277.38
	None	4,822	2,744,314	122,456	5650	1,709.85	120.27	1,830.12
					5950	1,495.56	120.27	1,615.83
					6250	1,281.28	120.27	1,401.55

Hence, the railroad cannot produce more than 1300 units. In the two situations, the guaranteed service constraint is non-binding during the lowest demand period (z=6250) since shippers purchase less than 1300 units of guaranteed service. In the remaining two demand states (z=5950 and 5650) shippers desire to purchase more than 1400 units, but are constrained to 1300 units.

In this example, the railroad is able to identify the low demand period, but is unable to distinguish between the other two demand states. In the absence of rail car productivity gains, Figure 5.8 shows the relationship between shipper salvage value and guaranteed service purchased with and without the 1300 unit limit on guaranteed service purchased. With the constraint the railroad is unable to extract the private shipper salvage information whenever shippers order 1300 units of guaranteed service.

There are three possible tariff rate responses to the guaranteed service limit. First, the railroad may increase the tariff rate until it is able to distinguish between all of the demand states. The tariff rate is increased until the amount of guaranteed service in the middle demand state (z=5950) is less than the guaranteed service limit. In this case, shippers purchase the guaranteed service limit only if their salvage value is very low (z=5650) and the railroad is able to identify each demand state. Second, the railroad may

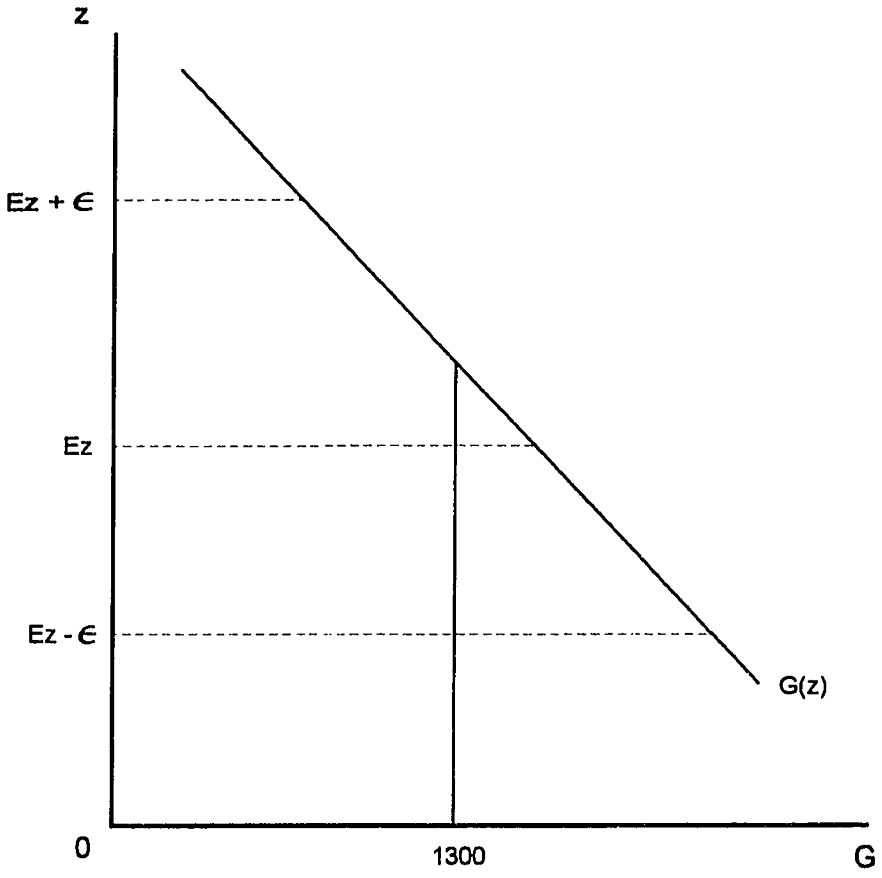


Figure 5.8. The effect of limiting guaranteed service.

alter its tariff rate but remain unable to distinguish between the middle and high demand states. Finally, the railroad could decrease its tariff rate until it is unable to distinguish between all demand states. The tariff rate is decreased until the amount of guaranteed service purchased in the low demand state (z=6250) is equal to the guaranteed service limit.

Table 5.28 shows the change in the tariff rate, conventional and guaranteed capacities, expected railroad profits, and expected shipper profits due to the guaranteed service limit of 1300 units. Expected railroad and shipper profits decreased in response to the limit, while the tariff increased. In each instance, the tariff rate was increased so the railroad could identify each demand state. In each instance, the tariff rate is increased until the amount of guaranteed service in the middle demand state is slightly below the limit.

CHAPTER 6

CONCLUDING REMARKS

The findings of this research are presented by highlighting the conclusions of previous chapters. Also, extensions of the model and suggestions for further research are presented.

Conclusions

The movement of grain by the railroad industry is plagued by the consistent presence of car shortages and surpluses. Due to these difficulties and others the Staggers Rail Act of 1980 was passed. Since the passage, the railroad industry has begun experimenting with different types of rail car ordering systems.

Previous to Staggers, railroads offered only conventional rail service. In the pre-Staggers system, shippers ordered rail service on a spot basis. Shippers have full information about grain market conditions when ordering conventional service. However, the conventional service order may be rationed.

The most recent car ordering systems offer guaranteed service in addition to conventional rail service. Guaranteed service is ordered by shippers in advance and before possessing full grain market information. However, guaranteed service orders cannot be rationed by the railroad. The railroad uses the guaranteed service orders to make a more informed capacity decision. Furthermore, the advance information concerning demand also allows the railroad to route its assets more efficiently and reduce operating costs. Conventional service is handled in the same manner as the pre-Staggers system.

The model representing the pre-Staggers system replicated the persistent existence of car shortages and car surpluses. The railroad choosing its tariff and capacity before knowing demand creates the car shortages and car surpluses. The railroad is assumed to have constant per unit operating costs and constant per unit capacity costs. This problem of a monopolist choosing capacity and price before knowing demand has been discussed previously in the literature.

The effect of increased demand variability, by the use of a mean preserving spread, on railroad decisions indicate that the tariff rate decreases and the railroad capacity either increases or decreases. Since the grain industry export demand for rail service is more volatile than its domestic demand, a railroad serving primarily export markets has a lower tariff rate than a railroad serving primarily domestic markets. Furthermore, government policies stabilizing demand for rail service increases the tariff rate. The effect on railroad capacity is indeterminate.

However, due to the shipper inventory constraint, larger mean preserving spreads of the random demand variable no longer correspond to a mean preserving spread of aggregate demand. Under such conditions, aggregate demand eventually becomes either all or nothing. The tariff rate increases to take advantage of shippers needing rail service. The effect on capacity is still indeterminate.

A recent trend in American business is for customers and suppliers to develop closer working relationships by sharing information. If shippers share their grain market information with the monopolist railroad the expected shipper profit decreases and expected railroad profit increases. Expected shipper profit decreases due to a slight increase in the tariff rate. Expected railroad profit increases due to the increased tariff rate and the increased information it possesses when determining its capacity. Total welfare increases since the increase in expected railroad profit exceeds the decrease in expected shipper profit. Then the monopolist railroad would have the incentive to transfer a portion of its increased expected profits to shipper in order to obtain their grain market information.

The distribution of operating costs to capacity costs has no effect on the tariff and capacity decisions of the monopolist when demand is known. Given total unit costs, monopolists with relatively higher operating costs than capacity costs act the same as monopolists with relatively lower operating costs than capacity costs. The only factor affecting the decisions of the monopolist is the sum of unit operating and unit capacity costs. However, under demand uncertainty, a monopolist with higher operating costs relative to capacity costs will have a greater tariff rate and capacity level than a monopolist with higher capacity costs relative to operating costs.

Recently, railroads have instituted car ordering systems offering guaranteed service as well as conventional tariff service. The effect of guaranteeing service was divided into the shipper externality, informational effect, and the rail car productivity effect.

The shipper externality was identified as the shippers failing to take into account the effect of their guaranteed car order on the conventional service ration quantity available to all shippers. The externality serves to reduce shipper expected profit.

The railroad is able to extract the grain market information possessed by shippers by offering guaranteed service. The additional grain market information allows the railroad to make a more informed capacity decision. This is the informational effect of guaranteeing service. The informational effect always increases total welfare and expected railroad profits. Expected shipper profit may increase or decrease.

Expected shipper profits decrease when capacity costs are high relative to operating costs. In these cases, the railroad becomes a scheduled carrier. The railroad increases its tariff rate (from the pre-Staggers rate) to take advantage of shippers fear of rationing. Conventional service demand and capacity is zero. Expected shipper profits decrease, despite the increased reliability in rail service, due to the increased tariff rate and the loss in marketing flexibility.

Expected shipper profits increase when capacity costs are low relative to operating costs. The fear of being rationed is not as great and the railroad must decrease its tariff, enticing shippers to purchase guaranteed service. The railroad is able to lock in business through the reduced tariff. In these cases, expected shipper profit increases due to the lower tariff rate and increased service offerings.

Guaranteed service is purchased in advance giving the railroad advance notice of the specific origin and destination of future movements. With this advanced information, the railroad is able to reduce its car cycle time and increase the productivity of its cars in guaranteed service. This is called the rail car productivity effect of guaranteeing service.

The rail car productivity effect always increases total welfare and expected railroad profit. Expected shipper profit either increases or remains unchanged. Rail car productivity effects lower the unit capacity costs of guaranteed service implying a lower total unit costs of producing guaranteed service (operating plus capacity costs). The railroad lowers its tariff rate (except in a few cases) in order to increase the purchase of guaranteed service. Expected shipper profit increases due to the lower tariff rate. In a few cases, the tariff rate is unchanged leaving demand unchanged. The railroad uses the productivity gains to lower its costs of producing the same output level. Expected shipper profit is unchanged in these cases.

Rail car productivity gains may increase the railroad capacity or leave it unaltered. However, the fleet size necessary to produce the improved or unaltered railroad capacity may actually decrease. Hence, with rail car productivity gains comparing the fleet sizes of pre-Staggers car ordering systems to current car ordering systems in order to make inferences about shipper welfare is meaningless.

Currently, railroads limit the amount of guaranteed service shippers may acquire. The reasons for this limit appear to be more political than economic. The limit appears to serve as a public relations device to ensure shippers there is enough rail capacity for it to satisfy its common carrier obligation. A smaller guaranteed service fleet implies a larger conventional service fleet, and thus the better the railroad becomes at providing adequate conventional tariff service at reasonable request.

The effect of the guaranteed service limit is to decrease expected railroad profits, expected shipper profits, and thus total welfare. The railroad increases its tariff rate, so shippers only purchase the guaranteed service limit when the future expected demand for conventional rail service is high. This allows the railroad to maintain its informational gain when making capacity decisions. The limit decreases guaranteed service capacity and increases conventional service capacity. However, total capacity of the railroad decreases. The guaranteed service limit increases conventional service capacity, but decreases the welfare of both the railroad and shippers.

A final result from guaranteeing service is its stabilizing effect on the tariff rate and expected railroad profits. A mean preserving increase in the volatility of rail demand leaves the tariff rate and expected railroad profits unchanged when the railroad offers both guaranteed service and conventional service. Hence, a railroad serving primarily domestic markets acts the same as a railroad serving primarily export markets. If the railroad offers only conventional rail service, an increase in demand volatility decreases the tariff rate and reduces expected railroad profit.

Suggestions for Further Research

The model presented in this research to study the effects of guaranteed service is very restrictive. The restrictions were necessary to simplify the analysis and to obtain initial results. The model consists of a single period, a single market, and a single carrier. Extensions of the model include a multi-market dynamic model allowing shippers to either sell their grain to many markets or store the grain to sell at a later date. The extended model could also include alternative modes of transportation or more than one carrier for each mode of transportation. The transportation industry could be modeled an oligopolistic industry with a few large carriers. Alternatively, the dominant firm model could be used to model the transportation industry, with the railroad as the dominant firm and the trucking industry as the competitive fringe [Wilson et al., 1987 and 1988].

The model assumed a single price for both tariff and guaranteed service which is representative of the Union Pacific Railroad. However, the Burlington Northern Railroad and Canadian Pacific Soo Line offer guaranteed service through a quasi auction. A model could be formulated allowing different prices for guaranteed service and conventional service. Also, the auction process of allocating guaranteed service could be modeled and the effects of the auction rules on the shipper and welfare be investigated [Wilson, 1989].

The model also assumed each shipper is identical. Each shipper could be assumed to possess different salvage parameters. Hence, the demand for guaranteed and conventional service would differ among shippers. Under these assumptions, the allocation rule used in this research to ration conventional service would be inefficient. Furthermore, if shippers value guaranteed service differently, the process used for rationing a limited supply of guaranteed service would affect the welfare of both the railroad and shippers.

Also, grain supply is assumed to be constant and homogenous. Shippers at the time of ordering guaranteed service may not know how much grain they will have in storage. Supply uncertainty would affect shippers desire for guaranteed service. Similarly, differing the inventory of each shipper would allow the distinction between how small and large shippers are treated by railroads under various car ordering systems.

With many carriers between a single origin and destination demand for rail services could be a function of reliability and price. Shippers are affected by the delay length in receiving timely service. Reliability could be measured as the number of days waiting for transport service.

The expected costs of waiting for transport service, the transport price, and the grain market price would determine where and how shippers move their grain. The expected costs of waiting for rail service has been estimated as well as the maximum amount shippers are willing to pay for more reliable rail service [Pautsch et al., 1995].

The model presented in this research assumes shippers either receive their entire car order on a timely basis or only a portion of the order on a timely basis. Queueing models could replicate the wait shippers experience when ordering rail service. Shippers could renege or cancel orders if the delay is too long. The fleet size could be the number of servers and car cycle times the customer service times. The affects of guaranteed service could be analyzed in a priority queue where guaranteed service receives service before conventional tariff service. The informational effect of guaranteed service on the delay length of conventional service has been formulated in a priority queue setting [Pautsch, 1995].

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