Railroad Cost Conditions - Implications for Policy

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Disclaimer

This report includes a simplified framework for examining the welfare implications of railroad mergers and competition. The framework is explained in a non-technical manner, so that it is accessible to those with minimal training in economics. In this non-technical explanation, many figures are presented for illustrative purposes, but these figures are not used to compute the welfare tradeoffs. Rather, the figures are provided to enable an intuitive understanding of the framework used to measure welfare tradeoffs attributable to mergers and competition.

Acknowledgment

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EXECUTIVE SUMMARY

Several recent trends in regulatory policy and in the structure of the railroad industry have drawn a renewed interest in railroad regulation. These trends have included: (1) deregulation of the telecommunications and electrical utility industries, (2) major railroad mergers of the Burlington Northern and Sante Fe railroads, the Union Pacific and Southern Pacific railroads, and Conrail with the CSX and Norfolk Southern Railroads, (3) the Surface Transportation Board's efforts to stream-line regulations governing the railroads, and (4) an increased intensity of Congressional interest in rail transportation issues. Recent complaints before the Surface Transportation Board regarding pricing and service, and the recent formation of shipper groups seeking regulatory change also suggest that interest in regulations affecting the rail industry is intense.

Renewed interest in railroad regulatory issues has generated at least three policy proposals for changing railroad regulations, which have been tied to reauthorization of funding for the Surface Transportation Board. The types of changes in regulations suggested by the proposals vary widely, but the main components of regulatory change suggested have included: (1) restrictions on merger activity, (2) changes in maximum reasonable rate determinations to introduce more equity among shippers, and/or (3) introduction of intramodal competition through open access to rail lines. To make an assessment of the desirability of various policies, at least two things might be considered, including: (1) the impacts of various policies on allocative efficiency or social welfare, and (2) the distributional impacts of each policy.

However, there is no clear way to assess the overall impact of various distributional impacts of policy on society. Comparing policies based on distributional impacts requires value judgements, which are made on grounds that are not scientific. Because it is not clear what the desirable distributional impacts of any policy would be, economic analyses of policy generally focus on social welfare maximization or allocative efficiency. Similarly, this study only considers the social welfare maximization criterion.

An assessment of the impacts of policy change on societal welfare requires knowledge of changes in consumer and producer surplus resulting from such policy changes. In total, the combination of consumer and producer surplus shows the value of goods and services to society in excess of the costs of resources used to produce them.

In examining the impacts of various railroad regulatory policies on social welfare or allocative efficiency, two questions are relevant: (1) How will the policy affect the cost of the resources used to produce railroad services? and (2) How will the policy affect the price of railroad services to shippers? Arguments advocating competitive policies in the rail industry generally highlight the textbook advantages of competition over monopoly of a larger sum of consumer and producer surplus due to a restriction on output by monopoly. However, the advantages of competition over monopoly are not as clear cut as the simple textbook illustrations show. The advantages are only so clear when the costs of providing services are the same for competitive or monopoly firms.[1] In cases where there are substantial economies of scale and scope in the production (as there appears to be in the rail industry), competition can increase the

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[1]When the monopolist practices price discrimination, monopoly does not necessarily result in lower social welfare than competition. For the purely price discriminating monopolist, the sum of consumer and producer surplus is equal to that of competition. Because railroads practice differential pricing, competition in this industry may not result in a large social welfare improvement over monopoly even if the costs of providing service are the same under competitive and monopoly industry structure.

costs of resources used in production, potentially reducing societal welfare. This study explores one component of the impacts of various policies on social welfare – the impacts that the policies have on resource costs. Specifically, the study examines the cost implications of mergers and competition over existing rail lines.

This study examines the cost implications of mergers and competition over existing rail lines by testing for the condition of cost subadditivity. That is, can industry output be provided at a lower cost by one firm than by more than one firm? This condition is examined directly by simulating single-firm and two-firm costs under various output combinations, using output-cost relationships estimated from a statistical cost function. Specifically, the study tests for the condition of cost subadditivity in the railroad industry under three different alternatives to single firm operation: (1) subadditivity of costs while holding network size constant, providing an assessment of the desirability of parallel railroad mergers; (2) subadditivity of costs while network size is expanded, providing an assessment of the desirability of end-to-end mergers; and (3) subadditivity of costs over a single railroad network after the costs associated with maintenance of way and structures are eliminated, providing an assessment of the desirability of multiple firm competition over existing rail networks. The last of the three tests is relevant for making an assessment of the desirability of recent proposals calling for "open access" or for opening bottleneck segments of the rail system to competition. Cost functions are estimated using Class I railroad annual report data (R-1 data) from 1983 through 1997 (215 observations).

In performing simulations of single-firm and two-firm costs, where the alternative to single-firm operation is separate railroads serving duplicate markets, the condition of strict cost subadditivity is met for 91.7 percent of observations using the 1983 cost structure, and for all observations using the 1997 cost structure. The condition of strict cost subadditivity is met when all hypothetical two-firm combinations have a higher total cost than the single firm. Moreover, the average increase in costs in 1997 resulting from duplicate service is estimated to be more than 40 percent. Thus, it is clear that Class I railroads are natural monopolies over a fixed network size. This suggests that duplicate service over the Class I rail network would result in excess resource costs. Further, large percentage price increases would be necessary for parallel mergers to result in a loss to society. Thus, policies preventing parallel rail mergers do not appear to be beneficial from the standpoint of maximizing social welfare.

Second, in performing simulations of single-firm and two-firm costs, where the alternative to single-firm operation is separate end-to-end networks, the condition of strict cost subadditivity is met for only 2.9 percent of the observations in 1997, and monopoly costs are lower than two firm costs only 13.2 percent of the time (on average, costs decrease with two-firm operation by 12.5 percent in 1997). Simulations also show that the condition of strict cost superadditivity is met for 51.5 percent of the observations in 1997. Strict cost superadditivity is the condition where all two-firm combinations have lower costs than the monopoly firm. Thus, there is little support for the notion that railroads are natural monopolies as network size is expanded. This suggests that further end-to-end mergers may not be beneficial from a cost perspective. However, further end-to-end mergers could result in service improvements to shippers. For example, replacing joint-line movements with single-line service has long been considered an important, but unquantifiable, service benefit of end-to-end mergers. Nonetheless, the cost results suggest that such service improvements would have to be substantial for further end-to-end mergers to be beneficial from a social welfare perspective.

Third, in performing simulations of single-firm and two-firm costs operating over one railroad network, 95 percent of all simulations show monopoly costs to be lower than two-firm costs in 1997. Moreover, the condition of subadditivity is met for more than 60 percent of all observations in 1997, and superadditivity is not met for any of the observations in 1997. These results suggest that multiple-firm operation over a single rail network would lead to large cost increases.[2] Further, social welfare would not be improved by multiple-firm competition over single rail networks unless large price decreases occurred.[3] Costs would increase in cases of total open access, or in cases of introducing competition to bottleneck segments.

These findings suggest that it may be more beneficial to address rate and service problems in the rail industry through policies that strengthen regulatory oversight rather than through policies of introducing or maintaining competition.

Finally, one additional point regarding the findings of this study is important to consider. The study uses a methodology that is similar to that used by Shin and Ying (1992) in evaluating whether the telecommunications industry is a natural monopoly. That study, and others, have found that the telecommunications industry is not a natural monopoly. The findings are in

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[2]Estimated cost increases from multiple firm operation over single rail lines range from 3.8 percent for a railroad with road mileage and density similar to the BNSF in 1997, to 15.5 percent for a railroad with road mileage and density similar to CSX in 1997. Since estimated cost increases are based on a quasi-cost function (not a true cost function), caution must be used in examining the magnitude of the estimated cost increase.

[3]For a railroad with road mileage and traffic similar to the BNSF in 1997, an elasticity of demand of ½, and an original markup by the railroad above average costs of 200 percent, prices would have to decrease by nearly 28 percent before competition would improve social welfare. For a railroad with road mileage and traffic similar to CSX in 1997, and the same demand elasticity and original markup, the price decrease would have to be nearly 56 percent for competition to improve social welfare.

contrast to those for the rail industry presented in this study. However, a close examination of the two different industries suggests that the cost implications of expanding service in the telecommunications industry should not be the same as the cost implications of expanding service in the railroad industry. In the telecommunications industry, expanding service in local markets means the installation of more access lines, while in the railroad industry an expansion of service in local markets does not require an expansion of the rail network.

1. INTRODUCTION

Several recent trends in regulatory policy and in the structure of the railroad industry have drawn a renewed interest in railroad regulation. These trends have included: (1) deregulation of the telecommunications and electrical utility industries, (2) major railroad mergers of the Burlington Northern and Sante Fe railroads, the Union Pacific and Southern Pacific railroads, and Conrail with the CSX and Norfolk Southern Railroads, (3) the Surface Transportation Board's efforts to stream-line regulations governing the railroads, and (4) an increased intensity of Congressional interest in rail transportation issues. Recent complaints before the Surface Transportation Board regarding pricing and service, and the recent formation of shipper groups seeking regulatory change also suggest that interest in the regulations affecting the rail industry is intense.

The renewed interest in railroad regulatory issues has generated at least three policy proposals for changing railroad regulations that have been tied to reauthorization of funding for the Surface Transportation Board. The types of changes in regulations suggested by the proposals vary widely, but the main components of regulatory change suggested have included: (1) restrictions on merger activity, (2) changes in maximum reasonable rate determinations to introduce more equity among shippers, and/or (3) introduction of intramodal competition through open access to rail lines or through reciprocal switching agreements. To make an assessment of the desirability of various policies, at least two points might be considered, including: (1) the impacts of various policies on allocative efficiency or social welfare, and (2) the distributional impacts of each policy.

However, there is no clear way to assess the overall impact of various distributional impacts of policy on society. Comparing policies based on distributional impacts requires value judgements, which are made on grounds that are not scientific. Because it is not clear what the desirable distributional impacts of any policy would be, economic analyses of policy generally focus on social welfare maximization or allocative efficiency. Similarly, this study only considers the social welfare maximization criterion.

In examining the impacts of various railroad regulatory policies on social welfare or allocative efficiency, two questions are relevant: (1) How will the policy affect the cost of resources used to produce railroad services? and (2) How will the policy affect the price of railroad services to shippers? This study explores one component of the impacts of various policies on social welfare – the impacts that the policies have on resource costs. Specifically, the study examines the cost implications of mergers and competition over existing rail lines.

The first part of the study provides a simplified framework for examining the welfare implications of mergers and competition, including an explanation of social welfare, natural monopoly, railroad characteristics, and the distinction between short-run and long-run costs. All of these issues are explained in a non-technical manner, so they are accessible to those with minimal training in economics. Next, a model for examining the cost implications of railroad mergers is presented. In addition to the model and estimation results, measures of economies of size and density are presented over time and by railroad, cost comparisons are made between monopoly and competing firms, and discussions regarding the implications for societal welfare are presented. Third, a model for examining the cost implications of multiple railroads operating over the same network is provided. Finally, a summary of results is presented, along with policy implications. A review of literature of similar studies performed in the electric utility and telecommunications industries is presented in an appendix. This review highlights similarities and differences between these industries and the railroad industry.

2. SOCIAL WELFARE AND INDUSTRY STRUCTURE

When economists use the term efficiency, they usually are referring to allocative efficiency or social welfare. The terms allocative efficiency and social welfare are interchangeable, referring to an allocation of resources in society that maximizes the value of goods and services received by society in excess of the costs of resources used in producing those goods.

The tools used to measure the social welfare implications of the structure and behavior of specific markets are consumer's and producer's surplus. For a particular market, consumer's surplus is defined as the sum of the value of the good or service for all consumers less the price that all consumers are charged for the good or service. Similarly, producer's surplus is defined as the sum of the revenues earned less the costs of resources used to produce those revenues (including opportunity costs). Thus, it can be defined as economic profits.

A better understanding of consumer's and producer's surplus can be gained by examining Figure 1.[4] Suppose that Figure 1 represents the interaction of demand and supply in the market

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[4]Technically, consumer's surplus should measure the amount consumers would need to be paid to not consume the good at its current price, and keep their level of utility unchanged. This is measured by the compensated (Hicksian) demand function, which shows price/quantity relationships obtained by minimizing the consumer's expenditures on goods and services subject to a constant utility level. In effect, the compensated demand function for a particular good or service shows how price changes will impact the consumer's choice if he or she is compensated for the price change in order to leave utility unchanged (that is, the change in quantity due to substitution away from that commodity). Thus, separate compensated demand functions exist for each level of utility. This makes it difficult to measure consumer's surplus using the compensated demand function, because a price increase in a particular market will result in a reduction in utility, and consequently a shift to a different compensated demand function. Thus,

for wheat. The demand function represents the horizontal summation of individual demands for wheat, showing the quantity demanded at various prices. The supply function represents the horizontal summation of individual farmer marginal cost curves, showing the amount of wheat farmers are willing to supply at various prices.

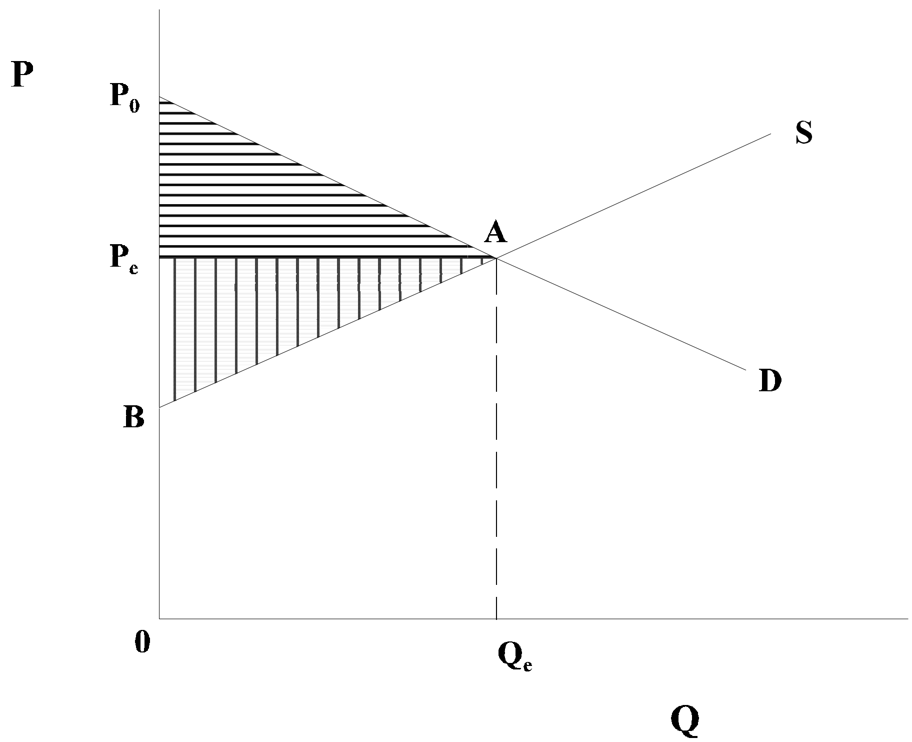

Figure 1

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not only is compensated demand unobservable, but there are two different measures of consumer's surplus using compensated demand. One measure uses the initial compensated demand function as the base (when the price rises, how much must the consumer be compensated to keep utility (u_0) at its initial level?) and the other uses the new compensated demand function as the base (if the price falls from its new level back to its initial level, how much must the consumer pay to keep utility (u_1) at its new level?). Willig (1976) has shown that consumer's surplus measured using the ordinary demand function will lie somewhere in between these two. Thus, in practice the ordinary demand function is frequently used to describe consumer's surplus. See Willig, Robert D. "Consumer's Surplus Without Apology," *The American Economic Review*, Vol 66, Sept. 1976, pp. 589-597.

It is apparent from Figure 1 that the equilibrium in this market occurs at a price of P_e and a quantity purchased of Q_e. For all quantities less than Q_e, consumers are willing to pay a higher price for wheat than P_e. This is shown by the demand function, suggesting that the area $P_0 A P_e$ is the total amount by which the value placed on obtaining the commodity by consumers exceeds the price that consumers must pay. This area is the consumer's surplus. Similarly, since the supply curve shows the amounts of wheat that farmers are willing to supply at each price, farmers would be willing to supply all quantities below Q_e at prices lower than P_e. The area $B A P_e$, which shows the total revenues earned in excess of resource costs, is the producer's surplus.[5] The total of consumer's and producer's surplus shows the difference between the value placed on wheat by consumers and the total resource costs needed to produce wheat. The market is economically efficient when the value placed on consuming one more unit of wheat is equal to the resource cost of producing one more unit. This occurs at the market clearing price of P_e and the quantity of Q_e. If more wheat than Q_e is produced, the resource costs associated with producing it will exceed the value placed on it by society. If less wheat than Q_e is produced, society places a higher value on consuming more wheat than the costs of the resources that would be needed to produce it.

The concepts of consumer's and producer's surplus can be used to show the effects of various product market structures on allocative efficiency. These concepts have been used to

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[5]If there is a fixed cost of production, this cost must be subtracted from producer's surplus.

show the well known finding that monopoly market structure results in a misallocation of resources in markets characterized by constant returns to scale.[6]

To understand the traditional argument for public policy to eliminate monopoly, examine Figure 2. Figure 2 shows the competitive and monopoly equilibria in a market characterized by a cost structure where the monopoly firm and the competitive firm have the same costs (constant returns to scale).

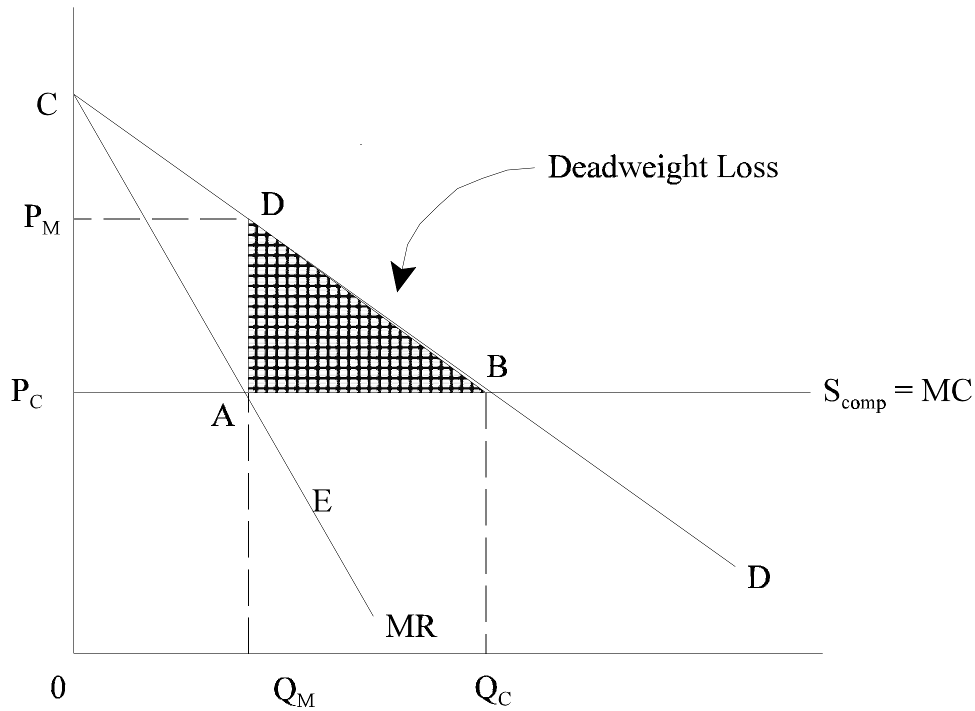

Figure 2

The competitive and monopoly price/quantity outcomes are shown in the figure. The price charged under competition is $P_{C,}$ and the total quantity sold under competition is $Q_{C.}$ Price is set equal to marginal cost under competition, because each firm is a price taker (each firm is

[6]The concept of returns to scale is examined in a subsequent section.

small relative to the market so that its action has a very small effect on price). Under monopoly, the firm faces a downward sloping demand curve. Thus, at any output level, to sell more output to customers it must reduce the price on all previous quantities sold.[7] Thus, the firm's marginal revenue (extra revenue from another unit sold) is equal to the price less the reduction in revenue on all previously sold units. For the monopolist, then, the marginal revenue of an extra unit sold is always less than price, while for the competitive firm the marginal revenue of an extra unit sold is always equal to price. Like the competitive firm (where marginal revenue equals price), the monopolist produces at the point where marginal revenue is equal to marginal cost (i.e. producing another unit will increase cost more than it increases revenue). The price charged under monopoly is P_M, while the quantity sold is Q_M.

Under competition, the total social welfare obtained in this market – that is the value placed on the good or service in excess of the resource costs used to produce it – is defined by the area C B P_C. This total value of social welfare obtained in this market is the sum of the consumer's surplus (C B P_C) and producer's surplus (none in this case). Under monopoly, the total social welfare obtained is defined by the area C D A P_C. This is the sum of the consumer's surplus (C D P_M) and producer's surplus (P_M D A P_C). Because monopoly limits the quantity sold to Q_M, there is a loss (labeled Deadweight Loss) to society. For quantities between Q_M and Q_C, society places a greater value on the good or service than the resource costs needed to produce it. Thus, there is a deadweight loss of D B A.

[7]We will assume a monopolist that is not able to price discriminate. If the monopolist is a price-discriminating monopolist, the welfare loss from monopoly is not likely to be as large. However, the income distribution effects are likely to be greater.

As Figure 2 shows, there also is a redistribution of income from consumers to producers resulting from the monopoly. A consumer surplus of P_M D A P_C is shifted to producers. Whether this is desirable or not depends on a value judgement. The most disturbing aspect of monopoly to economists is that too few resources are employed in the particular market. That is, society values the good or service produced by such resources more than the costs of using the resources to produce the good or service.

However, when an industry is characterized by increasing returns to scale, the welfare implications of monopoly market structure are not as clear. Consider Figure 3, which shows a single product industry where outputs are supplied at a lower cost by one firm than by more than one firm.[8] The monopoly firm limits output to a level of Q_M and charges a price of P_M, whereas competitive firms produce a combined output of Q_C and charge a price of P_C. Thus, the triangle defined by E C F is the traditional deadweight loss triangle due to monopoly. That is, for quantities of the good or service between Q_M and Q_C, consumers place a higher value on the good or service than the cost of production for competitive firms. However, there also is a deadweight

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[8]In the figure, the true average cost curves and marginal cost curves are not shown. Rather, AC_{MONOP} shows the average cost of producing output Q_M by the monopolist, and AC_{COMP} shows the average cost of producing output Q_C by competitors. The diagram is drawn in this manner for simplification purposes. We assume that marginal cost for the monopolist is close to the average cost at the point Q_M. Thus, the monopoly output will be close to the intersection of MR and AC.

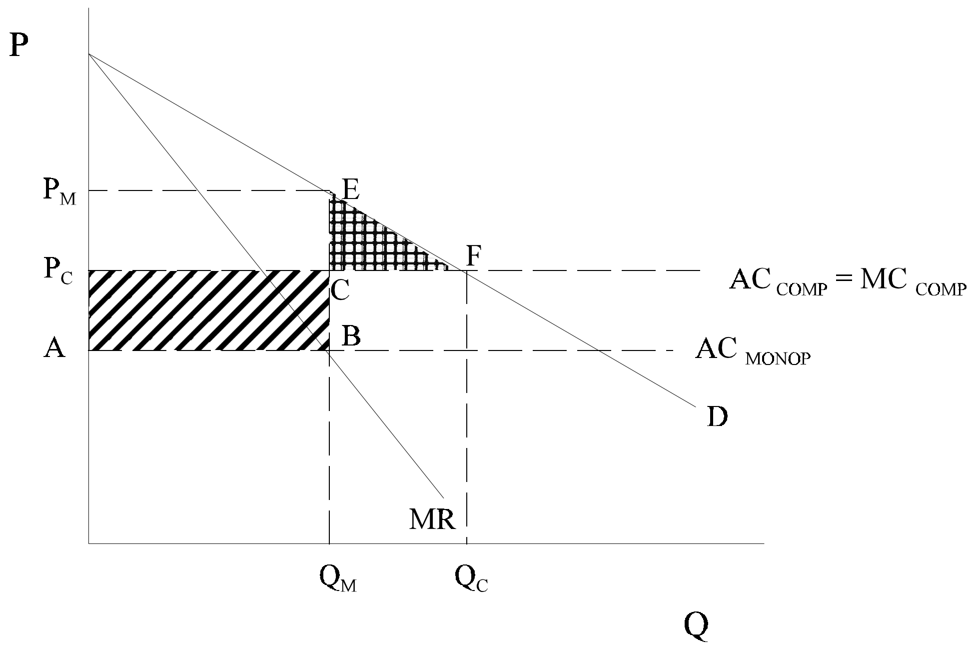

Figure 3

loss due to competition when compared to monopoly in this case. Because the monopoly firm realizes a lower cost of production than competitive firms, competition in this market creates a social welfare loss equal to the rectangle A B C P_C.[9] This rectangle represents the excess resource costs consumed in the production of Q_M under the competitive scenario. Thus, in cases where the monopoly cost of production is lower than the multiple firm cost of production, the total impact of each market structure on social welfare can only be made by comparing the total differences in resource costs (A B C P_C), and the traditional welfare loss triangle (E C F). In analyzing the welfare effects of mergers, Williamson (1968) has shown that small decreases in

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[9]Competitive firms realize higher average costs than the monopoly firm because they each are producing at a smaller scale. Thus, they are not able to take advantage of scale economies.

costs can offset large price effects resulting from increases in market power. For example, at an elasticity of demand of one (a one percent increase in price leads to a one percent decrease in quantity purchased) a merger that leads to a 30 percent increase in price still will have positive effects on social welfare as long as costs decrease by at least 6.4 percent.[10]

In this study, the cost implications of railroad mergers and of railroad competition over common rail lines are examined. Specifically, estimates of cost savings (or increases) from single firm operation over multiple-firm operation on separate and common networks are provided. The simple framework presented above can be used in conjunction with the cost estimates provided in this study, hypothesized demand elasticities, and hypothesized price effects of mergers in different markets to make an assessment of the potential social welfare implications of railroad mergers and railroad competition over common rail lines. In essence, the cost estimates provided in this study will provide an assessment of the size of the rectangle A B C P_C under various firm configurations. The next section of the study reviews basic cost concepts, providing a rationale for the empirical models used in subsequent sections.

3. COSTS, COST FUNCTIONS, AND NATURAL MONOPOLY

To make an assessment of the effects that various market structures are likely to have on costs, we must define a framework over which costs can be analyzed. Economists typically assume that the firm minimizes the costs of producing various levels of outputs, conditioned on prices paid for factors of production and the technology available to the firm.

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[10]This holds for the case where the original market power is negligible. The percentage decreases in costs necessary to offset various price increases are slightly higher when reasonable initial market power parameters exist. See Williamson, Oliver. "Economies as an Antitrust Defense: The Welfare Tradeoffs," *American Economic Review*, Vol. 58, March 1968, pp. 18-36.

The technology available to the firm is defined by a production possibilities set. The production possibilities set shows all the technologically feasible input/output combinations that are available to the firm. The subset of production possibilities that are technologically efficient for the firm producing only one good or service are shown by the production function. The production function shows the maximum amount of output that can be produced with different combinations of inputs that are part of the firm's production possibilities. Mathematically, the production function can be defined as: $Y=f(\mathbf{x})$, where Y is the maximum output that can be produced from a vector of inputs, **x** . For the firm that produces multiple products or services (as rail firms do), technologically efficient production plans are represented by a transformation function, rather than a production function. The transformation function shows the maximum vector of outputs that can be produced with a vector of inputs. The transformation function is shown as: $T(\mathbf{y}, \mathbf{x}) = 0$, where **y** is a vector of outputs and **x** is a vector of inputs. The transformation function is equal to zero only when the maximum **y** is produced with a given **x**.

In examining the cost minimizing problem of the firm, a distinction is made between the short run and the long run. It is recognized that there is some period of time where certain inputs of the firm cannot be adjusted. For example, in the railroad industry, the amount of track in place and the overall quality of the track cannot be adjusted instantaneously. That is, although the most efficient way to increase the amount of rail services provided might involve an increase in the quality of rail track, there is some period of time where the firm will not be able to make such an adjustment. Moreover, if the increase in rail services is temporary, the firm may not want to make such an adjustment. This period of time where some inputs of the firm are fixed or cannot be adjusted is defined as the short run. In the short run, the cost minimizing problem for the multiproduct firm is to choose the amounts of variable inputs used to produce a particular level of output, given some fixed amount of capital stock and given the technology available, in order to minimize costs. Mathematically, the short-run cost minimizing problem is:

$$\min_{x_{i \neq k}} \left(\sum_i w_i \cdot x_i + w_k x_k \right) \quad s.t. \quad T(y, x) = 0$$

$$\begin{aligned} where:\ & x_i \text{ are variable inputs} \\ & x_k \text{ is a fixed input in the short run} \\ & w_i \text{ are prices of variable inputs} \\ & w_k \text{ is the price of the fixed input} \end{aligned}$$

This is set up as a constrained optimization problem, and solved using classical optimization techniques (calculus). The solution to the constrained minimization problem is the optimal amounts of variable inputs to employ as a function of input prices, output level, and the amount of the fixed input employed or the scale of operation. These optimal amounts of inputs to employ as a function of input prices, output level, and the amount of the fixed input employed are known as short-run conditional input demand functions. They are substituted into the expression representing the firm's total expenditures to obtain the short-run cost function for the firm. Mathematically:

The solution to cost minimization problem yields:

$$x_i^* = x_i^*(w_i, y, x_k) -- \textit{conditional input demands.}$$

These are substituted into the following:

$$C = \sum_i w_i x_i + w_k x_k \;, \quad \textit{to get the short-run cost function:}$$

$$C = \phi(w_i, k, q) + b(k),$$

$$\begin{aligned} where: &\phi(k, q) = \textit{variable costs} \\ &b(k) = \textit{fixed costs} = w_k x_k \end{aligned}$$

The short-run cost function shows the minimum cost of producing any output level, given input prices and the levels of fixed factors.

In the long run, the firm is able to adjust all of its inputs to minimize costs, including inputs that are fixed in the short run. Thus, in the long run, the cost minimizing problem for the multiproduct firm is to choose the amounts of all inputs used (including those fixed in the short run) in order to minimize costs for a producing a particular level of output. Mathematically, the long-run cost minimizing problem is:

$$\min_{x_i} \left(\sum_i w_i \cdot x_i \right) \quad s.t. \quad T(y, x) = 0$$

$$\begin{aligned} where: \; &x_i \textit{ are all inputs} \\ &w_i \textit{ are prices of all inputs} \end{aligned}$$

The conditional input demand functions obtained from applying classical optimization techniques to this problem will show input demand as a function of input prices and output levels. These conditional input demand functions are substituted into the expression for the firm's total costs to obtain the firm's long-run cost function. The firm's long-run cost function shows the minimum costs associated with producing any level of output. The main difference between the long-run cost function and the short-run cost function is that the long-run cost function shows the costs of producing any output level while the factor that is fixed in the short run (typically capital stock) is at its cost minimizing level for that output, while the short-run cost function shows the costs of producing any output level while the fixed factor is at some constant level. Thus, the cost of producing any output level on the long-run cost function is always less than or equal to the cost of producing that output level on any short-run cost function.

Since each output level will have an appropriate capital stock level for minimizing costs, and since each short-run cost function is conditioned on a particular capital stock level, the long-run cost function is obtained from each short-run cost function where the capital stock level is the minimum cost capital stock level for a particular output. Figure 4 shows this relationship for a single product firm, illustrating the fact that the long-run cost function is the envelope of all the short-run cost functions.

Recall that each short-run cost function shows the minimum achievable costs for producing each level of output, for a fixed level of capital. As Figure 4 shows, for each level of output q, there is a short-run cost function that results in the lowest possible costs. For example, in Figure 4, C_{SR1} is the short-run cost function for a capital stock of k_1. It provides the lowest cost of producing q_1 of any short-run cost function. Similarly, C_{SR2} is the short-run cost function for a capital stock of k_2, providing the lowest cost of producing q_2 of any short-run cost function. Since C_{SR1} provides the lowest possible cost of producing q_1 and C_{SR2} provides the lowest possible cost of producing q_2, the firm would choose a level of capital stock equal to k_1 to

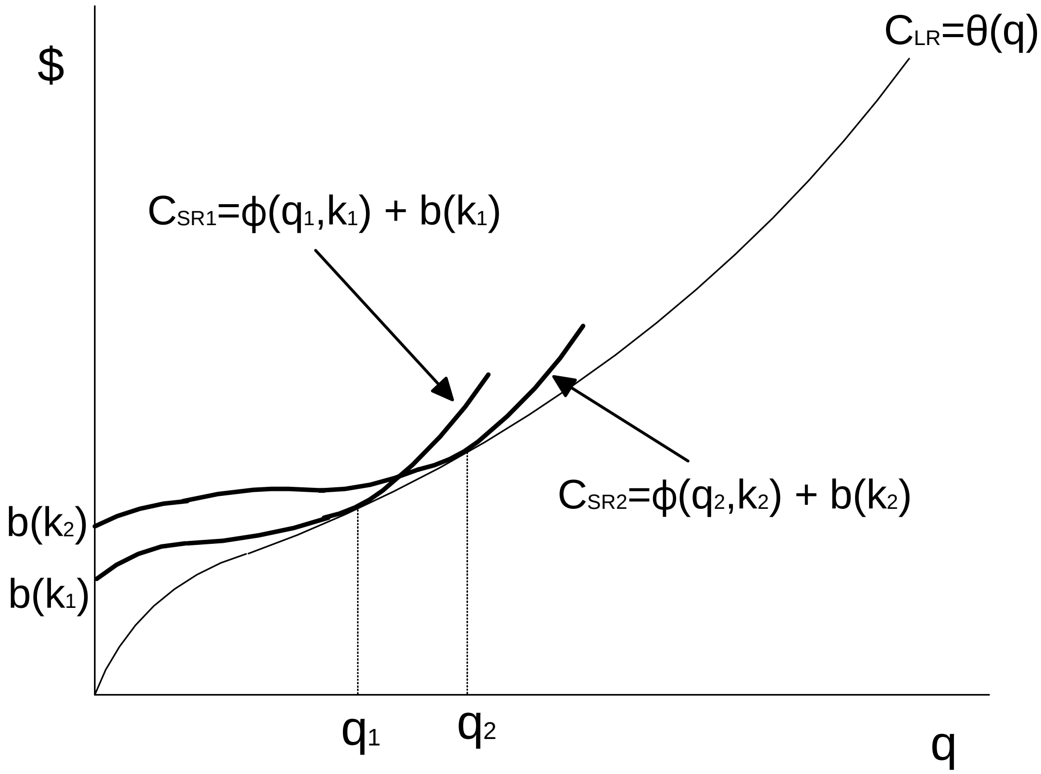

Figure 4

produce q1 and a level of capital stock equal to k2 to produce q2 in the long run. Thus, the long-run cost curve is tangent to each short-run cost curve where the short-run cost curve shows the minimum cost for producing a particular output level.

Because, the long-run cost function shows the minimum cost of producing a particular output level for the single-product firm, or a particular combination of outputs for the multiple-product firm, it can be used to assess the technology used to produce outputs.[11] Thus, we can estimate the cost function and use it to make assessments regarding economies of scale, weak

[11]This property is known as duality.

cost complementarities, and natural monopoly.[12] Moreover, we can examine the implications of the technology generating outputs in the industry for efficient firm configurations and the desirability of different industry structures.[13]

In making assessments of the cost implications of mergers and of competition over existing rail lines, the concept of natural monopoly is germane. It is important that we distinguish natural monopoly from monopoly behavior. As noted in a previous section of the report, economists object to monopoly behavior because too few resources are employed in a particular market.[14] That is, society values the good or service produced by a bundle of resources more than the costs of using such resources to produce the good or service in question. This negative aspect of monopoly behavior should not be confused with the technological condition of natural monopoly. Natural monopoly is a purely technological condition, showing that the outputs produced in an industry can most efficiently be produced by one firm.

Natural monopoly is a simple concept. If the outputs produced in an industry can be produced at a lower cost by one firm than by some combination of firms, then a natural monopoly exists. The cost condition that is necessary and sufficient for a natural monopoly to exist is known as strict cost subadditivity. Strict cost subadditivity is a condition where the costs of producing industry output by one firm are lower than the costs of producing industry output

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[12]These are defined in momentarily.

[13]It is important to remember that when we examine technology using this cost function approach, we are assuming that firms are combining inputs to minimize costs. However, in reality not all firms will act in this way.

[14]Again, this negative aspect of monopoly may not apply to the case of a price discriminating monopolist.

under all possible multiple firm combinations. Mathematically, strict cost subadditivity can be defined as:

$$C\left(\sum_{i=1}^{n} y_i\right) < \sum_{i=1}^{n} C(y_i)$$

where, yi's are outputs produced by each of n firms in the single product case and output vectors in the multi-product case. Since the condition of strict cost subadditivity just says that the cost of producing industry output by one firm is less than the cost of producing industry output by two or more firms, it can be rewritten as follows:

$$C(y, y') < C(y) + C(y') \quad \forall y, y'$$

where: y and y' are output vectors adding up to total industry output – y and y' can include any combinations of the firm's outputs

Because the condition of cost subadditivity is a basic concept and many types of cost functions can meet this condition, it is difficult to relate cost concepts that traditionally are examined by economists to the condition of subadditivity. Furthermore, as shown by Sharkey(1982), Baumol, Panzar, and Willig (1988), and others, many of the economic cost concepts traditionally examined are either: (1) not sufficient to guarantee subadditivity, or (2) are not necessary for subadditivity. The insufficiency of the cost concepts traditionally examined for subadditivity implies that the cost conditions traditionally examined can be met, and subadditivity still may not be met. The fact that cost concepts traditionally examined are not necessary for subadditivity implies that the cost conditions traditionally examined may not be met while subadditivity is met (the condition is too strong). This section will briefly describe some economic cost concepts traditionally examined, and their relationships to the condition of cost subadditivity.

First, it is useful to start out in the single-product setting, since the cost concepts are more easily understood in such a context. Sharkey (1982) and Baumol, et. al (1988) show that in the single product setting, the concepts of economies of scale and decreasing average costs imply cost subadditivity, but they are not necessary at the appropriate output level for subadditivity to exist. The standard textbook definition of economies of scale, also referred to as increasing returns to scale, is that a proportional increase in all inputs equal to t leads to an increase in output by more than t. Mathematically, this is defined as:

$$f(tx) > tf(x), \quad for\ t > 1$$

where: f(x) is the production function, and x is the vector of inputs

Others, including Baumol, et. al (1988) use a looser definition of economies of scale. Their definition of economies of scale is equivalent to declining average costs, and states that increasing output in the most efficient manner (all inputs don't have to be expanded by the same proportion) results in a drop in average costs. Mathematically, the degree of scale economies defined in this way is:

$$S = \frac{C(y)}{y \cdot \frac{\partial C}{\partial y}}$$

It is easily seen that this is the same as average costs divided by marginal costs.

$$S = \frac{C(y)}{y \cdot \frac{\partial C}{\partial y}} = \frac{\frac{C(y)}{y}}{\frac{\partial C}{\partial y}} = \frac{AC}{MC}$$

Since marginal cost is the cost of producing one more unit of output, marginal cost below average cost always implies that average cost is declining. Thus, if this measure is greater than 1, average costs are falling. If average costs are falling throughout the relevant range of output, it is obvious that the single product output can be provided at a lower total resource cost by one firm. That is, the condition of falling average costs implies natural monopoly in the single product case. However, an examination of Figure 5, shows that subadditivity can be met in a region of rising average costs (that is falling average costs at the level of industry output are not necessary for cost subadditivity). In the figure, there is no way to produce output q at a cost as low as AC(q) with any combination of more than one firm, even though average cost is increasing at output q.

In the multi-product case, we can't define declining average cost in the same way as we can in the single product case, because the way to measure average cost is not clear (there is no common output measure to divide into cost). For example, if we produce hamburger, we can

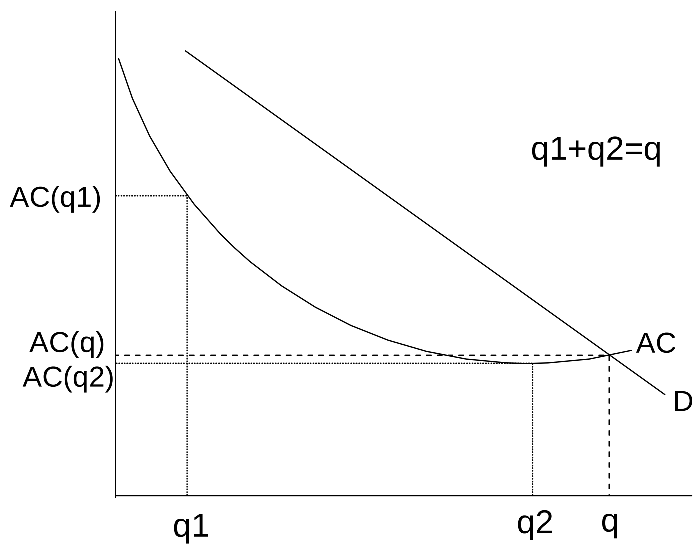

Figure 5

define average cost as total cost divided by the number of pounds. Similarly, if we produce soft drinks in cans, we can define average cost as total cost divided by cans of soft drink. However, if we produce hamburger and soft drinks, what do we use as the denominator in defining average cost? Certainly a pound of hamburger is not the same as a can of soft drink.

Because of this problem, economists examine the behavior of costs as relative output proportions are held constant using ray average costs. In essence, a composite good is formulated based on the relative output proportions chosen, and one particular bundle of composite good is chosen as having a value of one. Then, by expanding the outputs in the same proportion an output value can be formulated for each bundle based on the size of that bundle relative to that chosen as the unit bundle. Specifically, Baumol et. al (1988) define ray average costs as:

$$RAC = \frac{C(ty^o)}{t}$$

where: RAC = ray average cost
y^o = the unit bundle for the composite good
t = the number of unit bundles in the bundle $y=ty^o$

Just as single-product scale economies were described by the ratio of average costs to marginal costs, multi-product scale economies can be described by the ratio of ray average costs to marginal costs. The marginal cost of the composite good is:

$$\frac{\partial C(ty^o)}{\partial t} = y_1^o \frac{\partial C}{\partial ty_1^o} + y_2^o \frac{\partial C}{\partial ty_2^o} + y_3^o \frac{\partial C}{\partial ty_3^o} + \ldots$$

$$\Rightarrow \frac{\partial C(ty^o)}{\partial t} = \sum_i \frac{\partial C}{\partial ty_i^o} y_i^o$$

If we divide the ray average cost by this marginal cost, we get the following:

$$S = \frac{RAC}{MC} = \frac{C(ty^o)}{t \cdot \sum_i y_i^o \frac{\partial C}{\partial ty_i^o}}, \quad since\ ty^o = y$$

$$\Rightarrow S = \frac{RAC}{MC} = \frac{C}{\sum_i y_i \frac{\partial C}{\partial y_i}}$$

If S>1, then multiproduct scale economies exist. However, conversely to the single-product case, the condition of multiproduct scale economies does not imply cost subadditivity. Sharkey (1982) presents the following cost function to show that multiproduct scale economies do not imply cost subadditivity.

$$C(q_1, q_2) = q_1^{1/2} + q_2^{1/2} + (q_1 q_2)^{1/2}$$

We can calculate the returns to scale for this cost function as follows:

$$S = \frac{C}{q_1 \frac{\partial C}{\partial q_1} + q_2 \frac{\partial C}{\partial q_2}} = \frac{C}{\frac{1}{2} q_1^{1/2} + q_1^{1/2} q_2^{1/2} + \frac{1}{2} q_2^{1/2}}$$

We can substitute any quantities in for q_1 and q_2 to get the value of cost at those output levels, and to calculate the returns to scale. Suppose we set each output equal to 4. Then,

$$S = \frac{8}{6} = 1.333$$

This implies economies of scale. However, suppose we compare the costs of eight with joint

$$\begin{aligned} &C(4,0) = 2, \\ &C(0,4) = 2 \\ &\Rightarrow C(4,4) > C(4,0) + C(0,4) \end{aligned}$$

production to the costs of producing each output separately, as follows:

In this case, the cost of producing the outputs separately by two firms is cheaper. Thus, the condition of subadditivity is not met, even though there are multi-product economies of scale.

Sharkey (1982) and Baumol, et. al (1988) show several sufficient conditions for cost subadditivity in a multiproduct setting. Each of these conditions uses some form of cost complementarity in addition to economies of scale. Roughly, cost complementarity means that producing more of any output reduces the costs of producing other outputs. The most widely understood form of cost complementarity is economies of scope.

Economies of scope are savings in unit costs resulting from a firm producing several different types of outputs concurrently. Economies of scope often are the result of a shared input in the production of different outputs. This can result from an input that is indivisible or lumpy. In the railroad industry, roadway and structures are indivisible (i.e. whether you transport one ton over a rail line or one million tons over a rail line, some minimum investment in roadway and structures is needed – the amount of roadway and structures does not increase proportionally to tonnage hauled over the line). Thus, economies of scope can result from transporting different types of traffic over the same rail line (e.g. coal and grain). The concept of economies of scope can be formally defined as follows:

$$C\left(\sum_{j=1}^{n} y^{j}\right) < \sum_{j=1}^{n} C\left(y^{j}\right)$$

where: y^j 's are disjoint output vectors; i.e. $y^a \cdot y^b = 0$, $a \neq b$

However, as noted by Sharkey (1982) and Baumol, et. al, economies of scale and scope combined are not sufficient for cost subadditivity in the multi-product setting. Thus, stronger forms of complementarity are needed. One form of cost complementarity is called *strong cost complementarity*. Strong cost complementarity means that marginal costs of any output decline when that output or any other output increases. This condition alone is sufficient for subadditivity, but it is an extremely strong condition, and therefore, rarely met.

Because the sufficient conditions for subadditivity are much stronger than the actual condition, and because of difficulties in measuring some of these conditions, a direct approach to measuring subadditivity is preferred. This study uses a direct approach originally introduced by Shin and Ying (1992). The next section of the study reviews previous rail cost studies that have attempted to examine the natural monopoly issue.

4. REVIEW OF RAILROAD COST STUDIES

Over the past 40 years, there have been several studies that have estimated railroad cost functions. In fact, the first railroad cost functions were estimated in the late 1950s (Meyer 1958), but until the middle 1970s most cost function estimations were ad hoc and/or specified as linear functions.

Keeler (1974) pointed out the problems present in most of the early cost studies. As Keeler pointed out, nearly all the previous cost studies either estimated total costs as a function of output without including a measure of capacity, or total costs as a linear function of output and track mileage. Keeler was critical of the first approach because it assumed that railroads had adjusted to long-run equilibrium – an assumption that was surely incorrect given the institutional constraints placed upon the rail industry prior to deregulation. This problem was previously illuminated by Borts (1960), who referred to the bias present when firms are assumed to be on their long run cost curve, but have systematic deviations from planned output as regression fallacy. The second approach assumed that factor proportions between track and other inputs were fixed. Keeler argued that such a model was not appropriate and that marginal maintenance and operating costs should rise as the railroad plant is used more intensively. To remedy these problems, Keeler formulated a short run cost function from neoclassical economic theory using a

Cobb-Douglas production function. One important contribution of Keeler's study was that he distinguished between two different types of scale economies in the rail industry – each with markedly different implications for the behavior of railroad costs and policies aimed at railroad efficiency. Economies of density result when average costs decrease with increases in traffic density over a fixed system. Economies of size result when average costs decrease with increases in the size of the network.

Another important contribution of Keeler's study was the method he used to obtain a long-run cost function. He estimated a short-run cost function because most railroads were operating at excess capacity, and then derived the optimal capital stock and plugged it into the short-run cost function to get the long-run cost function. This approach merely follows the text book microeconomic derivation of the long-run cost function, but nonetheless made a significant contribution to the estimation of railroad cost functions. He found substantial returns to traffic density, constant long-run returns to scale, and substantial excess capacity for all railroads studied.

The next landmark study in rail cost analysis was done by Harris (1977), who studied economies of density in railroad freight services. Harris pointed to several problems in previous rail cost studies, including: (1) continued confusion between economies of density and size, despite the paper by Keeler; (2) use of inappropriate measures of output and capacity; previous studies used gross ton-miles for output, which include empty mileage and equipment weight, and miles of track for capacity, which includes duplicate track over the same route; (3) inadequate division of costs between passenger and freight services, which biased against finding economies of density; (4) no clear rationale behind regional stratification; (5) failure to include important variables such as average length of haul, resulting in biased coefficient estimates; and (6) failure to include return on capital investment in costs. The author originally explained total rail costs with revenue ton-miles, revenue freight-tons, and miles of road. Because of heteroskedasticity due to a larger error term with larger firm size, he divided the entire equation by revenue ton-miles. This is equivalent to estimating average rail costs for freight services with the reciprocals of average length of haul and traffic density. Harris found significant economies of traffic density for rail freight services, and through the estimation of several cost accounts with the same formulation, he found that there was a significant increase in density economies when return on capital investment costs were included, that fixed operating costs accounted for a significant portion of economies of density, and that maintenance of way and transportation expense categories combined to account for more than 50 percent of economies of density. Harris' study made a large contribution to the study of rail costs by showing the biases caused by several flaws in previous rail cost studies and by showing a need to consider data measurement and specification issues when estimating rail cost functions.

A major breakthrough in railroad cost analysis took place with the introduction of the transcendental logarithmic (translog) function by Christensen, Jorgenson, and Lau (1973). The translog function has a basic advantage over other functional forms in estimating costs – it is flexible and does not place the heavy restrictions on production structure that other functional forms do. In fact, the translog function can be thought of as a second order approximation to an arbitrary function.

The first study to use the translog function to examine railroad cost structure was performed by Brown, Caves, and Christensen (1979). In examining the benefits of the translog cost function over previous functional forms, they estimated a long-run railroad cost function with the unrestricted translog cost function (linear homogeneity of factor prices was the only restriction imposed), one with separability in outputs imposed, and one with homogeneity in outputs imposed. The authors found the translog cost function to be a significant generalization of the other two models. In examining long-run returns to scale, they found significant multiproduct scale economies for 66 out of the 67 railroads in the sample. Moreover, significant errors in estimating marginal costs and scale economies were present when using the restricted models.

The next major contribution to the study of railroad costs was contained in a book by Freidlaender and Spady (1980) that examined the potential impacts of railroad and trucking deregulation. In the book, the authors estimated a short-run variable cost function for railroads, making several innovations to the translog cost function. Innovations in their estimation procedure included: (1) distinguishing between way and structures capital and route mileage (route mileage represents increased carrier obligation, while way and structures capital are a factor of production); (2) including the percentage of ton-miles that are due to the shipment of manufactured products as a technological variable (accounts for differences in costs associated with different types of traffic); and (3) distinguishing between high and low density route miles. Because they distinguished between way and structures capital and route miles, the authors were able to measure short-run returns to density (holding way and structures capital fixed) and long-run returns to density (allowing way and structures capital to vary, but holding route miles fixed). They found long-run increasing returns to density, but decreasing returns to firm size.

Friedlaender and Spady's study made a contribution by making major improvements in the railroad cost function, many of which have not been repeated in more recent studies.[15]

One problem that was present in early railroad cost studies that used the translog function was the existence of zero passenger output for some railroads. Since the translog cost function is in logarithms, zero values for output cannot be included in the estimation. Because of this problem, early translog rail cost studies eliminated all observations for railroads that did not provide passenger service. However, Caves, Christensen, and Tretheway (1980) came up with a solution to this problem by proposing a generalized translog multiproduct cost function. The generalized translog cost function differs from the translog cost function in that it uses the Box-Cox Metric for outputs, rather than just the log of outputs. The authors also evaluated the generalized translog cost function along with three other cost functions using three criteria, including: (1) whether it met linear homogeneity in input prices for all possible price and output levels, (2) the number of parameters that had to be estimated, and (3) whether it permitted a value of zero for one or more outputs. The quadratic, translog, and combination of Leontif cost function with a generalized linear production function were all shown to have problems with one or more of these criteria, while the generalized translog cost function did not. When testing the generalized translog cost function against the translog cost function using railroad cost data, the authors found significant differences resulting from using the full sample instead of only those with non-zero outputs for passenger and freight output.

[15]More recently, papers by Berndt, Friedlaender, Chiang, & Velturo (1993), and Friedlaender, Berndt, Chiang, Showalter, and Velturo (1993) have included similar innovations of distinguishing route miles from way and structures capital, and including the percentages of output due to various types of commodities. Using 1974-1986 data, these studies have shown increasing returns to density, and slightly increasing returns to firm size.

At the same time as these other innovations in the translog cost function were taking place, two studies aimed at measuring the changes in railroad total factor productivity over time also made use of the translog cost function (Caves, Christensen, and Swanson 1979 and 1980). Caves, Christensen, and Swanson showed that using a flexible production structure resulted in a much different estimate of productivity growth than the previous studies that used index procedures to measure productivity growth, implicitly imposing several restrictive assumptions, such as constant returns to scale and separability of outputs and inputs. Their cost estimations included a short-run variable cost function that held way and structures capital fixed, and a long-run total cost function. Both models showed slightly increasing long-run returns to scale when increased ton-miles and passenger miles were assumed to result solely from increases in length of haul, but showed constant returns to scale when increased ton-miles and passenger miles were assumed to result solely from increases in tonnage and passengers. The models were not able to distinguish between returns to density and returns to size, but nonetheless provided another estimate of overall returns to scale.

Brauetigam, Daughety, and Turnquist (1984) brought attention to a problem that was present in many previous railroad cost estimations. They showed that because there are many basic differences between railroad firms, estimation of a cost function that fails to consider firm effects can lead to biases in the coefficients of important policy variables. The authors estimated a railroad cost function using time-series data for an individual firm, in an attempt to highlight biases in studies using cross-sectional or panel data. In addition to focusing attention on the possible biases from failure to consider firm effects in a cost function estimation, their study also provided two other useful innovations to the estimation of railroad costs. First, they included speed of service as a proxy for service quality and found that its omission resulted in an understatement of economies of density. Second, they included a measure of "effective track," which considered mileage and the amount invested in existing track above that required to offset normal depreciation. This essentially was equivalent to the innovation employed by Friedlaender and Spady (1980), which was to include track mileage and way and structures capital. Finally, the authors found significant economies of density for the railroad studied.

Another study that brought attention to the importance of considering firm effects in estimating returns to density was a study by Caves, Christensen, Tretheway, and Windle (1985). The authors estimated long-run cost function using 1951 through 1975 data, finding substantial increasing returns to density and slightly increasing or constant returns to overall scale. Like Friedlaender and Spady, they distinguished route miles from way and structures capital, as they included a capital price and a route miles variable. The study made significant contributions in highlighting the bias that may occur from estimating returns to density without considering firm effects, and in precisely defining measures of returns to density and scale.

All of the previously mentioned studies used data that was prior to railroad deregulation. Since the study by Caves et. al there has been an assortment of studies using post deregulation data. However, for the most part, these studies have failed to include many of the important innovations introduced in the pre-deregulation cost studies.

Barbera, Grimm, Phillips, and Selzer (1987) estimated a translog cost function for the railroad industry using data from 1979 through 1983. The study made improvements over some previous studies in its measurement of capital expenses, as it used the replacement cost of capital rather than book values in calculating return on investment costs, and by using depreciation accounting techniques rather than the railroad convention of betterment accounting.[16] However, the study still expensed many maintenance of way and structures activities that really were a replacement of depreciated capital. The study found significant increasing returns to density for rail freight services, but constant overall returns to scale. It highlighted the importance of including the current replacement cost of capital in cost estimates, but its failure to include measures of service quality, measures of traffic mix, the percent of shipments made by unit trains, or measures of high density and low density track was disappointing.

Lee and Baumel (1987) estimated a short-run average variable cost function as part of a system of cost and demand using 1983-1984 data. They found mild economies of density, and constant returns to overall scale. However, the authors used the elasticity of short-run variable costs with respect to traffic to imply economies of density and compared this to previous estimates of economies of density. By not including fixed costs in their cost function and measuring economies of density in this way, it is likely that the authors' estimates of economies of density grossly understated actual economies of density. In fact, a comparison to previous studies in their paper showed considerably smaller returns to density than most others. Other studies that have estimated variable cost functions (e.g. Friedlaender and Spady) have used theoretical relationships between long-run and short-run costs to estimate long-run returns to density. Moreover, in terms of policy implications, long-run returns to density and scale certainly are the relevant concepts.

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[16]However, studies by Friedlaender and Spady (1980), Caves, Christensen, and Swanson (1979, 1981) and others make similar improvements.

Dooley, Wilson, Benson, and Tolliver (1991) estimated a short-run variable cost function in revisiting the measurement of total factor productivity in the post-deregulation era. The study used more recent data (1978-1989), while maintaining some of the innovations used in the studies using pre-deregulation data such as using high density and low density miles of track, speed to measure the quality of capital, and the percent of shipments that were made by unit trains. The study also added several other innovations by including variables such as the percent of traffic interlined with other carriers, high density and low density gross ton miles, and firm specific dummy variables meant to measure the effects discussed by Braeutigam, et. al. However, while these innovations were noteworthy, the study suffered from the same problem that was present in the one by Lee and Baumel (1987). Returns to density and to overall scale were measured as the elasticity of variable costs with respect to density and overall scale. Because fixed costs were not considered, the moderate returns to density found are likely to have grossly understated actual returns to density.

Another recent study is noteworthy, not because of its railroad cost estimates, but because of its policy implications and recommendations. Winston, Corsi, Grimm, and Evans (1990) performed a study attempting to quantify the effects of railroad and trucking deregulation on shippers, carriers, and labor. To estimate the effects of deregulation on shippers the authors used compensating variations, or the amount of money shippers could sacrifice following beneficial rate and service quality changes and be as well off as before the changes. Compensating variations were assessed by using a mode choice probability model. The authors found that shippers have realized a large increase in welfare from deregulation. To estimate the effects of deregulation on rail carriers they performed a counter factual projection of economic profits in

1977 as if deregulation were in place versus actual profits in 1977. They estimated a railroad cost function with 1985 data using a log-linear specification and found economies of density. When applying the cost coefficients to 1977 variables and using a rail rate deflator to place rates in 1977 deregulated levels, the authors found that deregulation led to an increase in railroad profits. To examine the effects of deregulation on rail labor, they cited an American Association of Railroads estimate suggesting that wages were 20 percent lower under deregulation than they would have been with continued regulation. The part of the authors' study that perhaps is most relevant to the current study examined the impacts of interline competition (competition over part of a rail line) and single-line competition (competition over an entire line) on the difference between shipper welfare under deregulation and shipper welfare under marginal cost pricing. They found that single-line and interline competition led to substantial improvements in consumer welfare for all commodities but coal and grain, where the increase in consumer welfare is minimal. They then went on to suggest that:

> *Past ICC rail merger policy has not effectively preserved rail competition. ... As Alfred Kahn and others have noted of the airline industry, it is important to recognize that deregulation did not authorize the government to abdicate its antitrust responsibility and to fail to take actions to preserve competition. To the extent that railroad mergers can enable railroads to improve service and reduce costs without concomitant anticompetitive effects, they should be encouraged. It is the ICC's responsibility to scrutinize carefully potential anticompetitive effects from both parallel and end-to-end mergers. In particular, a policy of continuing to discourage parallel mergers appears to be in order.*

However, such a policy recommendation cannot be made without considering the impact of requiring competition on overall societal resources (e.g. the impact on carrier profit must also be assessed). Furthermore, since coal and grain account for nearly half of all originated tonnage and

30 percent of all railroad revenue, the finding that consumer welfare on coal and grain is not improved much by competition is significant.

As noted above, many studies using post-deregulation data failed to include innovations introduced in previous rail cost function estimations. One notable exception was a study by Ivaldi and McCullough (1999), which examined economies of density in the Class I railroad industry using a cost function that differentiated between car miles of bulk traffic, high value equipment, and other equipment. In addition to examining economies of density, the study also examined vertical relationships between freight operations and infrastructure. The study found substantial returns to density and cost complementarities between different outputs, suggesting that "open access" could lead to increased costs. Moreover, it found anticomplementarities between output and infrastructure, suggesting potential coordination problems if railroad operations and infrastructure were separated. The study made a significant contribution by more closely capturing the multi-product nature of railroads, and by including methods to measure output-infrastructure cost relationships. However, one potential problem with the study was in its use of car miles, as car miles do not necessarily represent the output of railroad firms. The next section of the study examines previous studies that have examined the necessary and sufficient condition for natural monopoly – cost subadditivity.

5. REVIEW OF EMPIRICAL TESTS OF NATURAL MONOPOLY

Many studies have examined the cost structure of regulated industries to assess the most efficient industry configuration. Most of these studies have either directly or indirectly addressed the problem of natural monopoly. However, most have done so by testing for economies of scale and/or scope in the industry, conditions that, combined, are not sufficient for natural monopoly in the multiproduct case. Only two studies have empirically examined the condition that is necessary and sufficient for natural monopoly – cost subadditivity.

Evans and Heckman (1984) make note of the fact that despite the relevance of the measurement of subadditivity to the desirability of competition in regulated industries, few empirical studies have provided reliable evidence on the subject. They cite the need for global data in measuring subadditivity, the lack of information on cost data needed to apply the sufficient conditions of Baumol, et. al, and the possibility that the tests of Baumol, et. al will not provide an answer to the question of subadditivity (because they are stronger conditions than subadditivity) as reasons that reliable information on the existence of natural monopoly does not exist.

The authors formulate a local test of subadditivity that provides information on the subadditivity of costs within a certain "admissible" output range. Such a test is a test of a necessary, but not sufficient condition for global subadditivity (i.e. subadditivity must be met in the "admissible" region for it to hold globally, but subadditivity holding in the "admissible" region does not imply global subadditivity). They define the admissible region as one where: (1) neither hypothetical firm is allowed to produce less than the lowest value of output used to estimate the cost function, (2) the monopoly firm must have an output for each output that is at least twice the lowest value of that output in the sample, and (3) ratios of output 1 to output 2 for the hypothetical firms are within the range of ratios observed in the sample. In performing their local test of subadditivity on time series data for one firm (the Bell System, 1947-1977), the authors find that subadditivity is rejected in all cases.

Mathematically, the Evans and Heckman test can be illustrated as follows:

$$\begin{aligned}
&\tilde{C}_t < \tilde{C}_t^a(\varphi,\omega) + \tilde{C}_t^b(\varphi,\omega), \forall \varphi,\omega\ \varepsilon(0,1) \\
&where: \quad \tilde{C}_t^a(\varphi,\omega) = \tilde{C}(\tilde{q}_t^a) = \tilde{C}(q_z + \hat{q}_t^a) \\
&\qquad\qquad \tilde{C}_t^b(\varphi,\omega) = \tilde{C}(\tilde{q}_t^b) = \tilde{C}(q_z + \hat{q}_t^b) \\
&\qquad\qquad \tilde{C}_t = \tilde{C}(\tilde{q}_t^a + \tilde{q}_t^b) = \tilde{C}(\tilde{q}_t) \\
&\qquad\qquad \hat{q}_t^a = ((1-\varphi)q_{1t}^*, (1-\omega)q_{2t}^*) \\
&\qquad\qquad \hat{q}_t^b = (\varphi q_{1t}^*, \omega q_{2t}^*) \\
&\qquad\qquad q_{1t}^* + q_{2t}^* = \tilde{q}_t - 2q_z \\
&\qquad\qquad q_z = (\min_t q_{1t}, \min_t q_{2t})
\end{aligned}$$

The test uses the mathematical definition of subadditivity, and tests for it directly. If the above condition is met at an observation for all ϕ and ω, then that observation displays subadditivity. However, the test is local, as it limits the subadditivity test to observations that have outputs that are at least twice the minimum for the sample. Using the 1947-1977 data for the Bell System, the authors find that 1958-1977 data meet this output restriction. Evans and Heckman made two significant contributions with this study: (1) they found convincing evidence that the Bell System was not a natural monopoly, suggesting that the breakup was justified, and (2) they introduced a direct test of local subadditivity that can be replicated for other industries.

Shin and Ying (1992) point out a potential problem with previous studies that have examined natural monopoly in the telephone industry: all have relied on aggregate time series data. They suggest that because output and technological change have been highly correlated over time, it is possible that technological change has mistakenly been identified as scale economies.

To correct this problem, Shin and Ying use pooled cross sectional-time series data to examine subadditivity in the telephone industry. Specifically, they examine subadditivity of local exchange carriers (LECs) using a pooled data set of 58 LECs from 1976 to 1983. Their examination of subadditivity is performed by estimating a multiproduct translog cost function and using the parameter estimates to perform a global test of subadditivity for LECs.

The Shin and Ying test for subadditivity is similar to the Evans and Heckman test, except that it does not place a restriction on which observations the test is performed. Shin and Ying argue that the restrictions on the test imposed by Evans and Heckman are not needed with the larger data set where outputs cover a much wider range. The test splits their three output measures – number of access lines, number of local calls, number of toll calls – between two firms in several different ways for every observation in their data set and tests for lower costs by one firm under each split.

Mathematically, the authors tested for the following condition on each observation:

$$
\begin{aligned}
&C(q^M) < C(q^a) + C(q^b) \\
&\mathit{where:}\quad q^a = (kq_1^M, \lambda q_2^M, \gamma q_3^M) \\
&\qquad\qquad q^b = ((1-k)q_1^M, (1-\lambda)q_2^M, (1-\gamma)q_3^M) \\
&\qquad\qquad k, \lambda, \gamma = (0.1, 0.2, \ldots, 0.9)
\end{aligned}
$$

Using this test, Shin and Ying find that lower costs for the monopoly were only achieved in a range of 20 to 38 percent of the possible firm combinations between 1976 and 1983, and that the condition of subadditivity is not met for any of the observations in their data set (i.e. for some observations their were some splits of outputs where the monopoly achieved a lower cost, but the monopoly cost was not lower than all possible output splits for any observation). Shin and

Ying's study provides further support for the notion that the Bell System was not a natural monopoly, suggests that the local exchange carriers are not natural monopolies, and provides a global test of subadditivity that can be used for examining natural monopoly conditions in other industries. The current study tests for subadditivity in the railroad industry in this same way. The next section of the report presents descriptions of the data and methodology used to make assessments of the cost implications of railroad mergers and of competition over existing rail lines.

6. DATA AND METHODOLOGY

As noted earlier, this study examines the cost implications of railroad mergers and of railroad competition over existing rail lines. Because the conditions of multiproduct scale economies and scope economies are neither necessary nor sufficient for natural monopoly, the condition of cost subadditivity is examined directly by simulating single-firm and two-firm costs under various output combinations in a manner similar to that used by Shin and Ying (1992). Specifically, the study tests for the condition of cost subadditivity in the railroad industry under three different alternatives to single firm operation: (1) subadditivity of costs while holding network size constant, providing an assessment of the desirability of parallel railroad mergers; (2) subadditivity of costs while network size is expanded, providing an assessment of the desirability of end-to-end mergers; and (3) subadditivity of costs over a single railroad network after the costs associated with maintenance of way and structures are eliminated, providing an assessment of the desirability of multiple firm competition over existing rail networks. The last of the three tests is relevant for making an assessment of the desirability of recent proposals calling for “open access” or for opening bottleneck segments of the rail system to competition.

In addition to differences in the tests of cost subadditivity to examine each of these issues, two different cost functions are estimated in addressing these issues. First, a long-run total railroad cost function is estimated to examine subadditivity of costs while network size is constant and while network size is expanded. Next, a short-run quasi-cost function is estimated to examine subadditivity of costs, where the alternative to single firm operation is multiple firms operating over the same network. A description of each of the cost functions and of simulation methodologies is presented next. First, the long-run total cost function is presented.

A. The Long-Run Total Cost Function

To make an assessment of the cost implications of parallel and end-to-end railroad mergers, a long-run total cost function is estimated for the Class I railroad industry. The theoretical section above showed that the long-run cost function shows the minimum cost associated with producing any output level, given the levels of input prices. To estimate a cost function empirically, we must observe more than one firm, the same firm at a variety of time periods, or many firms over a variety of time periods. Thus, the empirical estimation measures an industry cost function over time, rather than an individual firm cost function at one period in time. Because of this, technological factors generally are included, in addition to output levels and factor prices. This accounts for the fact that costs may differ among firms or among time periods due to differences in the quality of the infrastructure, length of shipments made, network size, and general technological progress. The generalized long-run cost function for the railroad industry can be defined as[17]:

[17]One potential criticism of this study is its estimation of a long-run cost function, rather than a short-run cost function. Estimation of the long-run cost function assumes that all firms have adjusted their capital stock to efficient long-run levels. Given the lag between deregulation

$$C = C(w_l, w_{m+s}, w_f, w_e, w_t, UTGTM, WTGTM, TTGTM, MOR, ALH, SPEED, Time)$$

$$\begin{aligned} where:\quad & C = total\ costs \\ & w_l = price\ of\ labor \\ & w_{m+s} = price\ of\ materials\ and\ supplies \\ & w_f = price\ of\ fuel \\ & w_e = price\ of\ equipment \\ & w_t = price\ of\ way\ and\ structures \\ & UTGTM = unit\ train\ gross\ ton-miles \\ & WTGTM = way\ train\ gross\ ton-miles \\ & TTGTM = through\ train\ gross\ ton-miles \\ & MOR = miles\ of\ road \\ & ALH = average\ length\ of\ haul \\ & SPEED = train\ miles\ per\ train\ hour\ in\ road\ service \end{aligned}$$

This specification is a long-run specification, even though miles of road are held fixed. Previous authors have used a similar specification, but have excluded the price of way and structures, labeling it a short-run cost function. The argument for such a specification being a short-run cost function is that railroads cannot adjust miles of road in the short run, but can in the long run.[18] However, if one considers the nature of railroad operations, it is apparent that the above specification is a long-run specification and that a price of way and structures variable is necessary. The textbook explanations of short-run and long-run cost minimization are that firms choose levels of variable inputs to minimize costs for a given output and capital stock in the short run, while they choose levels of variable inputs and the level of capital stock to minimize costs for a given output in the long run. If a railroad is providing a given amount of services between

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and the first year of data used in this study, this is not an unrealistic assumption.

[18]Miles of road represent route miles, while miles of track include duplicate trackage over the same route miles.

two cities, A and B, it can adjust its capital stock to minimize long-run costs by making changes in the amount of side by side track between A and B or by making some other improvements in the road to increase capacity between A and B. However, it does not make changes in its capital stock for its A to B service by installing a new line to city C. The installation of a new line to city C represents an investment in capital stock for providing a whole new array of services. The specification above, with the price of way and structures included and with miles of road included, allows for the adjustment of way and structures capital to minimize costs for any output levels that may be provided over the railroad's current network.

The above specification also is unique in its output and service measures. The specification not only retains the innovations of including service quality variables such as SPEED and ALH, but also includes specific measures of the multiple outputs provided by railroads. This is an important innovation, since it more accurately captures the multi-product nature of the railroad industry. Three types of outputs are included in this estimation, including gross ton-miles used in unit train, way train, and through train services.[19] These are three distinct types of services provided by railroads, differing greatly from each other. Unit train services are those provided to extremely high volume shippers in a routine fashion. These shipments use trains that are dedicated to the movement of a single commodity between a particular origin-destination pair. The trains run regularly between the particular origin and destination. Because

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[19]Because gross ton-miles include empty mileage and the tare weight of the freight cars, they do not represent the true output of railroads. Thus, each output measure is multiplied by the ratio of revenue ton-miles (freight only ton-miles) to the sum of gross-ton miles in unit, through, and way train service. This adjustment gives approximate measures of revenue ton-miles in each category. It is not exact, since the ratio of gross ton-miles to revenue ton-miles is not necessarily the same in each output category.

of the high volume nature of unit trains, and the smaller switching requirement, unit trains typically are considered the most efficient form of service provided by railroads. Way train services are those provided for gathering cars and bringing them to major freight terminals. Because of the high switching requirements, small shipment sizes, short distances, and slow train speeds, way train services typically are considered the highest cost service provided by railroads. Through train services are those provided between two or more major freight terminals. The service typically is considered more efficient than way train service, but less efficient than unit train service, because some switching and reclassification still occurs on through train movements. However, through train service represents the largest service in terms of ton-miles for most railroads and generally occurs over high density main-line routes. Thus, while through train service generally is more efficient than way train service because of traveling greater distances at higher speeds and a lower switching requirement, additions to this service are likely to create higher additions to costs due to the additional maintenance and capacity requirements needed with such additions. It is likely that through train service is traveling over routes that have exhausted a greater portion of available density economies than way train service.

Another advantage of this specification over those used in previous studies is its use of total costs, rather than variable costs. As noted in the review of literature, some recent studies have used the estimated elasticity of variable costs with respect to output and output and size to assess returns to traffic density and overall returns to scale. Certainly, returns to traffic density have been understated in these studies.

B. The Quasi-Cost Function

One proposed change in regulation by shippers involves multiple-railroad operation over existing rail networks, where railroads would pay for access and usage of other firms' lines. Some shippers believe that such a system would result in reduced prices and/or improved service. To make an assessment of the welfare implications of such a scheme, its impacts on costs and prices should be examined. The second cost function estimated in this study aims to provide insight into the impacts of such a system on costs. The cost function also will provide insight into the cost implications of multiple-firm operation over bottleneck segments of the U.S. rail network.

In general, there are two basic cost issues associated with examining the impacts of multi-firm operation over single networks. The first issue is whether there are decreases in efficiency that may result from separating the activities of maintaining the roadbed from the activities of providing transportation service. That is, can the railroad substitute way and structures inputs for transportation services and vice-versa in providing railroad services? This issue can be assessed by testing the cost function for separability of way and structures inputs from other inputs.[20] When testing the cost function for separability between way and structures inputs and other inputs, the separability hypothesis is rejected. This suggests that there are cost savings resulting from jointly producing the roadway and the transportation services over it. For this reason, multiple-firm operation over the rail line likely will produce an increase in costs. A second issue

[20]The separability test amounts to placing a restriction of zero on the interaction terms between way and structures price and all other input prices in the long-run cost function, and testing for joint significance of these restrictions. When performing this test, the F-Statistic is equal to 3.84, suggesting that the cost function is not separable.

related to the cost impacts of multi-firm operation over single networks is that if economies of scale and scope exist in providing transportation services, after excluding the costs of way and structures, multiple-firm operation over a single network will result in an increase in costs. Although the separability test suggests that transportation services are not produced separately from way and structures inputs, the quasi-cost function is estimated to examine the potential cost savings in these transportation costs resulting from single-firm operation.[21]

To make an assessment of the cost implications of multiple firms operating over a single network, the quasi-cost function is estimated. The quasi-cost function includes all railroad costs, except way and structures costs. The rationale for excluding way and structures inputs from the quasi-cost function to assess the implications of multiple firms operating over the same network is as follows. In a case where multiple firms are operating over the same network, the way and structures inputs presumably would be maintained by the host railroad. Thus, any economies of scale and scope obtained in maintaining way and structures would presumably still be realized if multiple firms operated over this network. However, if economies of scale and scope are realized in providing transportation services over this network, after way and structures costs are eliminated, then multiple-firm operation over the network would result in excess resource costs. The quasi-cost function measures the extent of such economies that occur in providing transportation services after the costs of maintaining the roadbed are eliminated from consideration. The quasi-cost function is a short-run function, since the amount of way and

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[21]Since separability is not appropriate, there may be some bias in the quasi-cost function estimation. Nonetheless, its estimation will provide insight into the potential scale economies and cost complementarities that may exist from single-firm operation over one rail line.

structures inputs cannot be adjusted. That is, way and structures inputs are fixed by the host railroad.

The estimated function is labeled a quasi-cost function rather than a cost function, because it does not meet the theoretical properties of a true cost function. Unless a rail firm can separately produce the service of a roadbed and structures from the transportation service itself, a true cost function cannot separate out way and structures costs from transportation service costs. The generalized quasi-cost function for the railroad industry is defined as:

$$QC = QC(w_l, w_{m+s}, w_f, w_e, UTGTM, WTGTM, TTGTM, MOR, ALH, TRK, WSCAP, Time)$$

$$\begin{aligned}
where:\quad & QC = costs\ excluding\ way\ and\ structures\ costs \\
& w_l = price\ of\ labor \\
& w_{m+s} = price\ of\ materials\ and\ supplies \\
& w_f = price\ of\ fuel \\
& w_e = price\ of\ equipment \\
& UTGTM = adjusted\ unit\ train\ gross\ ton-miles \\
& WTGTM = adjusted\ way\ train\ gross\ ton-miles \\
& TTGTM = adjusted\ through\ train\ gross\ ton-miles \\
& MOR = route\ miles \\
& ALH = average\ length\ of\ haul \\
& TRK = miles\ of\ track\ per\ mile\ of\ road \\
& WSCAP = net\ investment\ in\ way\ and\ structures\ per\ mile\ of\ track
\end{aligned}$$

This specification retains the innovations of the total cost function by including the three different types of outputs and technological variables of miles of road, length of haul, and time. The specification also adds two new technological variables: miles of track per mile of road, and net investment in way and structures per mile of track. These variables provide an indication of the quality of way and structures maintained by a particular railroad. Even though way and structures costs are not included in the quasi-cost function, the quality of way and structures are likely to have a strong influence on the costs of providing transportation services over a particular railroad network. That is, the transportation costs associated with traveling over a high quality network should be lower than the transportation costs associated with traveling over a low quality network. Thus, the inclusion of these two quality variables holds track quality constant when looking at the implications of increased traffic on transportation costs. *A priori*, both of these variables are expected to have negative signs.

C. Flexible Functional Form

To estimate the generalized cost functions noted above, the translog cost functional form is used. The translog function is a flexible functional form used to estimate a cost function. It is flexible in the sense that it does not impose as many restrictions on costs as less flexible forms.[22] All continuous variables are specified in logarithms in the translog cost function, and each independent variable is interacted with each other independent variable. The translog specification for the long-run total cost function is as follows:[23] [24]

[22]The translog cost function first was introduced by Christensen, Joregenson, and Lau (1973). Friedlaender and Spady (1980) show that the translog cost function can be thought of as a second order Taylor series expansion of an arbitrary function.

[23]Time is included as a variable in the translog specification. However, it is not divided by its mean and it is included in level form rather than log form.

[24]The translog functional form also is used for the quasi-cost function.

$$\ln C = \alpha_0 + \sum_i \alpha_i \ln(w_i / \overline{w}_i) + \sum_j \beta_j \ln(y_j / \overline{y}_j) + \sum_n \lambda_n \ln(t_n / \overline{t}_n) +$$
$$\frac{1}{2}\sum_i \sum_m \gamma_{im} \ln(w_i / \overline{w}_i)\ln(w_m / \overline{w}_m) + \sum_i \sum_j \omega_{ij} \ln(w_i / \overline{w}_i)\ln(y_j / \overline{y}_j) +$$
$$\sum_i \sum_n \phi_{in} \ln(w_i / \overline{w}_i)\ln(t_n / \overline{t}_n) + \frac{1}{2}\sum_j \sum_l \psi_{jl} \ln(y_j / \overline{y}_j)\ln(y_l / \overline{y}_l) +$$
$$\sum_j \sum_n \nu_{jn} \ln(y_j / \overline{y}_j)\ln(t_n / \overline{t}_n) + \frac{1}{2}\sum_n \sum_o \xi_{no} \ln(t_n / \overline{t}_n)\ln(t_o / \overline{t}_o) + \varepsilon$$

where: *w are input prices*
y are outputs
t are techological variables

As with other estimations of the trans-log cost function, use is made of Shephard's Lemma to obtain share equations for each input. Shephard’s Lemma is a well known property of cost functions. The property of Shephard’s Lemma is that we can obtain the firm’s conditional input demands by differentiating the cost function with respect to the appropriate input price. Mathematically, Shephard’s Lemma can be represented as follows:

$$\frac{\partial C(w, y)}{\partial w_i} = x_i(w, y),$$

where: *w are factor prices*
y are outputs

To show that applying Shephard's Lemma to the cost function gives us the factor share equations, look at the partial derivative of the natural log of cost with respect to the natural log of factor price:

Thus, to obtain the factor share equations using Shephard's Lemma, we differentiate the translog cost function with respect to the log of factor price as follows:

$$\frac{\partial \ln C}{\partial \ln(w_i / \overline{w}_i)} = \alpha_i + \sum_m \gamma_{im} \ln(w_m / \overline{w}_m) + \sum_m \omega_{ij} \ln(y_j / \overline{y}_j) + \sum_m \phi_{in} \ln(t_n / \overline{t}_n)$$

$$\frac{\partial \ln C}{\partial \ln w_i} = \frac{\partial \ln C}{\partial C} \cdot \frac{\partial C}{\partial w_i} \cdot \frac{\partial w_i}{\partial \ln w_i} = \frac{1}{C} \cdot x_i \cdot w_i = \frac{x_i w_i}{C}$$

An error term is added to each of the factor share equations, and they are estimated in a seemingly unrelated system with the cost function. This is done to improve the efficiency of estimates obtained, as the errors associated with estimation of the cost function are certainly related to those associated with share equations.[25]

D. Other Features of the Estimation Procedure

Besides imposing symmetry conditions, and imposing the restriction that the parameter estimates in the share equations are consistent with those for the cost function, homogeneity of degree one in factor prices is imposed. Finally, firm dummies are included to account for fixed

[25] Share equations are estimated for all inputs but one, to avoid perfect collinearity.

effects.[26] Because of mergers and railroads losing Class I status, observations for all railroads do not exist for every year. Thus, the way to include firm dummies is not clear cut. This study includes a firm dummy for each original firm, with the dummy retaining a value of one for the merged firm as well. In addition, the merged firm receives a dummy that is zero before merged data exists and one thereafter. Thus, for merged firms, the unique characteristics of the original railroads that may affect costs are represented as well as the unique characteristics of the merged system as a whole. Railroad merger definitions are taken from Dooley, et. al, who interviewed merged carriers about the effective dates of mergers.

E. Data

To estimate both translog multiproduct cost functions for the Class I railroad industry, data obtained from each Class I's Annual Reports (R-1 Reports) to the Interstate Commerce Commission are used from 1983 through 1997.[27] These data are the best available for the Class I

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[26] Although most cost studies include firm effects, there is some disagreement over whether they should be included. There is concern among some authors that collinearity between output or network variables and firm dummies may reduce the statistical significance or change the size of the output and network variable parameter estimates (see Oum and Waters, 1996). However, collinearity still does not lead to biased parameter estimates. Moreover, if some unobserved network variables influence costs, and they are correlated with included variables, a bias will result from not including firm effect variables. Statistical tests in a subsequent section show firm effects to be significant (at the 1% level), and nearly all first order terms are statistically significant. Thus, firm effects are included.

[27]The use of 1983-1997 data has an added advantage, as all data subsequent to 1983 in the R-1 Annual Reports uses depreciation accounting techniques rather than betterment accounting techniques. Because betterment accounting counts many items as expenses that are really long-term investments and because of a lack of comparability to data generated with depreciation accounting, use of post-1983 data is preferred. However, it should be noted that betterment accounting data can be converted to depreciation comparable data as some previous authors have done.

railroad industry and some of the best cost data available in any industry. Because some capital expenditures, such as tie replacement, track replacement, and signal replacement are included in the railroads operating expense accounts under their accounting system, some adjustments to costs were necessary. Table 1 provides a summary of all the variables used in either cost function, and their construction.[28] Table 2 provides a list of the railroads and years used, according to the merger definitions of Dooley, et. al.

Before presenting empirical results of the translog estimation, one other important feature of the translog cost function should be highlighted. As shown in the previous section, all independent variables in the translog cost function are divided by their overall sample means. This also is convenient for the interpretation of estimation results, since the first order term parameter estimates will show the elasticity of costs with respect to those variables when all variables are at their sample means.

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[28]All cost and factor price variables are placed in 1992 prices using the Gross Domestic Product Implicit Price Deflator (GDPPD).

Table 1: Data Definitions and Sources Used to Estimate the Railroad Cost Function*

Variable	Source
Cost Variable and Construction	
Real Total Cost	(OPERCOST-CAPEXP +ROIRD +ROILCM+ROICRS)/GDPPD
Real Quasi-Cost	(OPERCOST-TWSCOST+ROILCM+ROICRS)/GDPPD
OPERCOST	Railroad Operating Cost (R1, Sched. 410, ln. 620, Col F)
CAPEXP	Captial Expenditures Classified as Operating in R1 (R1, Sched 410, lines 12-30, 101-109, Col F)
ROIRD	Return on Investment in Road (ROADINV-ACCDEPR)*COSTKAP
ROADINV	Road Investment (R1, Sched 352B, line 31) + CAPEXP from all previous years
ACCDEPR	Accumulated Depreciation in Road (R1, Sched 335, line 30, Col. G)
COSTKAP	Cost of Capital (AAR *Railroad Facts*)
ROILCM	Return on Investment in Locomotives [(IBOLOCO+LOCINVL)-(ACDOLOCO+LOCACDL)]*COSTKAP
IBOLOCO	Investment Base in Owned Loc. (R1, Sched 415, line 5, Col. G)
LOCINVL	Investment Base in Leased Loc. (R1, Sched 415, line 5, Col. H)
ACDOLOCO	Accum. Depr. Owned Loc. (R1, Sched 415, line 5, Col. I)
LOCACDL	Accum. Depr. Leased Loc. (R1, Sched 415, line 5, Col. J)
ROICRS	Return on Investment in Cars [(IBOCARS+CARINVL)-(ACDOCARS+CARACDL)]*COSTKAP
IBOCARS	Investment Base in Owned Cars (R1, Sched 415, line 24, Col. G)
CARINVL	Investment Base in Leased Cars (R1, Sched 415, line 24, Col. H)
ACDOCARS	Accum. Depr. Owned Cars (R1, Sched 415, line 24, Col. I)
CARACDL	Accum. Depr. Leased Loc. (R1, Sched 415, line 24, Col. J)
TWSCOST	Total Way and Structures Expense (R1, Sched 410, line 151, Col. F)
Output Variables	
Unit Train Gross Ton-Miles	(R1, Sched 755, line 99, Col. B)
Way Train Gross Ton-Miles	(R1, Sched 755, line 100, Col. B)
Through Train Gross Ton-Miles	(R1, Sched 755, line 101, Col. B)
Adjustment Factor Multiplied by Each Output Variable	RTM / (UTGTM + WTGTM + TTGTM)
RTM	Revenue Ton-Miles (R1, Sched 755, line 110, Col. B)

Road Miles	
Miles of Road	(R1, Sched 700, line 57, Col. C)
Factor Prices (all divided by GDPPD)	
Labor Price	Labor Price per Hour (SWGE+FRINGE-CAPLAB) / LBHRS - all W&S labor costs are excluded from the labor share for the quasi-cost function
SWGE	Total Salary and Wages (R1, Sched 410, line 620, Col B)
FRINGE	Fringe Benefits (R1, Sched 410, lns. 112-114, 205, 224, 309, 414, 430, 505, 512, 522, 611, Col E)
CAPLAB	Labor Portion of Cap. Exp. Class. as Operating in R1 (R1, Sched 410, lines 12-30, 101-109, Col B)
LBHRS	Labor Hours (Wage Form A, Line 700, Col 4+6)
Equipment Price	Weighted Average Equipment Price (ROI and Ann. Depr. per Car and Locomotive - weighted by that type of equipment's share in total equipment cost)
Fuel Price	Price per Gallon (R1, Sched 750)
Materials and Supply Price	AAR Materials and Supply Index
Way and Structures Price	(ROIRD+ANNDEPRD)/ MOT
ANNDEPRD	Annual Depreciation of Road (R1, Sched 335, line 30, Col C)
MOT	Miles of Track (R1, Sched 720, line 6, Col B)
Technological Conditions	
Speed	Train Miles per Train Hour in Road Service = TRNMLS/(TRNHR-TRNHS)
TRNMLS	Total Train Miles (R1, Sched 755, line 5, Col. B)
TRNHR	Train Hours in Road Service - includes train switching hours (R1, Sched 755, line 115, Col. B)
TRNHS	Train Hours in Train Switching (R1, Sched 755, line 116, Col. B)
Average Length of Haul	RTM / REVTONS
REVTONS	Revenue Tons (R1, Sched 755, line 105, Col. B)
Track miles per route mile	MOT/MOR
Way and Structures Capital Per Mile of Track	(ROADINV-ACCDEPR)/MOT/GDPPD

Note: * *Italics* indicate that the variable is used directly in the translog estimation

Table 2: Observations in the Data Set - with Merger Definitions

Railroad	Years in Data Set
Atchison, Topeka, & Sante Fe (ATSF)	1983-1995 - merged into BN
Baltimore & Ohio (BO)	1983-1985 - merged with CO, SCL to form CSX
Bessemer & Lake Erie (BLE)	1983-1984 - lost Class I status
Boston & Maine (BM)	1983-1988 - lost Class I status
Burlington Northern (BN)	1983-1997 - from 1996-1977 includes merged ATSF, BN system
Chesapeake & Ohio (CO)	1983-1985 - merged with BO, SCL to form CSX
Chicago & Northwestern (CNW)	1983-1994 - merged into UP
Consolidated Rail Corporation (CR)	1983-1997
CSX Transportation (CSX)	1986-1997 - formed with the merger of BO, CO, SCL
Delaware & Hudson (DH)	1983-1987 - lost Class I status
Denver, Rio Grande & Western (DRGW)	1983-1993 - merged into the SP
Detroit, Toledo, & Ironton (DTI)	1983 - merged into GTW
Duluth, Missabe, & Iron Range (DMIR)	1983-1984 - lost Class I status
Florida East Coast (FEC)	1983-1991 - lost Class I status
Grand Trunk & Western (GTW)	1983-1997 - from 1984-1997 incl. merged GTW, DTI
Illinois Central Gulf (ICG)	1983-1997
Kansas City Southern (KCS)	1983-1991 - data for hours of work not reported after 1992
Milwaukee Road (MILW)	1983-1984 - acquired by SOO
Missouri-Kansas-Texas (MKT)	1983-1987 - merged into UP
Missouri Pacific (MP)	1983-1985 - merged into UP
Norfolk Southern (NS)	1985-1997 - formed with the merger of SRS, NW
Norfolk & Western (NW)	1983-1984 - merged with SRS to form NS
Pittsburgh, Lake Erie (PLE)	1983-1984 - lost Class I status
Seaboard Coast Line (SCL)	1983-1985 - merged with BO, CO to form CSX
SOO Line (SOO)	1983-1997 - from 1985-1997 incl. merged SOO, MILW
Southern Railway System (SRS)	1983-1984 - merged with NW to form NS
Southern Pacific (SP)	1983-1996 - from 1990-1993 incl. merged SP, SSW - from 1994-1996 incl. merged SP, SSW, DRGW - merged into UP
Saint Louis, Southwestern (SSW)	1983-1989 - merged into SP
Union Pacific (UP)	1983-1997 - from 1986-1987 includes merged UP, WP, MP system - from 1988-1994 includes merged UP, WP, MKT system - from 1995-1996 includes merged UP, CNW system - for 1997 includes merged UP, SP system
Western Pacific (WP)	1983-1985 - merged into UP

*Source of merger information - Dooley, Wilson, Benson, Tolliver (1991)

7. EMPIRICAL RESULTS OF TOTAL COST FUNCTION

Table 3 shows the estimated translog total cost function.[29] As the table shows, all the first order terms have the expected signs, and all but two are significant at conventional levels. Labor, road investment, and materials comprise the largest shares of total costs, accounting for approximately 34.5, 25.6, and 18.6 percent of total costs, respectively.[30] Equipment and fuel account for approximately 14.8 percent and 6.6 percent of total costs, respectively. In terms of output variables each is positive and significant, with widely varying elasticities. Moreover, the magnitudes of each elasticity seems plausible. The elasticity of costs with respect to way train service (.0807) is the lowest, probably reflecting the fact that way train service is provided on lines where a much lower portion of capacity is being used than where other types of service are provided. The elasticity of costs with respect to through train service (.4458) is by far the highest, likely reflecting the fact that most through train service is provided on lines where a much greater portion of capacity is being used than on lines where other types of service are being provided, and reflecting the inherent inefficiencies of through train service relative to unit train service. Although unit train service is relatively more efficient than way train service, the elasticity of costs with respect to unit train service (.1371) is higher than that with respect to way train service. This apparently reflects the higher portion of line capacity being used on lines carrying unit trains than on lines carrying way trains.

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[29]Observations with zero values for unit train gross ton-miles have been deleted. Discussions with those familiar with the R-1 database at the Surface Transportation Board raised doubts regarding the validity of such observations. Table A4 of the appendix shows the estimated translog cost function with the Box-Cox transformation applied to outputs ($(q^{\lambda}-1)/\lambda$). A lambda of .0001 is used as it produces nearly identical results to the log transformation when using the same observations. Table A5 of the appendix provides the parameter estimates for the firm dummy variables.

[30]Recall, the elasticity of total costs with respect to factor price is equal to that factors share of total costs, by Shephard's Lemma.

Table 3: Seemingly Unrelated Regression of Translog Cost Function and Share Equations - Controlling for Firm Effects (observations with zero UTGTM are deleted)

First Order Terms	
Intercept	22.0212* (0.0691)
ln Labor Price	0.3451* (0.0072)
ln Equipment Price	0.1476* (0.0057)
ln Fuel Price	0.0663* (0.0017)
ln Materials and Supply Price	0.1856* (0.0096)
ln Way and Structures Price	0.2555* (0.0065)
ln Unit Train Gross Ton-Miles (Adjusted)	0.1371* (0.0262)
ln Way Train Gross Ton-Miles (Adjusted)	0.0807* (0.0249)
ln Through Train Gross Ton-Miles (Adjusted)	0.4458* (0.0759)
ln Speed	0.0279 (0.1083)
ln Miles of Road	0.5547* (0.0957)
ln Average Length of Haul	-0.0660 (0.1062)
Time	-0.0283* (0.0067)
Second Order Terms	
½ (ln Labor Price)^2	0.0987* (0.0139)
½ (ln Equipment Price)^2	0.0219* (0.0047)
½ (ln Fuel Price)^2	0.0491* (0.0033)
½ (ln Materials Price)^2	0.0277 (0.0191)
½ (ln Way and Structures Price)^2	0.1452* (0.0088)
ln Labor Price*ln Equipment Price	-0.0167* (0.0053)
ln Labor Price*ln Fuel Price	-0.0162* (0.0033)
ln Labor Price*ln Materials Price	0.0089 (0.0135)

(Cont'd)

Table 3. Cont'd

ln Labor Price*ln Way and Structures Price	-0.0746* (0.0080)
ln Equipment Price*ln Fuel Price	-0.0013 (0.0014)
ln Equipment Price*ln Materials Price	0.0167** (0.0070)
ln Equipment Price*ln Way and Structures Price	-0.0207* (0.0045)
ln Fuel Price*ln Materials Price	-0.0175* (0.0047)
ln Fuel Price*ln Way and Structures Price	-0.0141* (0.0022)
ln Materials Price*ln Way and Structures Price	-0.0357* (0.0098)
½ (ln Unit Train GTM)^2	0.0395* (0.0106)
½ (ln Way Train GTM)^2	-0.0137 (0.0192)
½ (ln Through Train GTM)^2	0.2198* (0.0772)
ln Labor Price*ln Unit Train GTM	-0.0048** (0.0023)
ln Labor Price*ln Way Train GTM	0.0006 (0.0039)
ln Labor Price*ln Through Train GTM	0.0151*** (0.0077)
ln Equipment Price*ln Unit Train GTM	0.0067* (0.0018)
ln Equipment Price*ln Way Train GTM	0.0142* (0.0031)
ln Equipment Price*ln Through Train GTM	0.0219* (0.0059)
ln Fuel Price*ln Unit Train GTM	0.0045* (0.0005)
ln Fuel Price*ln Way Train GTM	-0.0034* (0.0009)
ln Fuel Price*ln Through Train GTM	0.0035*** (0.0019)
ln Materials Price*ln Unit Train GTM	-0.0142* (0.0031)
ln Materials Price*ln Way Train GTM	-0.0205* (0.0052)
ln Materials Price*ln Through Train GTM	-0.0079 (0.0106)
ln Way and Structures Price*ln Unit Train GTM	0.0078* (0.0021)

Cont'd

Table 3. Cont'd

ln Way and Structures Price*ln Way Train GTM	0.0091** (0.0036)
ln Way and Structures Price*ln Through Train GTM	-0.0326* (0.0074)
ln Unit Train GTM*ln Way Train GTM	-0.0089 (0.0104)
ln Unit Train GTM*ln Through Train GTM	-0.0398 (0.0279)
ln Way Train GTM*ln Through Train GTM	-0.0179 (0.0219)
½ $(\ln \text{Speed})^2$	-0.3289* (0.1225)
½ $(\ln \text{Miles of Road})^2$	-0.0213 (0.0979)
½ $(\ln \text{Average Length of Haul})^2$	-0.1002 (0.2205)
½ $(\text{Time})^2$	-0.0010 (0.0007)
ln Labor Price*ln Speed	-0.0109 (0.0104)
ln Labor Price*ln Miles of Road	0.0043 (0.0103)
ln Labor Price*ln Average Length of Haul	-0.0542* (0.0099)
ln Labor Price*Time	-0.0042* (0.0008)
ln Equipment Price*ln Speed	-0.0053 (0.0083)
ln Equipment Price*ln Miles of Road	-0.0437* (0.0079)
ln Equipment Price*ln Average Length of Haul	-0.0317* (0.0080)
ln Equipment Price*Time	-0.0041* (0.0006)
ln Fuel Price*ln Speed	-0.0012 (0.0024)
ln Fuel Price*ln Miles of Road	-0.0120* (0.0025)
ln Fuel Price*ln Average Length of Haul	0.0367* (0.0023)
ln Fuel Price*Time	0.0002 (0.0002)
ln Materials Price*ln Speed	0.0372* (0.0137)
ln Materials Price*ln Miles of Road	0.0324** (0.0140)

Cont'd

Table 3. Cont'd

ln Materials Price*ln Average Length of Haul	0.0224*** (0.0131)
ln Materials Price*Time	0.0045* (0.0010)
ln Way and Structures Price*ln Speed	-0.0199** (0.0095)
ln Way and Structures Price*ln Miles of Road	0.0190*** (0.0098)
ln Way and Structures Price*ln Average Length of Haul	0.0269* (0.0090)
ln Way and Structures Price*Time	0.0036* (0.0007)
ln Unit Train GTM*ln Speed	-0.0021 (0.0312)
ln Unit Train GTM*ln Miles of Road	0.0122 (0.0377)
ln Unit Train GTM*ln Average Length of Haul	0.0356 (0.0320)
ln Unit Train GTM*Time	-0.0027 (0.0022)
ln Way Train GTM*ln Speed	-0.0234 (0.0378)
ln Way Train GTM*ln Miles of Road	0.1022* (0.0318)
ln Way Train GTM*ln Average Length of Haul	-0.0336 (0.0400)
ln Way Train GTM*Time	-0.0027 (0.0024)
ln Through Train GTM*ln Speed	0.1378*** (0.0807)
ln Through Train GTM*ln Miles of Road	-0.0781 (0.0808)
ln Through Train GTM*ln Average Length of Haul	-0.1764 (0.1258)
ln Through Train GTM*Time	-0.0049 (0.0057)
ln Miles of Road*ln Average Length of Haul	0.4178* (0.1540)
ln Speed*ln Average Length of Haul	0.0020 (0.1314)
ln Speed*Time	-0.0148 (0.0114)
ln Average Length of Haul*Time	0.0248** (0.0102)
ln Miles of Road*ln Speed	-0.0631 (0.1073)

Cont'd

Table 3. Cont'd

ln Miles of Road*Time	0.0093 (0.0068)

System Weighted R^2 = .9958
System Weighted MSE = 1.16
Number of Observations = 215
DW = 1.91
*significant at the 1 percent level
**significant at the 5 percent level
***significant at the 10 percent level
firm specific dummies also are included in the cost function estimation (parameter estimates for firm dummies are not shown)

The widely varying elasticities of costs with respect to the various outputs suggest that aggregating outputs into one as previous studies have done may distort the relationships between costs and outputs. To examine whether it is appropriate to impose the restriction of homogeneous elasticities of costs with respect to the various outputs, the same cost function is estimated with revenue ton-miles as the only output variable. An F-Test is used to assess whether such a restriction is appropriate. The following F-Test is used to assess the validity of such a restriction.

$$F = \frac{(RSS_R - RSS_U)/num.of\ restrictions}{RSS_U / d.f._U}$$
$$= \frac{(.23123 - .12637)/23}{.12637/102} = 3.68$$

where: RSS_U = Unrestricted residual sum of squares
RSS_R = Restricted residual sum of squares
$d.f._U$ = Degrees of freedom for the unrestricted model

As the F-test shows, there is a significant improvement in the model resulting from using multiple outputs, and the restriction of a homogeneous cost elasticity with respect to each output is not valid.

In addition to outputs and factor prices, miles of road also are positive and significant, and suggest that a one percent increase in mileage will result in about a .56 percent increase in costs. Speed has a positive sign, reflecting the increased maintenance of way and capital costs associated with maintaining a higher quality road, but it is not significant at conventional levels. Average length of haul has a negative sign, reflecting the increased efficiencies resulting from longer hauls, but it also is not significant at conventional levels. Finally, the time trend suggests that total railroad costs have been declining at approximately 2.8 percent per year.

The estimated cost function also appears to meet the theoretical properties of a cost function. The estimated cost function is increasing in factor prices, continuous in factor prices by assumption, and concave in factor prices for all 215 observations.[31]

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[31]To test for concavity of the cost function in factor prices, the characteristic roots of the Hessian matrix are taken for every observation in the sample. The characteristic roots are all negative for every observation in the sample. Because the estimation is in logs, the translog parameters must be transformed to obtain the Hessian matrix. The following equation shows the relevant Hessian matrix, and the relationships between translog parameters and Hessian parameters obtained from simple differentiation.

$$H = \begin{bmatrix} \frac{\partial^2 C}{\partial w_i^2} & \frac{\partial^2 C}{\partial w_i \partial w_j} \\ \frac{\partial^2 C}{\partial w_i \partial w_j} & \frac{\partial^2 C}{\partial w_j^2} \end{bmatrix}$$

$$where: \quad \frac{\partial^2 C}{\partial w_i^2} = \frac{C}{w_i^2}\left[\frac{\partial^2 \ln C}{\partial \ln w_i^2} - \frac{\partial \ln C}{\partial \ln w_i} + \frac{\partial \ln C}{\partial \ln w_i}\frac{\partial \ln C}{\partial \ln w_i}\right]$$

$$\frac{\partial^2 C}{\partial w_i \partial w_j} = \frac{C}{w_i w_j}\left[\frac{\partial^2 \ln C}{\partial \ln w_i \partial \ln w_j} + \frac{\partial \ln C}{\partial \ln w_i}\frac{\partial \ln C}{\partial \ln w_j}\right]$$

This Hessian matrix is a two by two matrix. This is shown only for illustrative purposes. A five by five matrix is used in this study.

Before discussing the preliminary assessment of natural monopoly resulting from this estimation, an important point regarding economies of density, scale, and scope should be made. Previous studies have referred to decreasing average costs of output while holding miles of road constant as economies of density. Moreover, the studies have stated that economies of density are a short-run concept, and that economies of overall scale can only be determined by considering the change in average costs with output while allowing miles of road to vary. As discussed in the previous section, an increase in miles of road presents an opportunity for the provision of a whole new array of services, not an adjustment to capital stock in providing the same services. Thus, while the change in railroad costs with changes in miles of road is important, its measurement shows returns to scope and not returns to overall scale.

A preliminary way to assess the existence of natural monopoly in local markets would be to examine the first order terms, and examine the elasticity of costs with respect to output holding miles of road constant. In terms of the potential impacts of railroad mergers on costs, economies of scale are relevant for assessing the potential impacts of mergers with duplicate trackage, while the concept of economies of scope is relevant for assessing the potential impacts of end to end mergers. When summing up the parameter estimates for output, multi-product economies of scale are shown to be strong. The parameter estimates suggest that in 1983 the elasticity of long-run total costs with respect to output was approximately .66, while in 1997 the elasticity of long-run total costs with respect to output was approximately .52.[32] These results

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[32]Because all variables are divided by their means in the translog cost function, these elasticities are for mean levels of all variables over the entire period, including mean output levels. If the elasticity of costs with respect to output is calculated for the Burlington Northern and Union Pacific Railroads (the two largest railroads in 1997), the elasticity of cost with respect to 1983 output levels is .70 and .69, and the elasticity of cost with respect to 1997 output levels is

provide strong preliminary evidence that Class I railroads are natural monopolies in local markets.[33] Furthermore, the elasticity of total costs with respect to output has been decreasing throughout the entire time period shown by the output-time interaction variables.[34] However, this finding does not guarantee subadditivity. Evidence of weak cost complementarities between unit train and way train service, unit train and through train service, and way train and through train service also is shown in the interaction terms. To obtain preliminary evidence of economies of scope in serving different markets, the elasticity of costs with respect to output can be added to the elasticity of costs with respect to miles of road. This shows the percentage change in total

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.73 and .72 for the Burlington Northern and Union Pacific, respectively. These elasticities are calculated by taking the partial derivative of the natural logarithm of costs with respect to outputs while holding technological variables (except time) and factor prices at their mean levels. They are somewhat different from those reported in Table A1, since they hold technological variables at their mean levels. The elasticity of costs with respect to the mean 1997 output level is .56.

[33]Table A1 of Appendix A shows the elasticity of costs with respect to the three outputs for each railroad in each year. The elasticity of costs with respect to each output is obtained by taking the partial derivative of the natural logarithm of costs with respect to the output variable while holding factor prices at their mean levels. All other variables are set at the level appropriate for that railroad and that year (e.g. miles of road, average length of haul, etc.). The estimated elasticities show that railroads with smaller output levels in ton-miles have more unrealized economies.

[34]At first, this result may seem to go against conventional wisdom (that is, since rail networks are handling more traffic, shouldn't the elasticity of cost with respect to output be increasing as more density economies are exhausted?). However, further thought will suggest that this result is exactly what we should expect. The decreasing elasticities over time show that the elasticity of cost with respect to output is decreasing as output level is held constant. That is, for a given output level, elasticities are decreasing over time. With rapid improvements in train control technologies, increasing computerization, and increasing train sizes, we should expect the elasticity of costs with respect to output to decline over time as output is held constant. That is, the effective capacity of rail lines has increased due to technological advances. This does not mean that higher outputs mean lower cost elasticities. In fact, the opposite is true. The fact that higher outputs mean higher cost elasticities can be seen in the large positive coefficients for the squared terms of unit train and through train ton-miles.

costs given a one percent change in output, when the output change is the result of a one percent increase in miles of road. As the parameter estimates suggest, there is evidence of diseconomies of scope in serving different markets, with the elasticity of costs with respect to output and miles of road of approximately 1.22 in 1983 and approximately 1.20 in 1997.[35]

8. TESTS OF COST SUBADDITIVITY FOR THE LONG-RUN COST FUNCTION

Two separate tests of cost subadditivity are performed using the long-run total cost function. First, the existence or non-existence cost subadditivity of Class I carriers in localized markets is assessed by simulating firm costs for separate firms and one firm, while allowing unit train, way train, and through train ton-miles to vary, but holding network size constant. This is equivalent to testing for subadditivity where the alternative to one firm service would entail separate firms serving the same markets over duplicate trackage. This assessment of cost subadditivity is most relevant for consideration of the desirability of multifirm competition over duplicate networks (i.e. intramodal competition). Second, overall Class I railroad cost subadditivity's existence or nonexistence is assessed by simulating firm costs for separate firms and one firm, while allowing unit train, way train, and through train ton-miles to vary and allowing network size to vary. This is equivalent to testing for subadditivity where the alternative to one-firm service would entail separate end-to-end firms. Overall Class I railroad cost subadditivity for a given output level and network size would suggest that end to end mergers of smaller networks up to that size may be beneficial. This assessment of cost

[35]Table A2 of Appendix A shows the elasticity of costs with respect to outputs and miles of road for each railroad and year. Factor prices are set at their mean levels.

subadditivity is most relevant for considering the potential benefits of mergers that increase the overall size of rail networks.

To assess cost subadditivity, both simulations test directly for the subadditivity condition, like Shin and Ying (1992). The subadditivity condition for localized markets is:

$$
\begin{aligned}
& C(q^M) < C(q^a) + C(q^b) \\
& where: \quad C(q^M = C(q_1, q_2, q_3) \\
& \qquad C(q^a) = C(\varphi q_1^M, \lambda q_2^M, \gamma q_3^M) \\
& \qquad C(q^b) = C((1-\varphi) q_1^M, (1-\lambda) q_2^M, (1-\gamma) q_3^M) \\
& \qquad \varphi, \lambda, \gamma = (0.1, 0.2, \ldots, 0.9) \\
& \qquad q_1, q_2, q_3 = unit\ train, way\ train, and\ through\ train\ GTM
\end{aligned}
$$

The parameter estimates obtained from the translog total cost function are used to estimate one- and two-firm costs, where all variables other than outputs, time, and miles of road are placed at their sample means.[36] For each of the observations that have positive marginal costs for each output (i.e. unit train ton-miles, way train ton-miles, and through train ton-miles), simulations are performed by splitting outputs into the 365 unique vector combinations.[37] Table 4 summarizes simulations for cost subadditivity with a fixed network. As the table shows, the condition of strict cost subadditivity is met for 154 out of 168 observations (91.7 percent) that have positive marginal costs using the 1983 cost structure, and for all observations that have positive marginal costs using the 1997 cost structure. Thus, it is clear that Class I railroads are natural monopolies over a fixed network size. This suggests that duplicate service over the Class I rail network would result in excess resource costs. However, a full assessment of the impacts of intramodal

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[36]Subadditivity is evaluated using the 1983 through 1997 cost structures.

[37]For each of the 215 observations in the data set, the sign of marginal cost of each output is examined using the cost structure from every year. Therefore, an observation may be used in the subadditivity simulations for one year, but not for another.

competition on societal welfare would require an assessment of the role played by such competition in limiting carrier pricing power.

The test for overall subadditivity (alternative is separate end-to-end railroads) is performed in the same fashion, except miles of road also are split between two firms. With four variables, there now are a total of 3,281 unique vector combinations. The simulations are performed using the 1983 through 1997 cost structures. This allows an assessment of natural monopoly shortly after railroad deregulation and nearly 18 years after deregulation. Table 5 summarizes results of the simulations for 1983 through 1997. As the table shows, there is little support for the notion that railroads are natural monopolies as network size is expanded. Simulations show that the condition of strict cost subadditivity is only met for 3 percent of the observations that have positive marginal costs for all outputs in 1997, and that monopoly costs are lower than two firm costs only 13 percent of the time; on average, costs decrease with 2-firm operation by 12.5 percent in 1997. Simulations also show that the condition of strict cost superadditivity is met for 52 percent of the observations in 1997. Strict cost superadditivity is the condition where all two-firm combinations have lower costs than the monopoly firm.

Further insight regarding the firm size where cost subadditivity no longer occurs can be obtained by examining subadditivity simulations for different firm configurations. The simulations of overall cost subadditivity using the 1997 cost structure show that for railroad networks that have less than 2,500 route miles, monopoly costs are lower than two-firm costs 100 percent of the time; for railroad networks between 2,500 miles and 4,700 miles, monopoly costs are lower than two-firm costs 88.1 percent of the time; for railroad networks between 4,700 miles and 5,700 miles, monopoly costs are lower than two-firm costs 29.9 percent of the time;

for railroad networks between 5,700 miles and 8,000 miles, monopoly costs are lower than two-firm costs 20.8 percent of the time; and for larger railroad networks, monopoly costs are lower than two-firm costs less than one percent of the time. These findings suggest that there is not a cost justification for further end-to-end mergers in the railroad industry.

While the cost implications of changes in the length of haul and speed of service are controlled for in the cost function specification, changes in service quality available to shippers resulting from a merger cannot be assessed. It is possible that changes in length of haul or speed of service resulting from mergers improve the quality of the product available to shippers. Moreover, other network effects of mergers, such as the sharing of equipment between regions where the products shipped have complementary seasonal shipment patterns may confer benefits upon shippers. Nonetheless, the cost function estimation results suggest that the service benefits would have to be substantial for further end-to-end mergers to be beneficial from a social welfare perspective.

Table 4: Summary of Subadditivity Simulations while Network Size is Held Fixed

Year	Number of Simulations	Monopoly Costs Lower Than Two-Firm Costs		Percent Increase in Costs from Splitting the Monopoly (over all 78,475 simulations)[38]			Number of Observations	Cost Subadditivity Condition Met	
		Number	Pct.	Average	Maximum	Minimum		Number	Pct.
1983	61,320	61,107	99.7	30.6	111.0	-11.6	168	154	91.7
1984	60,590	60,439	99.8	31.4	113.5	-10.5	166	155	93.4
1985	59,495	59,386	99.8	32.1	116.0	-9.4	163	155	95.1
1986	59,130	59,044	99.9	33.0	118.5	-8.2	162	158	97.5
1987	57,670	57,603	99.9	33.5	121.0	-7.1	158	155	98.1
1988	56,575	56,519	99.9	34.2	123.5	-6.0	155	152	98.1
1989	55,845	55,808	99.9	35.0	126.1	-5.0	153	151	98.7
1990	53,655	53,631	100.0	36.2	128.8	-4.0	147	145	98.6
1991	52,560	52,546	100.0	37.0	131.4	-3.0	144	142	98.6
1992	52,195	52,188	100.0	38.0	134.1	-2.0	143	141	98.6
1993	51,465	51,463	100.0	38.9	136.9	-0.9	141	139	98.6
1994	51,100	51,100	100.0	39.8	139.6	0.1	140	140	100.0
1995	50,370	50,370	100.0	40.6	142.4	1.2	138	138	100.0
1996	49,640	49,640	100.0	41.3	145.3	2.3	136	136	100.0
1997	49,275	49,275	100.0	42.1	148.1	3.4	135	135	100.0

[38] Negative values suggest a cost decrease from multiple-firm operation.

Table 5: Summary of Subadditivity Simulations while Network Size Varies

		Monopoly Costs Lower Than Two-Firm Costs		Percent Increase in Costs from Splitting Monopoly (over all 705,415 simulations)[39]				Cost Subadditivity Condition Met		Cost Superadditivity Condition Met	
Year	Number of Simulations	Number	Pct.	Average	Maximum	Minimum	Number of Observations	Number	Pct.	Number	Pct.
1983	551,208	109,494	19.9	-11.6	79.5	-60.7	168	1	0.6	96	57.2
1984	544,646	107,804	19.8	-11.5	80.4	-60.8	166	1	0.6	96	57.8
1985	534,803	101,862	19.1	-11.7	81.4	-60.9	163	1	0.6	96	58.9
1986	531,522	100,366	18.9	-11.7	82.3	-61.0	162	1	0.6	96	59.3
1987	518,398	92,518	17.9	-11.9	83.3	-61.0	158	1	0.6	96	60.8
1988	508,555	87,104	17.1	-12.0	84.4	-61.1	155	1	0.7	96	61.9
1989	501,993	82,592	16.5	-12.1	85.4	-61.1	153	2	1.3	96	62.8
1990	482,307	81,248	16.9	-11.9	86.4	-61.1	147	2	1.4	95	64.6
1991	472,464	74,014	15.7	-12.1	87.5	-61.1	144	4	2.8	95	66.0
1992	469,183	73,730	15.7	-12.0	88.6	-61.1	143	5	3.5	93	65.0
1993	462,621	70,342	15.2	-12.0	89.7	-61.0	141	5	3.6	92	65.3
1994	459,340	68,605	14.9	-12.1	90.9	-61.0	140	5	3.6	89	63.6
1995	452,778	63,796	14.1	-12.3	92.0	-60.9	138	6	4.4	84	60.9
1996	446,216	60,581	13.6	-12.7	92.0	-60.9	136	5	3.7	79	58.1
1997	446,216	58,924	13.2	-12.5	94.4	-60.7	136	4	2.9	70	51.5

[39] Negative values suggest a cost decrease from multiple-firm operation.

9. EMPIRICAL RESULTS OF QUASI-COST FUNCTION

Table 6 shows the estimated translog quasi-cost function. As the table shows, all first order terms except one have the expected signs, and all but four are significant at conventional levels. Similar to the results for the total-cost function, the output variables show widely varying elasticities. Through train ton-miles again have the highest elasticity (.7150), likely reflecting the fact that through train output is the largest output, and consequently has exhausted more of the available scale economies than other outputs. Way train ton-miles have an elasticity of about .20, suggesting that a one percent increase in way train ton-miles will lead to a .20 percent increase in costs. Unit train ton-miles have the smallest elasticity of the three outputs (.1480).

In addition to output variables, other variables that have the expected signs include input price variables and technological variables, except average length of haul. Way and structures capital per mile of track and miles of track per mile of road have negative signs, suggesting that the transportation costs associated with operating over a rail line are lower when the quality of the way and structures is higher. The time trend shows that railroad costs excluding way and structures costs have declined by about 4.7 percent per year.

Table 6: Seemingly Unrelated Regression of Translog Quasi-Cost Function and Share Equations - Controlling for Firm Effects (observations with zero UTGTM are deleted)

First Order Terms	
Intercept	21.7679* (0.1040)
ln Labor Price	0.4298* (0.0082)
ln Equipment Price	0.2192* (0.0090)
ln Fuel Price	0.1008* (0.0028)
ln Materials and Supply Price	0.2502* (0.0125)
ln Unit Train Gross Ton-Miles (Adjusted)	0.1480* (0.0459)
ln Way Train Gross Ton-Miles (Adjusted)	0.1977* (0.0398)
ln Through Train Gross Ton-Miles (Adjusted)	0.7150* (0.1303)
ln Way and Structures Capital per Mile of Track	-0.1989 (0.1286)
ln Miles of Track per Mile of Road	-0.0493 (0.1736)
ln Miles of Road	0.2001 (0.1514)
ln Average Length of Haul	0.0675 (0.1571)
Time	-0.0484* (0.0118)
Second Order Terms	
½ (ln Labor Price)^2	0.0999* (0.0155)
½ (ln Equipment Price)^2	0.0213* (0.0068)
½ (ln Fuel Price)^2	0.0627* (0.0048)
½ (ln Materials Price)^2	0.0512** (0.0202)
ln Labor Price*ln Equipment Price	-0.0328* (0.0061)
ln Labor Price*ln Fuel Price	-0.0246* (0.0049)

Cont'd

Table 6. Cont'd

ln Labor Price*ln Materials Price	-0.0425* (0.0155)
ln Equipment Price*ln Fuel Price	-0.0089* (0.0021)
ln Equipment Price*ln Materials Price	0.0205** (0.0089)
ln Fuel Price*ln Materials Price	-0.0292* (0.0068)
½ (ln Unit Train GTM)^2	0.0650* (0.0171)
½ (ln Way Train GTM)^2	-0.0423 (0.0318)
½ (ln Through Train GTM)^2	0.0606 (0.3002)
ln Labor Price*ln Unit Train GTM	-0.0069* (0.0026)
ln Labor Price*ln Way Train GTM	-0.0023 (0.0044)
ln Labor Price*ln Through Train GTM	-0.0355* (0.0120)
ln Equipment Price*ln Unit Train GTM	0.0123* (0.0029)
ln Equipment Price*ln Way Train GTM	0.0223* (0.0049)
ln Equipment Price*ln Through Train GTM	0.0445* (0.0133)
ln Fuel Price*ln Unit Train GTM	0.0079* (0.0009)
ln Fuel Price*ln Way Train GTM	-0.0037** (0.0015)
ln Fuel Price*ln Through Train GTM	0.0093** (0.0040)
ln Materials Price*ln Unit Train GTM	-0.0133* (0.0039)
ln Materials Price*ln Way Train GTM	-0.0163** (0.0067)
ln Materials Price*ln Through Train GTM	-0.0182 (0.0182)
ln Unit Train GTM*ln Way Train GTM	0.0347** (0.0152)

Cont'd

Table 6. Cont'd

ln Unit Train GTM*ln Through Train GTM	-0.0042 (0.0509)
ln Way Train GTM*ln Through Train GTM	-0.1390** (0.0597)
½ (ln Way and Structures Capital per Mile of Track)	-0.3607*** (0.2121)
½ (Miles of Track per Mile of Road)^2	0.4076 (0.4897)
½ (ln Miles of Road)^2	-0.0671 (0.3797)
½ (ln Average Length of Haul)^2	0.3168 (0.3433)
½ (Time)^2	0.0002 (0.0013)
ln Labor Price*ln Way and Structures Capital per Mile of Track	-0.0147 (0.0106)
ln Labor Price*ln Miles of Track per Mile of Road	0.0737* (0.0150)
ln Labor Price*ln Miles of Road	0.0641* (0.0151)
ln Labor Price*ln Average Length of Haul	-0.0402* (0.0103)
ln Labor Price*Time	-0.0009 (0.0009)
ln Equipment Price*ln Way and Structures Capital per Mile of Track	-0.0024 (0.0116)
ln Equipment Price*ln Miles of Track per Mile of Road	-0.0474* (0.0165)
ln Equipment Price*ln Miles of Road	-0.0754* (0.0167)
ln Equipment Price*ln Average Length of Haul	-0.0567* (0.0114)
ln Equipment Price*Time	-0.0056* (0.0010)
ln Fuel Price*ln Way and Structures Capital per Mile of Track	0.0012 (0.0035)
ln Fuel Price*ln Miles of Track per Mile of Road	-0.0236* (0.0049)
ln Fuel Price*ln Miles of Road	-0.0216* (0.0050)
ln Fuel Price*ln Average Length of Haul	0.0501* (0.0035)

Cont'd

Table 6. Cont'd

ln Fuel Price*Time	0.0001 (0.0004)
ln Materials Price*ln Way and Structures Capital per Mile of Track	0.0159 (0.0160)
ln Materials Price*ln Miles of Track per Mile of Road	-0.0027 (0.0226)
ln Materials Price*ln Miles of Road	0.0329 (0.0229)
ln Materials Price*ln Average Length of Haul	0.0468* (0.0156)
ln Materials Price*Time	0.0064* (0.0014)
ln Unit Train GTM*ln Way and Structures Capital per Mile of Track	-0.1310** (0.0549)
ln Unit Train GTM*ln Miles of Track per Mile of Road	-0.1303** (0.0620)
ln Unit Train GTM*ln Miles of Road	-0.0581 (0.0644)
ln Unit Train GTM*ln Average Length of Haul	0.0384 (0.0498)
ln Unit Train GTM*Time	-0.0001 (0.0037)
ln Way Train GTM*ln Way and Structures Capital per Mile of Track	0.1672** (0.0788)
ln Way Train GTM*ln Miles of Track per Mile of Road	0.1177 (0.0916)
ln Way Train GTM*ln Miles of Road	0.2118** (0.0889)
ln Way Train GTM*ln Average Length of Haul	-0.0533 (0.0500)
ln Way Train GTM*Time	-0.0125* (0.0045)
ln Through Train GTM*ln Way and Structures Capital per Mile of Track	0.4839*** (0.2530)
ln Through Train GTM*ln Miles of Track per Mile of Road	0.0496 (0.3025)
ln Through Train GTM*ln Miles of Road	0.1414 (0.3150)
ln Through Train GTM*ln Average Length of Haul	0.0204 (0.2069)
ln Through Train GTM*Time	-0.0321* (0.0101)

Cont'd

Table 6. Cont'd

ln Way and Structures Capital per Mile of Track*ln Miles of Track per Mile of Road	0.1335 (0.2170)
ln Way and Structures Capital per Mile of Track*ln Miles of Road	-0.3926 (0.3059)
ln Way and Structures Capital per Mile of Track*ln Average Length of Haul	-0.5257* (0.1756)
ln Way and Structures Capital per Mile of Track*Time	0.0322* (0.0122)
ln Miles of Track per Mile of Road*ln Miles of Road	0.0301 (0.3162)
ln Miles of Track per Mile of Road*ln Average Length of Haul	0.2132 (0.3147)
ln Miles of Track per Mile of Road*Time	-0.0082 (0.0158)
ln Miles of Road*ln Average Length of Haul	0.0148 (0.2400)
ln Miles of Road*Time	0.0407* (0.0126)
ln Average Length of Haul*Time	-0.0263*** (0.0153)

System Weighted R^2 = .9945
System Weighted MSE = 1.10
Number of Observations = 215
DW = 1.98
*significant at the 1 percent level
**significant at the 5 percent level
***significant at the 10 percent level
firm specific dummies also are included in the cost function estimation (parameter estimates for firm dummies are not shown)

To make a preliminary assessment of whether railroads are natural monopolies in providing transportation services over their own network, we can examine the elasticity of cost with respect to the three outputs. The parameter estimates suggest that in 1983, the elasticity of cost excluding way and structures costs with respect to output was approximately 1.06 at the point of means, suggesting that slight multiproduct diseconomies of scale in providing transportation services over one railroad network existed. However, the sum of these output elasticities was approximately .43 in 1997 at the point of means, suggesting strong multiproduct economies of scale in providing transportation services over one railroad network.[40] The large drop in cost elasticities of output likely reflects technological advances in train control systems, increases in train sizes, increases in computerization, and other technological improvements that have occurred over time. In essence, technological advances have improved railroads' abilities to handle more traffic over a particular system. These strong multiproduct scale economies suggest that multiple firm operation on a single rail network is likely to lead to cost increases. The next section performs subadditivity tests in the same fashion as was done for the total railroad cost function.

10. TESTS OF COST SUBADDITIVITY FOR SHORT-RUN QUASI-COST FUNCTION

To test for cost subadditivity in providing transportation services over one rail line, the same type of simulations are performed that were performed to assess cost subadditivity in local markets. The parameter estimates from the quasi-cost function are used to estimate one-firm and two-firm quasi-costs, with all variables other than outputs, time, and miles of road placed at their sample means. Single-firm and two-firm costs are estimated by splitting the three outputs into unique vector combinations (365) for each of the observations that have positive marginal quasi-costs associated with each type of output.[41]

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[40] Just as in the case of the long-run total cost function, these cost elasticities are for mean levels of all variables over the entire period, including mean output levels.

[41] For each of the 215 observations in the data set, the sign of marginal quasi-cost of each output is examined using the cost structure from every year. Therefore, an observation may be used in the subadditivity simulations for one year, but not for another.

Table 7 summarizes the subadditivity simulations for railroad operation over a single railroad's network. As the table shows, there is strong evidence to suggest that railroads are natural monopolies in providing transportation services over one rail network. In 1997, nearly 95 percent of all simulations show monopoly costs to be lower than two-firm costs. Moreover, the condition of subadditivity is met for more than 60 percent of all observations, and superadditivity is not met for any of the observations. These results suggest that multiple-firm operation over a single rail network would lead to cost increases.[42] This would be true in cases of total open access or in cases where competition is introduced to bottleneck rail segments.[43] The next section of the report examines the implications of scale economies for pricing in the railroad industry.

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[42]Some caution must be used in interpreting the magnitude of cost increases resulting from two-firm operation shown in Table 7, since way and structures inputs are not produced separately from transportation services. Further, the percent cost increases shown are for quasi-costs, not for total costs.

[43]The estimated cost increases from multiple-firm operation are due only to a decreased ability to realize density economies resulting from a single firm's output being split between two hypothetical firms. They do not show impacts of congestion or interference between railroads resulting from competition. Moreover, they do not show the potential impacts of competition on the quality of service. If substantial delays occur as a result of competition over an existing rail line, customers may realize higher inventory costs or lost sales costs, as lead times become longer and more variable. These impacts can not be estimated with available data.

Table 7: Summary of Subadditivity Simulations for Costs without Maintenance of Way for Observations Having Positive Marginal Costs

		Monopoly Costs Lower Than Two-Firm Costs		Percent Increase in Costs (excluding way and structures costs) Due to 2-Firm Operation (over all 78,475simulations)[44]				Cost Subadditivity Condition Met		Cost Superadditivity Condition Met	
Year	Number of Simulations	Number	Pct.	Average	Maximum	Minimum	Number of Observations	Number	Pct.	Number	Pct.
1983	56,210	15,398	27.4	-7.9	49.0	-57.6	154	2	1.3	58	37.7
1984	56,210	21,330	38.0	-5.1	53.6	-55.7	154	2	1.3	48	31.2
1985	56,210	27,358	48.7	-2.3	58.5	-53.7	154	4	2.6	40	26.0
1986	56,210	32,596	58.0	0.7	63.7	-51.5	154	13	8.4	36	23.4
1987	55,845	36,534	65.4	3.7	69.1	-49.3	153	28	18.3	31	20.3
1988	55,115	39,328	71.4	6.8	74.7	-46.9	151	35	23.2	24	15.9
1989	54,750	41,913	76.6	10.0	81.7	-44.4	150	49	32.7	16	10.7
1990	54,750	44,458	81.2	13.5	90.5	-41.7	150	72	48.0	16	10.7
1991	53,655	45,075	84.0	17.0	99.8	-38.9	147	86	58.5	15	10.2
1992	51,830	44,504	85.9	20.2	109.7	-35.9	142	93	65.5	14	9.9
1993	50,735	44,502	87.7	23.9	120.3	-32.8	139	102	73.4	7	5.0
1994	44,530	39,678	89.1	25.4	74.8	-29.4	122	88	72.1	0	0.0
1995	39,420	35,937	91.1	27.8	83.4	-26.6	108	75	69.4	0	0.0
1996	34,310	31,901	93.0	30.2	93.5	-24.9	94	63	67.0	0	0.0
1997	28,470	26,915	94.5	32.1	104.4	-23.1	78	47	60.3	0	0.0

[44]Negative values suggest a cost decrease from multiple-firm operation.

11. IMPLICATIONS OF MULTI-PRODUCT SCALE ECONOMIES FOR RR PRICING

The degree of multi-product scale economies has important implications for railroad pricing.[45] Just as single-product scale economies imply falling average costs, multi-product scale economies imply falling ray average costs. These imply that marginal costs of providing services are less than the average costs of providing services. Thus, the well known socially optimum pricing rule of setting price equal to marginal costs will lead to a revenue shortfall when multi-product scale economies exist.

A. The Rationale for Differential Pricing

In a regulated industry, when the socially optimum rule is not feasible, economists suggest the application of "second best" rules. Second best rules, as the term implies, are rules that attempt to approximate the socially optimal rules as closely as possible, while recognizing the constraints that prevent such rules from being feasible. In the case of scale economies, the second best rule advocated by most economists is known as Ramsey Pricing. Ramsey Pricing is a regulatory pricing rule derived through classical optimization techniques by maximizing social welfare subject to a break-even constraint. Basically, the prescribed rule under Ramsey Pricing is to price inversely to the price elasticity of demand.[46] Thus, in "captive" markets that are

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[45]Recall that multi-product scale economies are defined as the inverse of the cost elasticity of output:

$$S = \frac{C}{\sum_i \frac{\partial C}{\partial y_i} y_i}$$

[46]Technically, this is only true where there are no substitute services (cross-price elasticities are zero). In general, Ramsey pricing results in reducing all quantities by the same proportion relative to the quantities that would equate price with marginal cost. The price elasticity of demand for rail service shows the percentage decrease in quantity demanded of rail

characterized by a limited number of transportation alternatives, the markups above marginal costs are greater than in "competitive" markets where many transportation alternatives exist. Mathematically, the basic Ramsey Pricing Rule is as follows:

$$\frac{P_i - MC_i}{P_i} = \frac{\lambda}{\varepsilon_i}$$

where:	P_i	=	Price in market i
	MC_i	=	marginal cost
	ϵ_i	=	price elasticity of demand in market i
	λ	=	constant markup parameter reflecting the break-even constraint

The intuitive appeal of the Ramsey formula can be seen by examining Figure 6. As the figure shows, the deadweight loss associated with the same price markup is much higher in markets with elastic demands (def in the figure) than in markets with inelastic demands (abc in the figure). This is the case because the same price markup in elastic markets leads to larger reductions in quantities than in inelastic markets. Consequently, there are a larger amount of goods not being produced where the value placed on them by consumers is greater than the costs of resources used to produce them. If higher percentage markups are placed on goods or services sold in inelastic markets, and lower percentage markups are placed on goods or services sold in elastic markets, the total deadweight loss will be minimized. The presence of economies of scale in providing railroad services over a fixed network and the second best properties of Ramsey Pricing are the basic justifications for differential pricing in the railroad industry.

services as the price increases by one percent.

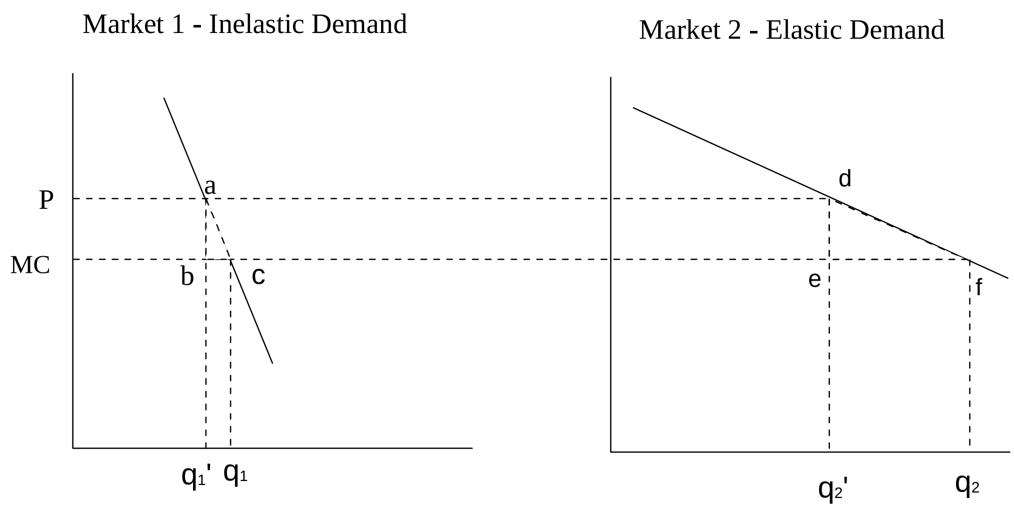

Figure 6

B. Scale Economies and Captive Markups

While scale economies in the railroad industry make differential pricing a necessity, it is interesting to examine the factors that influence the severity of differential pricing. That is, what kind of markups are needed in the most inelastic markets to obtain break-even revenues for the railroad?

Three important factors influence the size of the markup that must be charged in "captive" markets (those with inelastic demand) to ensure that the railroad breaks even. These include: (1) the degree of scale economies, (2) the elasticity of demand in competitive markets, and (3) the portion of traffic that is captive. First, the larger the degree of scale economies realized, the larger the difference between marginal and average costs. Consequently, the larger the degree of scale economies, the larger the overall markup above marginal costs that is needed to recoup total costs. Second, for a given degree of scale economies and a given competitive-captive traffic mix, the higher the elasticity of demand in competitive markets, the higher the markup necessary to recoup full railroad costs in captive markets. If the price elasticity of demand in competitive markets is so high that the railroad can only charge a small markup in such markets, the size of the markup that must be charged in captive markets is large. Finally, the smaller the portion of traffic that is captive, the larger average markup that must be paid by each of the captive shippers to recoup total railroad costs, holding the elasticity of demand in competitive markets and scale economies constant. Thus, captive shippers that are on railroads with the largest discrepencies between marginal costs and average costs, with the smallest captive customer base relative to the competitive base, and with the most price sensitive competitive traffic bases will be charged the largest markups, holding all other factors constant.

Friedlaender (1992) developed a theoretical methodology for determining the necessary markups in captive sectors for recovering full railroad costs given different assumptions about the degree of scale economies and the portion of traffic that is captive. This section of the report will describe Friedlander's framework, and apply the framework to the estimated multi-product scale economies over the fixed network obtained in the previous section.[47]

[47]This assumes that increased traffic is accommodated without an increase in miles of road. If increased traffic is accommodated with an increase in miles of road, the results are much different. The diseconomies of scale finding when output increases are the result of route mile increases suggests that the marginal cost of providing more output when it is accommodated by route mile increases is above average cost.

For simplicity, assume that there are only two markets: (1) a competitive market, and (2) a captive market. Friedlaender defines multiproduct economies of scale in the same way that we did previously, but considers captive market and competitive market outputs as two different products. Scale economies are defined as:

$$S = \frac{C(y_1, y_2)}{y_1 \frac{\partial C}{\partial y_1} + y_2 \frac{\partial C}{\partial y_2}}$$

where: y_1 = output in the competitive market
y_2 = output in the captive market

Now, if the railroad firm priced its competitive and captive outputs at marginal cost, it would earn revenues equal to RMC[48]:

$$RMC = \frac{\partial C}{\partial y_1} y_1 + \frac{\partial C}{\partial y_2} y_2$$

where: $\partial C/\partial y_i$ = marginal cost of producing output i (these marginal costs are assumed to be equal)

Next, suppose that the firm does not charge marginal cost for its outputs, but instead charges a price on each output so that the railroad earns revenues equal to the full costs of operating the railroad. This is shown as follows:

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[48]Marginal cost revenues and total costs for 1997 are shown in Table A3 of Appendix A. Marginal cost of unit train output is estimated using the following relationship:

$$\frac{\partial C}{\partial UTGTM} = \frac{\partial \ln C}{\partial \ln UTGTM} \cdot \frac{C}{UTGTM}$$

Marginal cost of way train and through train outputs are estimated in the same fashion, where the elasticity of cost with respect to each output is obtained by taking the partial derivative of the natural logarithm of cost with respect to the natural logarithm of the output variable while holding factor prices at their mean levels.

$$p_1 y_1 + p_2 y_2 = C(y_1, y_2)$$

But, if we multiply the degree of scale economies (S) by the revenues obtained from charging a price equal to marginal cost (RMC), we can see that they are equal to total cost:

$$S \cdot RMC = \frac{C(y_1, y_2)}{\frac{\partial C}{\partial y_1} y_1 + \frac{\partial C}{\partial y_2} y_2} \cdot \left(\frac{\partial C}{\partial y_1} y_1 + \frac{\partial C}{\partial y_2} y_2 \right) = C(y_1, y_2)$$

This implies that the degree of scale economies multiplied by the revenues that would accrue from marginal cost pricing is equal to the revenues obtained when charging breakeven prices:

$$S \cdot RMC = p_1 y_1 + p_2 y_2$$

If we solve this equation for S, we get the following:

$$S = \frac{p_1 y_1 + p_2 y_2}{\frac{\partial C}{\partial y_1} y_1 + \frac{\partial C}{\partial y_2} y_2}$$

which is equal to:

$$S = \left(\frac{p_1}{\frac{\partial c}{\partial y_1}} \right) \cdot \left(\frac{\frac{\partial c}{\partial y_1} y_1}{\frac{\partial c}{\partial y_1} y_1 + \frac{\partial c}{\partial y_2} y_2} \right) + \left(\frac{p_2}{\frac{\partial c}{\partial y_2}} \right) \cdot \left(\frac{\frac{\partial c}{\partial y_2} y_2}{\frac{\partial c}{\partial y_1} y_1 + \frac{\partial c}{\partial y_2} y_2} \right)$$

In this equation, the first term in brackets represents the price/marginal-cost markup in the competitive sector that allows the firm to break even, the second term in brackets represents the share of marginal cost revenues that are accounted for in the competitive sector, the third term in brackets represents the price/marginal cost markup in the captive sector that allows the firm to break even, and the last term in brackets represents the share of marginal cost revenues accounted for by the captive sector. We can define each of these more compactly as follows:

λ_1 = price/marginal cost ratio in the competitive market allowing the firm to break even
λ_2 = price/marginal cost ratio in the captive market allowing the firm to break even
γ_1 = share of marginal cost revenues accounted for by the competitive sector
γ_2 = share of marginal cost revenues accounted for by the captive sector

Then, the above equation can be expressed as:

$$S = \lambda_1 \gamma_1 + \lambda_2 \gamma_2$$

We can solve for the price/marginal cost ratio in the captive market that will allow the firm to break even, as follows:

$$\lambda_2 \gamma_2 = S - \lambda_1 \gamma_1 \Rightarrow \lambda_2 = \frac{S - \lambda_1 \gamma_1}{\gamma_2}$$

If it is assumed that there is perfect competition in the competitive sector, so the elasticity of demand for rail service in the competitive sector is equal to negative infinity, then the price/marginal cost ratio in the competitive sector would be equal to one. That is, price would equal marginal cost in the competitive sector. The relevant equation for determining the markup needed in the captive sector for the railroad to break even would be as follows:

$$\lambda_2 = \frac{S - \gamma_1}{\gamma_2}$$

Note, that the markup needed in the captive sector to ensure that the railroad breaks even is independent of the elasticity of demand in either sector. It only depends on the degree of scale economies realized and the proportion of marginal cost revenues accounted for by each sector. Consistent with our earlier discussion, the markup needed in the captive sector is positively related to the degree of scale economies realized and negatively related to the size of the captive sector relative to the competitive sector. The markups obtained from this equation are termed "polar" Ramsey markups by Friedlaender.

To estimate "polar" Ramsey Markups using the estimated scale economies from this study, some idea of the size of the "captive" sector served by each railroad is needed. The degree of captivity realized for a particular shipment will be a function of the available alternatives for making the particular shipment. Factors such as access to barge loading facilities, the degree of railroad concentration in a region, and the type of commodity will have an influence on the degree of captivity realized for a particular shipment.

Because price elasticity data for rail shipments are not available, two alternative approaches to estimating the "polar" Ramsey Markups are used here. First, "polar" Ramsey Markups are estimated for each railroad under varying competitive/captive traffic mixes. This will show how varying degrees of multi-product scale economies can influence the markups necessary in captive markets to recover railroad costs, including a return on investment necessary to attract capital. Second, “polar” Ramsey Markups are estimated for each railroad by examining the portion of each railroad’s traffic that are comprised of “captive commodities”.

Table 8 shows the “polar” Ramsey Markups for 1997, with varying portions of traffic that are captive.[49] As the table shows, railroads with greater scale economies must charge higher markups to captive traffic than those with fewer scale economies, for a given proportion of traffic that is captive. Moreover, the table shows that for a given degree of scale economies, the polar markup decreases as the proportion of traffic that is captive increases. That is, the revenue shortfall from competitive traffic is shared among more captive shippers.

To make an assessment of the portion of each railroad’s traffic that is comprised of commodities that may be considered captive, a multi-step process is followed. First, revenue-to-variable cost ratios are calculated for each commodity, using nationwide average shipment characteristics. Second, commodities with average revenue-to-variable cost ratios above 1.8 are considered captive. Finally, the portion of each railroad’s traffic that is comprised of these “captive” commodities is estimated.

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[49]It is important to remember that these polar markups assume that all traffic that is not captive moves at a price equal to marginal cost. In reality there is a continuum of demand elasticities facing each railroad in different markets. That is, some “competitive” traffic is charged slightly more than marginal costs, some that is a little less competitive is charged a little bit more, etc. Thus, the polar markups probably are higher than the actual markups necessary for the railroad to break even. Moreover, the polar markups are average markups needed to recover costs from captive traffic. Thus, markups to captive traffic would be above and below these markups. Of course, captive traffic may not necessarily be willing to pay such markups.

Table 8: Polar Ramsey Markups – Given Varying Portions of Traffic that is Captive - 1997					
Railroad	**10 percent Captive**	**20 percent Captive**	**30 percent Captive[50]**	**40 percent Captive**	**Scale Economies - Network Fixed**
Burlington Northern-Sante Fe	7.33	4.17	3.11	2.58	1.63
CONRAIL	7.46	4.23	3.15	2.62	1.65
CSX Transportation	8.47	4.74	3.49	2.87	1.75
Grand Trunk & Western	17.37	9.19	6.46	5.09	2.64
Illinois Central	21.03	11.02	7.68	6.01	3.00
Norfolk Southern	7.19	4.10	3.06	2.55	1.62
Soo Line	15.68	8.34	5.89	4.67	2.47
Union Pacific	6.37	3.69	2.79	2.34	1.54

Variable costs for each commodity at nationwide average characteristics are estimated from the Uniform Railroad Costing System (URCS). The average characteristics include commodity specific average shipment size and load factor obtained from the Public Use Waybill Sample, commodity specific average length of haul obtained from the Surface Transportation Board[51], and the most frequent rail car type for a commodity from the Public Use Waybill

[50]Using 1993 data, the Surface Transportation Board found that 33 percent of all rail traffic moved at revenue-to-variable cost ratios above 1.8. Under 49 U.S.C. 10707(d)(1), 1.8 is the jurisdictional threshold revenue-to-variable cost ratio for challenging a rail rate. Moreover, a revenue-to-variable cost ratio of 1.8 is often used as a demarcation between captive and competitive traffic. See Ex Parte No. 347 (Sub-No. 2), Rate Guidelines-- Non Coal Proceedings, December 27, 1996.

[51]Surface Transportation Board, Office of Economics, Environmental Analysis, and Administration. "Rail Rates Continue Multi-Year Decline," internet document.

Sample. These costs are estimated using western and eastern regional averages of railroad characteristics.[52]

Revenues per ton-mile are obtained for each commodity from the Surface Transportation Board.[53] Table 9 shows the estimated revenue-to-variable cost ratios for commodities commonly shipped by rail. As the table shows, metallic ores, transportation equipment, chemicals, paper products, and stone products all have estimated revenue-to-variable cost ratios exceeding 1.8. Thus, for purposes of estimating polar Ramsey markups, these commodities are considered captive.[54]

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[52]It should be noted that costing the nationwide average characteristics may not necessarily show the average cost of all shipments of a particular commodity, as shipment characteristics within a commodity grouping may vary widely. Nonetheless, the ratio of nationwide revenues to the nationwide average movement costs still will provide an indicator of the relative captivity of a particular commodity.

[53]Ibid.

[54]It should be noted that the relative captivity of a rail shipment depends on the transportation alternatives in the region where the shipment is made in addition to the type of commodity being shipped.

Table 9: Estimated Revenue-to-Variable Cost Ratios Using Nationwide Average Shipment Characteristics	
Commodity (STCC)	**Revenue-to-Variable Cost Ratio**
Farm Products (01)	1.27
Metallic Ores (10)	2.41
Coal (11)	1.57
Nonmetallic Minerals (14)	1.62
Food and Kindred Products (20)	1.40
Lumber and Wood (24)	1.67
Pulp, Paper, and Allied Products (26)	1.96
Chemicals (28)	1.98
Petroleum and Coal Products (29)	1.64
Stone, Clay, Glass, and Concrete Products (32)	1.96
Primary Metal Products (33)	1.78
Transportation Equipment (37)	2.17
Waste and Scrap Materials (40)	1.65

For estimating the "polar" Ramsey Markups, the portion of each railroad's ton-miles comprised of metallic ores, transportation equipment, chemicals, paper products, and stone products is used to determine the portion of its shipments that are captive.[55] Table 10 shows the estimated portions of captive traffic and the estimated polar Ramsey markups by railroad.

[55]The Surface Transportation Board's, *Freight Commodity Statistics* are used to determine tons of various commodities shipped by railroad. These tons are multiplied by the nationwide average length of haul by commodity to obtain an estimate of ton-miles by commodity. This is equivalent to assuming that the relative shipment distances of all commodities are the same on each railroad.

Table 10: Estimated Polar Ramsey Markups by Railroad, 1997		
Railroad	**Prop. Captive**	**Polar Markup**[56]
Burlington Northern-Sante Fe	0.1578	5.01
CONRAIL	0.2404	3.69
CSX Transportation	0.2631	3.84
Grand Trunk & Western	0.4476	4.66
Illinois Central	0.3169	7.32
Norfolk Southern	0.2346	3.64
Soo Line	0.2896	6.07
Union Pacific	0.2439	3.20

The next section of the study examines the welfare implications of single rail firm operation in comparison to duplicate networks or multi-firm competition over one network.

12. MEASURING THE WELFARE IMPACTS OF MONOPOLY

As discussed earlier in the study, the welfare impacts of monopoly depend on the cost and pricing implications of such an industry structure. The previous section shows that there are savings in resource costs associated with single-firm operation compared to duplicate networks and that there are savings in costs associated with single-firm operation over an individual railroad's network. On the other hand, duplicate railroad networks or multiple-firm operation

[56]The polar markup shows the markup above marginal cost that would be needed for the railroad to break even, given the estimated scale economies over the fixed network, the estimated portion of traffic that is captive, and the assumption that all non-captive traffic moves at a price equal to marginal cost.

over an individual network may lead to decreases in price and increases in output resulting from competition.

Figure 7, which is similar to Figure 3, shows the tradeoff when the alternative to one-firm operation is oligopoly.[57] The welfare gain from monopoly operation is the resource cost savings,

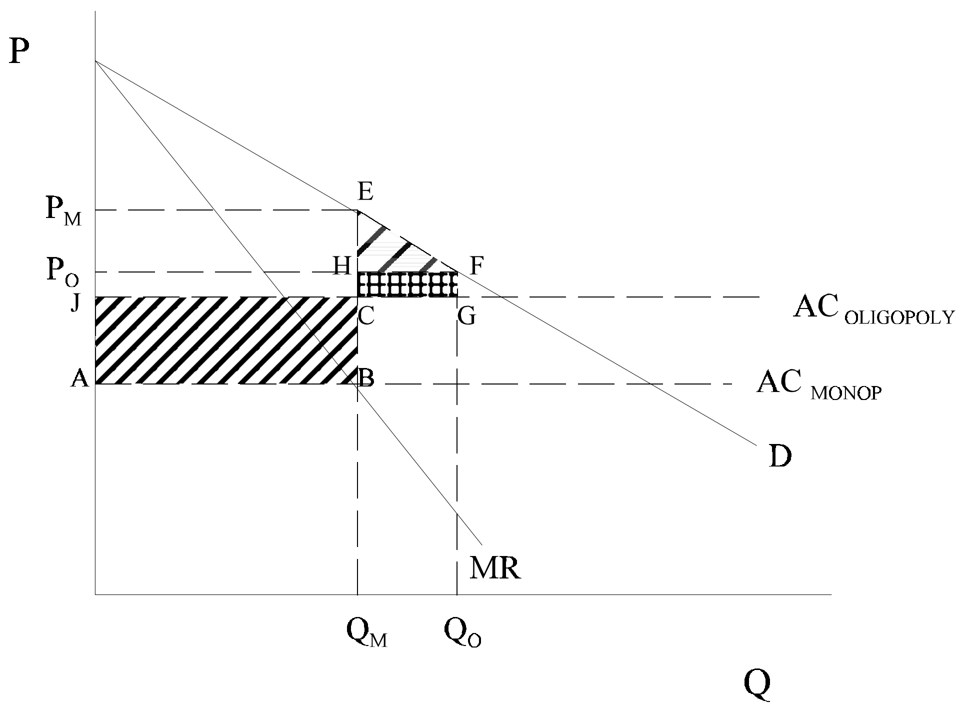

Figure 7

(the area A B C J). The welfare loss from monopoly operation is the traditional welfare loss triangle (the area H F E), plus the lost profits on the output no longer produced (the area C G F H).[58] Insight into the welfare implications of single-firm operation compared to duplicate-firm operation, and of single-firm operation over an individual railroad's network compared to multi-

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[57]Figure 3 showed this tradeoff, where the alternative to single-firm operation was competition.

[58]Recall that societal welfare is the sum of consumer and producer surplus, or the value placed on goods or services by society above the costs needed to produce them.

firm competition over that network can be obtained by comparing the traditional welfare loss of monopoly to the welfare gain resulting from lower monopoly firm costs than multiple firm costs.[59]

A. Welfare Implications of Parallel Mergers

Williamson (1968) developed a simple framework for examining the welfare implications of cost saving monopolies. A similar approach is taken here for examining the welfare implications of parallel mergers in the railroad industry. In Figure 7, the total welfare loss from monopoly is ½ $(P_M - P_O)*(Q_O-Q_M) + (P_O - AC_O)*(Q_O-Q_M)$. The total welfare gain from monopoly is $Q_M * (AC_O - AC_M)$. If we assume a linear demand function, or approximately linear, we can measure the total gains or losses from single-firm rail operation by comparing these two:

$$\left(\frac{1}{2}(P_M - P_O) + (P_O - AC_O)\right)(Q_O - Q_M) > Q_M\,(AC_O - AC_M) \Rightarrow \textit{net loss to single-firm operation}$$
$$\left(\frac{1}{2}(P_M - P_O) + (P_O - AC_O)\right)(Q_O - Q_M) < Q_M\,(AC_O - AC_M) \Rightarrow \textit{net benefit to single-firm operation}$$
$$\left(\frac{1}{2}(P_M - P_O) + (P_O - AC_O)\right)(Q_O - Q_M) = Q_M\,(AC_O - AC_M) \Rightarrow \textit{no change from single-firm operation}$$

We can define the change in price from a switch to monopoly as ΔP, the change in quantity from a switch to monopoly as ΔQ, and the change in average cost from a switch to monopoly as ΔAC. Since quantity and average costs both decrease with the switch to monopoly, we use the absolute values of ΔQ and ΔAC in the formulas for gains and losses of monopoly, so that both areas we are measuring are positive.

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[59]The analysis is partial equilibrium, and does not consider the impacts of railroad market structure on other markets.

The total loss from monopoly is measured as the traditional deadweight loss triangle ($\frac{1}{2}\Delta P|\Delta Q|$) plus the foregone profits from producing a smaller output ($|\Delta Q|(P_O - AC_O)$), and the total gain from monopoly is measured as $|\Delta AC|Q_M$. Thus, to measure the gain or loss from a single-railroad network compared to duplicate networks, the following relationship is examined:

$$\left(\frac{1}{2}\Delta P + (P_O - AC_O)\right)\cdot|\Delta Q| \quad \begin{matrix} > \\ = \\ < \end{matrix} \quad |\Delta AC|Q_M \qquad \text{(Eqn. 1)}$$

We could attempt to measure the two areas directly, but we would need to know the exact change in quantity, the exact change in price, and the exact change in average cost. It would be easier to estimate the impacts of single-firm railroad operation if we can define the equation in terms of percentage changes in prices, quantities, and average costs. To put this equation in terms of percentage changes, we can first divide both sides by P_O, as follows:

$$\left(\frac{1}{2}\frac{\Delta P}{P_O} + \frac{(P_O - AC_O)}{P_O}\right)\cdot|\Delta Q| \quad \begin{matrix} > \\ = \\ < \end{matrix} \quad \frac{|\Delta AC|}{P_O}Q_M \qquad \text{(Eqn. 2)}$$

In this equation, the first term inside the brackets is now ½ times the percentage change in price resulting from monopoly. We can use the P_O in the denominator of the second term in brackets and the P_O in the denominator of the term on the right hand side of the equation to put changes in average costs and the markup in the oligopoly market in percentage terms as well. To do this, we note that if firms in the oligopoly industry do not lose money, the price in the market is the average cost times some markup (e.g. if the price is 10 percent higher than average cost, then the markup is equal to 1.1). If the market structure is perfect competition, then the markup is equal to 1. If we define the markup in the market before the monopoly as θ, then we can express price in the market before monopoly as:

$$P_O = \theta AC_O \qquad \text{(Eqn. 3)}$$

We can substitute this relationship into equation 2 as follows:

$$\left[\frac{1}{2}\frac{\Delta P}{P_O} + \left(\frac{\theta AC_O - AC_O}{\theta AC_O}\right)\right]\cdot\left|\Delta Q\right| \begin{matrix} > \\ = \\ < \end{matrix} \frac{|\Delta AC|}{\theta AC_O} Q_M$$

$$\Rightarrow \left[\frac{1}{2}\frac{\Delta P}{P_O} + \left(1 - \frac{1}{\theta}\right)\right]\cdot\left|\Delta Q\right| \begin{matrix} > \\ = \\ < \end{matrix} \frac{|\Delta AC|}{\theta AC_O} Q_M$$

$$\Rightarrow \left(\frac{\theta}{2}\frac{\Delta P}{P_O} + (\theta - 1)\right)\cdot\left|\Delta Q\right| \begin{matrix} > \\ = \\ < \end{matrix} \frac{|\Delta AC|}{AC_O} Q_M$$

Finally, we can divide both sides by Q_M and state the left hand side of the equation in terms of elasticity by changing it as follows:

$$\left(\frac{\theta}{2}\frac{\Delta P}{P_O} + (\theta - 1)\right)\left(\frac{|\Delta Q|}{\Delta P}\right)\left(\frac{P_O}{Q_O}\right)\left(\frac{\Delta P}{P_O}\right)\left(\frac{Q_O}{Q_M}\right) \begin{matrix} > \\ = \\ < \end{matrix} \left(\frac{|\Delta AC|}{AC_O}\right)$$

$$\Rightarrow \left(\frac{\theta}{2}\frac{\Delta P}{P_O} + (\theta - 1)\right)|\varepsilon|\left(\frac{\Delta P}{P_O}\right)\left(\frac{Q_O}{Q_M}\right) \begin{matrix} > \\ = \\ < \end{matrix} \left(\frac{|\Delta AC|}{AC_O}\right)$$

This equation shows that if the sum of ½ the pre-monopoly markup parameter times the percentage price increase from monopoly and the markup parameter minus one multiplied by the elasticity of demand multiplied the percentage price increase from monopoly multiplied by the ratio of the competitive to monopoly quantity is greater than the percentage drop in average cost from monopoly, then multi-firm competition is desirable. Otherwise single-firm operation is desirable. If we assume a constant elasticity of demand, we can estimate the cost savings from monopoly necessary to offset any price increase that may result from monopoly, given a certain degree of market power under the alternative oligopoly setting.[60] Table 11 shows the cost savings necessary from monopoly to offset various percentage price increases resulting from monopoly. The table shows that small cost decreases can offset any negative welfare effects resulting from large price increases. The table also shows that the cost savings from monopoly that are necessary to offset price increases vary with the pre-monopoly market structure and the elasticity of demand. The percentage cost savings necessary to offset various percentage price increases are higher in markets characterized by more elastic demand.[61] They also are higher in markets where market power of the existing firms already is strong. This second result seems counterintuitive at first. As Figure 7 showed, the welfare loss from monopoly due to a price increase is greater when the original market structure is competition than when it is oligopoly. However, Table 11 shows that the cost savings necessary to offset a certain *percentage* price increase are higher under an initial market structure of oligopoly. It does not show this to be the case for a certain absolute price increase. Because oligopoly already has a higher price than competition, each percentage price increase represents a larger absolute price increase under oligopoly than under competition.

To examine the welfare implications of parallel mergers in the railroad industry, the simple framework outlined above is used to estimate the price increases necessary to offset the

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[60]A demand curve with a constant elasticity is not linear. Rather, it declines in price at a decreasing rate as quantity increases. This suggests that our formula will overstate the cost savings necessary to offset price increases for large percentage price increases.

[61]Elasticity of demand greater than one is not considered in the table, since a switch to monopoly in such markets should not result in an increase in price. An increase in price in such markets would lead to a decrease in total revenues.

cost savings resulting from monopoly while network size is held fixed. Table 12 shows the estimated price increases resulting from a parallel merger of two duplicate networks that would be necessary for the merger to have negative consequences for societal welfare, using today's railroad configurations.[62]

[62]This estimation only provides a proxy for the necessary price increases, since it assumes a constant elasticity of demand at different output levels, and is partial equilibrium in nature. Moreover, this estimation does not capture the fact that railroad demand elasticities vary in different markets. It provides an estimate of the price increase necessary in a particular market to offset the cost savings there if it is assumed that the cost savings are shared equally among all markets. Only railroads with positive marginal costs for all outputs are shown.

Table 11: Percentage Cost Decreases that Will Offset Price Increases from a Merger (smaller cost decreases suggest a welfare loss from the merger)				
	Elasticity of Demand = ½		**Elasticity of Demand =1**	
Percentage Increase in Price from Monopoly over the Alternative Oligopoly Structure	**θ=1 (Alternative to Monopoly is P=AC)**	**θ=1.1 (Alternative to Monopoly is P=AC*1.1)**	**θ=1 (Alternative to Monopoly is P=AC)**	**θ=1.1 (Alternative to Monopoly is P=AC*1.1)**
5	0.06%	0.33%	0.13%	0.67%
10	0.26%	0.82%	0.56%	1.72%
20	1.11%	2.33%	2.50%	5.25%
30	2.65%	4.68%	6.40%	11.36%
40	5.00%	8.00%	13.33%	21.33%
50	8.33%	12.50%	25.00%	37.50%

Table 12: Percentage Price Increases Necessary for Parallel Railroad Mergers to Result in Social Welfare Loss (larger price increases suggest a loss in welfare from the parallel merger)			
		Percentage Increase in Price Necessary for a Parallel Merger to Result in Social Welfare Loss θ=1.1	
Railroad	**Average Cost Savings From Monopoly (from Simulation with Network Size Fixed)**	**Elasticity of Demand = ½**	**Elasticity of Demand =1**
Burlington Northern-Sante Fe	13.58%	52.03%	32.68%
CONRAIL	23.81%	67.26%	41.89%
CSX Transportation	24.16%	67.69%	42.14%
Norfolk Southern	22.64%	65.79%	41.02%
Union Pacific	13.84%	52.50%	32.97%

B. Welfare Implications of Multiple-Firm Competition over One Network

To assess the welfare implications of multiple-railroad competition over one railroad network, we must estimate the price decreases resulting from multiple-firm operation over the rail network that are necessary to offset the cost increases resulting from multiple-firm operation over the network. A slightly different mathematical framework is necessary.

In this case, as intuition would tell us, for any given cost increase resulting from multiple-firm competition, the percentage price decrease necessary to increase total social welfare is higher for oligopoly than it is for pure competition. Thus, by assuming that the alternative to monopoly is competition, the framework outlined here will provide a conservative estimate of the benefits of single-firm operation over one network.

Multiple-firm operation over the single rail network will lead to a gain in consumer surplus equal to the traditional deadweight loss triangle (½ $|\Delta P|\Delta Q$), and a loss in consumer surplus equal to the increase in average costs on the output produced by the single-railroad firm $\Delta AC\ Q_M$. To measure the gain or loss from multiple-firm operation over one rail line when compared to single-firm operation over that line, the following relationship is examined.

$$\frac{1}{2}|\Delta P|\cdot\Delta Q \quad \begin{matrix} > \\ = \\ < \end{matrix} \quad \Delta AC\cdot Q_M$$

We can divide both sides of this equation by P_M, and divide through by Q_M, as follows:

$$\frac{1}{2}\frac{|\Delta P|}{P_M}\cdot\frac{\Delta Q}{Q_M} \quad \begin{matrix} > \\ = \\ < \end{matrix} \quad \frac{\Delta AC}{P_M}$$

Now, we can assume that the monopolist is charging some price above average cost, where the markup parameter is defined as ψ. Thus, average cost times ψ is equal to price:

$$P_M = \psi AC_M$$

We can substitute this relationship into the previous equation as follows:

$$\frac{1}{2}\frac{|\Delta P|}{P_M}\cdot\frac{\Delta Q}{Q_M} \begin{matrix} > \\ = \\ < \end{matrix} \frac{\Delta AC}{\psi AC_M}$$

Now, if we multiply both sides of the equation by the markup parameter under monopoly, and place the left hand side of the equation in terms of the elasticity of demand, we will have an equation defined in terms of percentage price decrease, percentage cost increase, elasticity, and monopoly markup, as follows:

$$\frac{\psi}{2}\left(\frac{|\Delta P|}{P_M}\right)^2\left(\frac{\Delta Q}{|\Delta P|}\frac{P_M}{Q_M}\right) \begin{matrix} > \\ = \\ < \end{matrix} \frac{\Delta AC}{AC_M}$$

$$\Rightarrow \frac{\psi}{2}\left(\frac{|\Delta P|}{P_M}\right)^2 |\varepsilon| \begin{matrix} > \\ = \\ < \end{matrix} \frac{\Delta AC}{AC_M}$$

This equation shows us that there will be a net benefit to allowing multiple-firm operation over one rail line only if the percentage price decrease squared multiplied by the elasticity of demand and half the monopoly markup exceeds the percentage increase in cost resulting from multiple-firm operation.

Table 13 shows the percentage cost increases resulting from multiple-firm operation that would offset the welfare gains of various price decreases. As the table shows, smaller cost increases offset a given percentage price decrease when the original monopoly markup is smaller. Furthermore, the cost increases that are needed to offset the benefits of price decreases from multiple-firm operation are larger with a larger elasticity of demand.

Table 14 shows the percentage price decreases necessary to make multiple-firm operation over single lines beneficial in terms of social welfare for today's railroad configurations.[63] As the table shows, large price decreases would be necessary to offset the increases in costs resulting from multiple-firm operation.[64] The next section of the report provides a summary of the results of this study, conclusions, and policy implications.[65]

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[63]Only those railroads showing positive marginal costs for every output in 1997 are shown.

[64]However, caution must be used in interpreting the magnitude of these cost increases since they are estimated from the quasi-cost function. As highlighted previously, a separability test suggests that transportation services and way and structures inputs are not separable.

[65]The appendix to the study provides a review of studies of natural monopoly characteristics in the electrical utility and telecommunications industries, showing similarities and differences of these industries to the rail industry.

Table 13: Percentage Cost Increases that Will Offset Price Decreases from Multiple-Firm Operation (larger cost increases suggest a loss in welfare from multiple-firm operation)				
	Elasticity of Demand = ½		**Elasticity of Demand =1**	
Percentage Decrease in Price from Multiple-Firm Operation	**ψ=3 (Monopoly Charges 3 times AC)**	**ψ=2 (Monopoly Charges 2 times AC)**	**ψ=3 (Monopoly Charges 3 times AC)**	**ψ=2 (Monopoly Charges 2 times AC)**
5	0.19%	0.13%	0.38%	0.25%
10	0.75%	0.50%	1.50%	1.00%
20	3.00%	2.00%	6.00%	4.00%
30	6.75%	4.50%	13.50%	9.00%
40	12.00%	8.00%	24.00%	16.00%
50	18.75%	12.50%	37.50%	25.00%

Table 14: Percentage Price Decreases Necessary to Make Multiple-Firm Operation of Rail Lines Beneficial in Terms of Social Welfare			
		Percentage Decrease in Price Necessary for a Multiple-Firm Operation to Result in Social Welfare Gain	
		Elasticity of Demand = ½	**Elasticity of Demand =1**
Railroad	**Average Percentage Increase in Costs from Two-Firm Operation over One Rail Line* (from Quasi-Cost Simulation)***	**ψ=2 (monopoly markup is 200 percent of AC)**	**ψ=2 (monopoly markup is 200 percent of AC)**
Burlington Northern-Sante Fe	3.79%	27.53%	19.47%
CONRAIL**	34.06%	82.54%	58.36%
CSX Transportation	15.50%	55.68%	39.37%
Norfolk Southern**	27.54%	74.22%	52.48%
Union Pacific	7.27%	38.13%	26.96%

*Percentage increases in costs without maintenance of way are adjusted to reflect percentage increases in total costs by multiplying the percentage increases by the proportion of total costs accounted for by the quasi-cost function. Some caution must be used in interpreting the magnitude of these cost increases, since they are obtained from the quasi-cost function. As noted earlier, a separability test shows that transportation services and way and structures inputs are not separable.
**CONRAIL and Norfolk Southern Railroads have negative marginal quasi-costs for way train ton-miles in 1997 (marginal quais-costs of through train and unit train ton-miles are positive for these railroads). Thus, the magnitude of the cost increases obtained from the simulation may be overstated for these railroads.

13. SUMMARY AND CONCLUSIONS

Recently, new interest in the regulations governing the rail industry has emerged. Industry merger trends, complaints before the Surface Transportation Board (STB), an interest in rail transportation issues by Congress, and the STB's efforts to stream-line regulations all have sparked this interest.

The renewed interest in railroad regulatory issues has generated at least three policy proposals for changing railroad regulations that have been tied to reauthorization of the funding for the Surface Transportation Board. The types of changes in regulations suggested by these proposals vary widely, but the main components of regulatory change suggested have included: (1) restrictions on merger activity, (2) changes in maximum reasonable rate determinations to introduce more equity among shippers, and/or (3) introduction of intramodal competition through open access to rail lines or through reciprocal switching agreements. An assessment of the desirability of these policies should be based on the impacts of each on societal welfare.

In examining the impacts of various railroad regulatory policies on societal welfare, two questions are relevant: (1) How will the policy affect the cost of resources used to produce railroad services? and (2) How will the policy affect the price of railroad services to shippers? This study explores one component of the impacts of various policies on social welfare - the impacts that the policies have on resource costs. Specifically, the study examines the cost implications of mergers and competition over existing rail lines.

In examining cost implications of mergers, two types of mergers are considered: (1) parallel mergers where the alternative to the merged firm is two firms serving duplicate networks, and (2) end-to-end mergers where the alternative to the merged firm is two smaller networks. In considering the issue of parallel mergers, the study finds evidence that suggests that railroads are natural monopolies over a fixed network size. This suggests that maintaining competition in markets impacted by parallel mergers is not justified by railroad cost considerations. It is also shown that price increases resulting from the parallel merger would have to be large before the prevention of such mergers would be beneficial from the viewpoint of society. In examining the issue of end-to-end mergers, the study finds evidence to suggest that railroads are not natural monopolies as network size is expanded. This suggests that further end-to-end mergers are not justified by railroad cost considerations. However, further end-to-end mergers could result in service improvements to shippers. Nonetheless, the cost results suggest that such service improvements would have to be substantial for further end-to-end mergers to be beneficial from a social welfare perspective.

In examining the cost implications of railroads competing over one rail network, the study finds: (1) that there are economies associated with vertically integrated roadway maintenance and transportation, suggesting that separating the two would result in increased resource costs, and (2) railroads are natural monopolies in providing transportation services over their own network, suggesting that multiple-firm competition over such a network would result in increased resource costs. These findings suggest that policies introducing railroad competition through "open access" or on bottleneck segments would not be beneficial from a cost perspective. Moreover, the price decreases necessary for the introduction of such competition to be beneficial would be large.   Thus, to the extent that rate and service problems exist in the railroad industry, policies aimed at strengthening rate reasonableness guidelines and service guidelines would be preferred to policies aimed at introducing or preserving competition.

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APPENDIX A

Individual Railroad Elasticities of Costs with Respect to Outputs and Network Size

Table A1: Measures of Returns to Scale over a Fixed Network				
1983 Railroads	Elasticity of Cost with Respect to Ton-Miles	% of Sim. where Two-Firm Cost Exceeds Monopoly Cost	Average Percentage Cost Increase above Monopoly from Two-Firm Operation	Revenue Ton-Miles (Billions)
Detroit, Toledo, & Ironton	0.1038	100	122.4	1.37
Boston & Maine	0.4333	100	71.1	2.44
Delaware & Hudson	0.3123	100	63.2	3.57
Grand Trunk & Western	0.4481	100	67.3	3.63
Missouri-Kansas-Texas	0.4042	100	59.9	7.67
Milwaukee Road	0.5172	100	46.7	10.62
Kansas City Southern	0.4633	100	54.9	11.28
Denver, Rio Grande & Western	0.3943	100	55.6	12.11
Baltimore & Ohio	0.6034	100	40.7	22.13
Chicago & Northwestern	0.5470	100	41.6	23.72
Illinois Central Gulf	0.5373	100	42.9	24.35
Chesapeake & Ohio	0.6275	100	34.3	28.01
Southern Railway System	0.7223	100	30.0	42.70
Missouri Pacific	0.6632	100	33.0	49.33
Union Pacific	0.6502	100	23.5	61.19
Southern Pacific	0.6450	100	23.9	62.10
Atchison, Topeka, & Sante Fe	0.6865	100	19.7	67.75
Consolidated Rail Corporation	0.7440	100	19.2	70.29
Burlington Northern	0.6502	100	18.0	172.34

Table A1: Measures of Returns to Scale over a Fixed Network				
1984 Railroads	**Elasticity of Cost with Respect to Ton-Miles**	**% of Sim. where Two-Firm Cost Exceeds Monopoly Cost**	**Average Percentage Cost Increase above Monopoly from Two-Firm Operation**	**Revenue Ton-Miles (Billions)**
Pittsburgh & Lake Erie	0.0984	100	159.53	1.01
Duluth, Missabe & Iron Range	0.5437	100	79.44	1.49
Boston & Maine	0.4635	100	70.29	2.64
Delaware & Hudson	0.3094	100	62.83	4.03
Western Pacific	0.3134	100	59.84	5.45
Grand Trunk & Western	0.4618	100	63.81	5.58
Missouri-Kansas-Texas	0.3932	100	61.31	8.39
Soo Line	0.4576	100	54.22	9.96
Kansas City Southern	0.4175	100	59.57	12.01
Milwaukee Road	0.4831	100	48.28	12.51
Denver, Rio Grande & Western	0.3915	100	55.37	13.06
Chicago & Northwestern	0.5393	100	43.15	24.43
Baltimore & Ohio	0.6099	100	39.40	26.50
Illinois Central Gulf	0.5183	100	45.32	27.02
Chesapeake & Ohio	0.6429	100	34.05	32.68
Norfolk & Western	0.7408	100	25.57	43.77
Southern Railway System	0.7232	100	29.96	46.01
Missouri Pacific	0.6618	100	33.86	52.84
Union Pacific	0.6348	100	23.91	67.05
Southern Pacific	0.6485	100	23.92	68.75
Atchison, Topeka, & Sante Fe	0.6842	100	19.58	75.09
Consolidated Rail Corporation	0.7299	100	20.10	76.82
Burlington Northern	0.6390	100	18.16	200.58

Table A1: Measures of Returns to Scale over a Fixed Network				
1985 Railroads	**Elasticity of Cost with Respect to Ton-Miles**	**% of Sim. where Two-Firm Cost Exceeds Monopoly Cost**	**Average Percentage Cost Increase above Monopoly from Two-Firm Operation**	**Revenue Ton-Miles (Billions)**
Boston & Maine	0.4138	100	74.06	2.30
Florida East Coast	0.3107	100	85.11	3.23
Delaware & Hudson	0.3493	100	61.45	3.65
Grand Trunk & Western	0.5066	100	61.80	4.96
Western Pacific	0.3179	100	56.86	5.79
Missouri-Kansas-Texas	0.3529	100	67.30	8.92
Kansas City Southern	0.3602	100	68.45	11.62
Denver, Rio Grande & Western	0.3954	100	57.54	11.64
Soo Line	0.5425	100	42.27	18.34
Chicago & Northwestern	0.5284	100	44.75	24.22
Baltimore & Ohio	0.5924	100	41.39	25.28
Illinois Central Gulf	0.5033	100	47.95	25.75
Chesapeake & Ohio	0.6457	100	35.28	32.21
Missouri Pacific	0.6529	100	34.22	51.37
Southern Pacific	0.6407	100	25.79	63.50
Atchison, Topeka, & Sante Fe	0.6607	100	21.98	69.09
Consolidated Rail Corporation	0.7146	100	21.38	74.13
Union Pacific	0.6450	100	23.90	74.61
Norfolk Southern	0.7791	100	19.09	91.75
Burlington Northern	0.6310	100	19.95	184.09

Table A1: Measures of Returns to Scale over a Fixed Network				
1986 Railroads	**Elasticity of Cost with Respect to Ton-Miles**	**% of Sim. where Two-Firm Cost Exceeds Monopoly Cost**	**Average Percentage Cost Increase above Monopoly from Two-Firm Operation**	**Revenue Ton-Miles (Billions)**
Boston & Maine	0.3508	100	83.06	1.65
Delaware & Hudson	0.4420	100	71.74	2.68
Florida East Coast	0.3546	100	76.42	3.65
Grand Trunk & Western	0.4902	100	63.68	5.15
Missouri-Kansas-Texas	0.3686	100	68.92	8.10
Denver, Rio Grande, & Western	0.4234	100	54.76	11.13
Kansas City Southern	0.3810	100	63.36	11.30
Soo Line	0.5125	100	42.45	19.50
Illinois Central Gulf	0.5155	100	50.78	19.92
Chicago & Northwestern	0.5307	100	44.44	26.58
Southern Pacific	0.6042	100	27.31	61.70
Atchison, Topeka & Sante Fe	0.6523	100	22.51	67.14
Consolidated Rail Corporation	0.7194	100	21.83	74.61
Norfolk Southern	0.7516	100	19.93	91.42
CSX	0.8022	100	18.88	127.50
Union Pacific	0.7168	100	20.14	136.10
Burlington Northern	0.6092	100	22.65	187.18

Table A1: Measures of Returns to Scale over a Fixed Network				
1987 Railroads	**Elasticity of Cost with Respect to Ton-Miles**	**% of Sim. where Two-Firm Cost Exceeds Monopoly Cost**	**Average Percentage Cost Increase above Monopoly from Two-Firm Operation**	**Revenue Ton-Miles (Billions)**
Delaware & Hudson	0.3792	100	76.24	2.88
Florida East Coast	0.3657	100	75.01	3.79
Grand Trunk & Western	0.4744	100	68.49	4.89
Missouri-Kansas-Texas	0.3298	100	70.96	9.71
Denver, Rio Grande, & Western	0.4223	100	52.58	10.86
Kansas City Southern	0.3716	100	65.47	11.55
Illinois Central Gulf	0.4903	100	54.33	16.99
Soo Line	0.4269	100	56.81	21.94
Chicago & Northwestern	0.5271	100	45.32	27.47
Southern Pacific	0.5942	100	27.70	66.43
Atchison, Topeka, & Sante Fe	0.6501	100	22.83	72.00
Consolidated Rail Corporation	0.7140	100	22.38	81.07
Norfolk Southern	0.7427	100	20.76	94.27
CSX Transportation	0.7160	100	21.67	141.26
Union Pacific	0.6968	100	18.93	157.22
Burlington Northern	0.5930	100	24.29	206.30

Table A1: Measures of Returns to Scale over a Fixed Network				
1988 Railroads	**Elasticity of Cost with Respect to Ton-Miles**	**% of Sim. where Two-Firm Cost Exceeds Monopoly Cost**	**Average Percentage Cost Increase above Monopoly from Two-Firm Operation**	**Revenue Ton-Miles (Billions)**
Florida East Coast	0.3564	100	74.30	4.46
Grand Trunk & Western	0.4527	100	67.98	5.11
Kansas City Southern	0.3492	100	68.45	11.53
Denver, Rio Grande & Western	0.4635	100	48.00	11.82
Saint Louis, Southwestern	0.4936	100	43.53	15.18
Illinois Central Gulf	0.4810	100	56.74	17.02
Soo Line	0.4235	100	58.95	20.61
Chicago & Northwestern	0.5747	100	39.53	30.45
Southern Pacific	0.6138	100	25.60	66.21
Atchison, Topeka, & Sante Fe	0.6591	100	22.78	77.27
Consolidated Rail Corporation	0.7174	100	22.85	85.39
Norfolk Southern	0.7211	100	22.59	100.77
CSX Transportation	0.7451	100	17.06	143.16
Union Pacific	0.6863	100	19.01	176.65
Burlington Northern	0.5935	100	24.33	223.55

Table A1: Measures of Returns to Scale over a Fixed Network				
1989 Railroads	**Elasticity of Cost with Respect to Ton-Miles**	**% of Sim. where Two-Firm Cost Exceeds Monopoly Cost**	**Average Percentage Cost Increase above Monopoly from Two-Firm Operation**	**Revenue Ton-Miles (Billions)**
Florida East Coast	0.3576	100	73.40	4.61
Grand Trunk & Western	0.4604	100	67.82	5.24
Kansas City Southern	0.3414	100	69.19	11.59
Denver, Rio Grande & Western	0.4373	100	50.53	13.21
Saint Louis, Southwestern	0.5288	100	43.42	17.03
Illinois Central Gulf	0.4550	100	60.69	17.31
Soo Line	0.3857	100	64.40	20.49
Chicago & Northwestern	0.5734	100	41.51	27.51
Southern Pacific	0.6407	100	26.16	69.38
Consolidated Rail Corporation	0.7162	100	24.04	82.12
Atchison, Topeka, & Sante Fe	0.6392	100	22.39	82.74
Norfolk Southern	0.7303	100	21.49	100.11
CSX Transportation	0.7604	100	16.93	146.93
Union Pacific	0.6698	100	20.11	183.02
Burlington Northern	0.5898	100	24.32	232.53

Table A1: Measures of Returns to Scale over a Fixed Network				
1990 Railroads	**Elasticity of Cost with Respect to Ton-Miles**	**% of Sim. where Two-Firm Cost Exceeds Monopoly Cost**	**Average Percentage Cost Increase above Monopoly from Two-Firm Operation**	**Revenue Ton-Miles (Billions)**
Florida East Coast	0.3583	100	73.42	4.27
Grand Trunk & Western	0.4272	100	71.92	5.02
Kansas City Southern	0.3644	100	69.01	12.01
Denver, Rio Grande & Western	0.4045	100	51.56	13.69
Illinois Central Gulf	0.4697	100	59.24	17.52
Soo Line	0.3864	100	63.68	22.93
Chicago & Northwestern	0.5525	100	43.91	28.50
Atchison, Topeka, & Sante Fe	0.6353	100	23.83	77.93
Consolidated Rail Corporation	0.7065	100	24.79	84.11
Southern Pacific	0.6488	100	24.22	86.10
Norfolk Southern	0.7433	100	20.87	108.64
CSX Transportation	0.7654	100	17.66	149.36
Union Pacific	0.6689	100	20.38	189.60
Burlington Northern	0.5856	100	25.10	234.29

Table A1: Measures of Returns to Scale over a Fixed Network				
1991 Railroads	**Elasticity of Cost with Respect to Ton-Miles**	**% of Sim. where Two-Firm Cost Exceeds Monopoly Cost**	**Average Percentage Cost Increase above Monopoly from Two-Firm Operation**	**Revenue Ton-Miles (Billions)**
Florida East Coast	0.3746	100	74.20	3.86
Grand Trunk & Western	0.4015	100	74.77	4.91
Kansas City Southern	0.3568	100	70.57	12.18
Denver, Rio Grande & Western	0.4095	100	54.81	14.03
Illinois Central Gulf	0.3853	100	63.70	19.36
Soo Line	0.3951	100	62.49	22.87
Chicago & Northwestern	0.5456	100	44.65	29.37
Atchison, Topeka, & Sante Fe	0.5764	100	29.26	80.84
Consolidated Rail Corporation	0.6862	100	26.49	82.50
Southern Pacific	0.6536	100	24.74	86.57
Norfolk Southern	0.6700	100	25.43	104.07
CSX Transportation	0.7516	100	18.30	145.00
Union Pacific	0.6732	100	20.52	200.86
Burlington Northern	0.5692	100	26.67	232.44

Table A1: Measures of Returns to Scale over a Fixed Network				
1992 Railroads	Elasticity of Cost with Respect to Ton-Miles	% of Sim. where Two-Firm Cost Exceeds Monopoly Cost	Average Percentage Cost Increase above Monopoly from Two-Firm Operation	Revenue Ton-Miles (Billions)
Grand Trunk & Western	0.3906	100	74.99	5.26
Denver, Rio Grande & Western	0.4018	100	53.98	16.04
Illinois Central Gulf	0.3706	100	67.01	18.73
Soo Line	0.4260	100	60.23	22.91
Chicago & Northwestern	0.5475	100	44.50	30.14
Atchison, Topeka, & Sante Fe	0.5661	100	30.87	85.64
Southern Pacific	0.6608	100	23.54	94.24
Norfolk Southern	0.6611	100	26.26	107.17
CSX Transportation	0.7320	100	19.43	147.28
Union Pacific	0.6728	100	21.00	209.11
Burlington Northern	0.5572	100	28.39	232.79

Table A1: Measures of Returns to Scale over a Fixed Network				
1993 Railroads	**Elasticity of Cost with Respect to Ton-Miles**	**% of Sim. where Two-Firm Cost Exceeds Monopoly Cost**	**Average Percentage Cost Increase above Monopoly from Two-Firm Operation**	**Revenue Ton-Miles (Billions)**
Grand Trunk & Western	0.3900	100	72.87	6.17
Denver, Rio Grande & Western	0.3638	100	59.60	17.40
Illinois Central Gulf	0.3576	100	65.39	20.33
Soo Line	0.4007	100	61.94	22.96
Chicago & Northwestern	0.5270	100	45.28	32.79
Consolidated Rail Corporation	0.6769	100	27.38	86.95
Atchison, Topeka, & Sante Fe	0.5508	100	31.94	93.11
Southern Pacific	0.6453	100	23.71	101.12
Norfolk Southern	0.6402	100	27.39	111.64
CSX Transportation	0.7158	100	19.83	145.10
Union Pacific	0.6549	100	21.29	220.70
Burlington Northern	0.5305	100	30.32	237.34

Table A1: Measures of Returns to Scale over a Fixed Network				
1994 Railroads	**Elasticity of Cost with Respect to Ton-Miles**	**% of Sim. where Two-Firm Cost Exceeds Monopoly Cost**	**Average Percentage Cost Increase above Monopoly from Two-Firm Operation**	**Revenue Ton-Miles (Billions)**
Grand Trunk & Western	0.4092	100	72.25	6.45
Soo Line	0.3721	100	64.93	20.56
Illinois Central Gulf	0.3853	100	65.26	21.16
Chicago & Northwestern	0.4566	100	45.59	37.20
Consolidated Rail Corporation	0.6544	100	27.76	94.43
Atchison, Topeka, & Sante Fe	0.5544	100	32.26	100.03
Norfolk Southern	0.6570	100	26.82	122.26
Southern Pacific	0.6415	100	23.58	132.97
CSX Transportation	0.6251	100	27.99	153.73
Union Pacific	0.6428	100	22.58	235.77
Burlington Northern	0.5208	100	30.58	260.57

Table A1: Measures of Returns to Scale over a Fixed Network				
1995 Railroads	**Elasticity of Cost with Respect to Ton-Miles**	**% of Sim. where Two-Firm Cost Exceeds Monopoly Cost**	**Average Percentage Cost Increase above Monopoly from Two-Firm Operation**	**Revenue Ton-Miles (Billions)**
Grand Trunk & Western	0.3827	100	63.79	6.47
Illinois Central Gulf	0.3526	100	66.84	24.64
Soo Line	0.4411	100	54.53	24.88
Consolidated Rail Corporation	0.6250	100	30.49	92.69
Atchison, Topeka, & Sante Fe	0.5750	100	32.30	104.49
Norfolk Southern	0.6411	100	27.24	127.12
Southern Pacific	0.6271	100	22.81	145.94
CSX Transportation	0.6053	100	30.37	159.70
Burlington Northern	0.5006	100	31.35	293.42
Union Pacific	0.6472	100	21.95	307.43

Table A1: Measures of Returns to Scale over a Fixed Network				
1996 Railroads	**Elasticity of Cost with Respect to Ton-Miles**	**% of Sim. where Two-Firm Cost Exceeds Monopoly Cost**	**Average Percentage Cost Increase above Monopoly from Two-Firm Operation**	**Revenue Ton-Miles (Billions)**
Grand Trunk & Western	0.4023	100	65.22	9.48
Illinois Central Gulf	0.3287	100	68.33	22.13
Soo Line	0.4227	100	55.88	24.68
Consolidated Rail Corporation	0.6106	100	30.98	94.74
Norfolk Southern	0.6307	100	28.29	129.78
Southern Pacific	0.6208	100	23.82	155.59
CSX Transportation	0.5886	100	31.46	157.47
Union Pacific	0.6103	100	22.96	323.35
Burlington Northern	0.6142	100	20.64	411.06

Table A1: Measures of Returns to Scale over a Fixed Network				
1997 Railroads	**Elasticity of Cost with Respect to Ton-Miles**	**% of Sim. where Two-Firm Cost Exceeds Monopoly Cost**	**Average Percentage Cost Increase above Monopoly from Two-Firm Operation**	**Revenue Ton-Miles (Billions)**
Grand Trunk & Western	0.3792	100	68.73	9.75
Soo Line	0.4052	100	61.00	21.47
Illinois Central Gulf	0.3330	100	69.05	22.16
Consolidated Rail Corporation	0.6075	100	31.24	97.72
Norfolk Southern	0.6176	100	29.26	135.92
CSX Transportation	0.5723	100	31.85	166.16
Burlington Northern	0.6124	100	15.71	424.59
Union Pacific	0.6505	100	16.06	451.86

Table A2: Measures of Returns to Scale while Network Size Varies

1983 Railroads	Elast. of Cost with Respect to Ton-Miles and Miles of Road	% of Sim. where Two-Firm Cost Exceeds Monopoly Cost	Average Percentage Cost Increase above Monopoly From Two-firm Operation[66]	Miles of Road
Detroit, Toledo, & Ironton	0.5112	100.0	36.54	527
Grand Trunk & Western	0.5896	100.0	20.27	950
Boston & Maine	0.4893	100.0	27.38	1,454
Delaware & Hudson	0.7325	100.0	19.38	1,585
Kansas City Southern	0.7845	99.5	11.25	1,661
Denver, Rio Grande & Western	0.9657	92.4	4.66	2,412
Milwaukee Road	0.8471	93.4	4.58	3,090
Missouri-Kansas-Texas	0.8432	91.0	5.51	3,099
Chesapeake & Ohio	0.9926	62.5	-7.28	4,653
Baltimore & Ohio	0.9635	51.5	-7.64	5,534
Illinois Central Gulf	1.0197	0.6	-8.55	7,086
Chicago & Northwestern	1.0225	0.9	-9.39	7,842
Southern Railway System	1.0204	0.0	-13.85	8,589
Union Pacific	1.2912	0.0	-13.18	9,081
Southern Pacific	1.3770	2.0	-17.64	10,642
Missouri Pacific	1.2192	0.0	-15.44	11,056
Atchison, Topeka, & Sante Fe	1.3575	0.0	-16.81	12,079
Consolidated Rail Corporation	1.2197	0.2	-18.69	16,233
Burlington Northern	1.4196	0.0	-22.22	28,068

[66]Negative numbers indicate an average decline in costs from two firm operation.

Table A2: Measures of Returns to Scale while Network Size Varies

1984 Railroads	Elast. of Cost with Respect to Ton-Miles and Miles of Road	% of Sim. where Two-Firm Cost Exceeds Monopoly Cost	Average Percentage Cost Increase above Monopoly from Two-firm Operation[1]	Miles of Road
Pittsburgh & Lake Erie	0.1925	100.00	53.40	408
Grand Trunk & Western	0.6840	95.25	13.01	1,325
Boston & Maine	0.4988	99.73	27.80	1,410
Western Pacific	0.8418	96.43	14.92	1,426
Delaware & Hudson	0.7239	98.11	18.61	1,581
Kansas City Southern	0.8310	87.41	8.64	1,661
Denver, Rio Grande & Western	0.9701	78.24	4.70	2,392
Milwaukee Road	0.9032	72.20	2.45	3,023
Missouri-Kansas-Texas	0.8560	77.84	4.58	3,099
Chesapeake & Ohio	1.0247	10.58	-8.42	4,579
Soo Line	0.9776	70.86	2.49	4,628
Baltimore & Ohio	1.0104	8.26	-8.88	5,316
Illinois Central Gulf	1.0336	2.22	-9.18	6,676
Chicago & Northwestern	1.0201	1.13	-9.31	7,416
Norfolk & Western	1.0692	6.74	-10.38	7,746
Southern Railway System	1.0184	0.00	-14.03	8,595
Union Pacific	1.2963	0.00	-13.64	8,932
Southern Pacific	1.3855	0.12	-18.29	10,696
Missouri Pacific	1.2221	0.00	-15.59	10,992
Atchison, Topeka, & Sante Fe	1.3807	0.00	-17.45	11,943
Consolidated Rail Corporation	1.2356	0.00	-19.21	15,468
Burlington Northern	1.4381	0.00	-22.61	27,583

[1] Negative numbers indicate an average decline in costs from two firm operation.

Table A2: Measures of Returns to Scale while Network Size Varies

1985 Railroads	Elast. of Cost with Respect to Ton-Miles and Miles of Road	% of Sim. where Two-Firm Cost Exceeds Monopoly Cost	Average Percentage Cost Increase above Monopoly from Two-firm Operation[1]	Miles of Road
Florida East Coast	0.6280	100	21.99	487
Grand Trunk & Western	0.5841	97.68	16.78	1,310
Boston & Maine	0.4480	99.88	30.32	1,404
Western Pacific	0.7995	97.23	16.33	1,409
Delaware & Hudson	0.6460	99.48	23.40	1,530
Kansas City Southern	0.8280	86.92	8.45	1,661
Denver, Rio Grande & Western	0.9321	81.71	5.78	2,248
Missouri-Kansas-Texas	0.8551	81.65	7.04	3,147
Chesapeake & Ohio	1.0304	13.84	-7.68	4,500
Illinois Central Gulf	1.0096	5.12	-7.40	4,772
Baltimore & Ohio	1.0139	7.80	-8.49	5,268
Chicago & Northwestern	1.0181	4.42	-8.29	7,301
Soo Line	1.0159	26.94	-4.58	7,975
Union Pacific	1.2948	0	-13.66	8,783
Southern Pacific	1.3631	0.12	-17.46	10,478
Missouri Pacific	1.2129	0	-15.22	10,920
Atchison, Topeka, & Sante Fe	1.3691	0	-16.92	11,869
Consolidated Rail Corporation	1.2328	0	-18.37	14,025
Norfolk Southern	1.2181	0	-20.93	17,620
Burlington Northern	1.4256	0	-21.50	26,780

[1]Negative numbers indicate an average decline in costs from two firm operation.

Table A2: Measures of Returns to Scale while Network Size Varies

1986 Railroads	Elast. of Cost with Respect to Ton-Miles and Miles of Road	% of Sim. where Two-Firm Cost Exceeds Monopoly Cost	Average Percentage Cost Increase above Monopoly from Two-firm Operation[1]	Miles of Road
Florida East Coast	0.5919	100	23.80	487
Grand Trunk & Western	0.6015	97.59	16.23	1,311
Boston & Maine	0.3817	100.00	35.44	1,350
Delaware & Hudson	0.6223	99.76	28.01	1,501
Kansas City Southern	0.8071	90.77	10.87	1,666
Denver, Rio Grande, & Western	0.8875	87.20	8.40	2,248
Missouri-Kansas-Texas	0.8108	84.00	8.39	3,377
Illinois Central Gulf	0.9418	26.46	-3.85	3,788
Chicago & Northwestern	1.0265	1.40	-8.60	6,305
Soo Line	1.0151	24.54	-4.74	7,747
Southern Pacific	1.3637	0.18	-16.97	10,048
Atchison, Topeka & Sante Fe	1.3589	0	-16.05	11,661
Consolidated Rail Corporation	1.2250	0	-18.02	13,739
Norfolk Southern	1.2400	0	-20.68	17,520
Union Pacific	1.3932	0	-23.12	21,416
CSX	1.2631	0	-24.74	22,887
Burlington Northern	1.4300	0	-21.21	25,539

[1]Negative numbers indicate an average decline in costs from two firm operation.

Table A2: Measures of Returns to Scale while Network Size Varies

1987 Railroads	Elast. of Cost with Respect to Ton-Miles and Miles of Road	% of Sim. where Two-Firm Cost Exceeds Monopoly Cost	Average Percentage Cost Increase above Monopoly from Two-firm Operation[1]	Miles of Road
Florida East Coast	0.5822	100	24.60	487
Grand Trunk & Western	0.5696	98.84	18.04	943
Delaware & Hudson	0.6867	99.57	25.06	1,501
Kansas City Southern	0.8104	89.88	10.02	1,665
Denver, Rio Grande, & Western	0.8879	89.30	9.42	2,247
Missouri-Kansas-Texas	0.8482	83.63	8.44	3,130
Illinois Central Gulf	0.9021	47.97	-1.88	3,205
Soo Line	1.1059	7.74	-7.19	5,809
Chicago & Northwestern	1.0203	1.86	-8.39	6,214
Southern Pacific	1.3958	0.21	-17.35	9,901
Atchison, Topeka, & Sante Fe	1.3754	0	-16.56	11,709
Consolidated Rail Corporation	1.2431	0	-18.59	13,341
Norfolk Southern	1.2521	0	-20.83	17,254
Union Pacific	1.4558	0	-23.78	20,944
CSX Transportation	1.3176	0	-25.69	21,494
Burlington Northern	1.4404	0	-21.22	23,476

[1]Negative numbers indicate an average decline in costs from two firm operation.

Table A2: Measures of Returns to Scale while Network Size Varies

1988 Railroads	Elast. of Cost with Respect to Ton-Miles and Miles of Road	% of Sim. where Two-Firm Cost Exceeds Monopoly Cost	Average Percentage Cost Increase above Monopoly from Two-firm Operation[1]	Miles of Road
Florida East Coast	0.6141	99.88	23.49	442
Grand Trunk & Western	0.5683	98.78	18.27	931
Kansas City Southern	0.8241	89.27	9.57	1,681
Denver, Rio Grande & Western	0.8602	92.32	11.18	2,246
Saint Louis, Southwestern	1.0124	77.63	4.32	2,898
Illinois Central Gulf	0.8849	52.70	-1.21	2,900
Chicago & Northwestern	0.9628	15.00	-5.39	5,794
Soo Line	1.1009	9.94	-6.39	5,807
Southern Pacific	1.3386	0	-15.18	9,879
Atchison, Topeka, & Sante Fe	1.3721	0	-16.77	11,652
Consolidated Rail Corporation	1.2556	0	-18.75	13,111
Norfolk Southern	1.2726	0	-21.72	17,006
CSX Transportation	1.2742	0	-23.47	20,376
Union Pacific	1.4715	0	-24.37	22,653
Burlington Northern	1.4403	0	-21.37	23,391

[1]Negative numbers indicate an average decline in costs from two firm operation.

Table A2: Measures of Returns to Scale while Network Size Varies

1989 Railroads	Elast. of Cost with Respect to Ton-Miles and Miles of Road	% of Sim. where Two-Firm Cost Exceeds Monopoly Cost	Average Percentage Cost Increase above Monopoly from Two-firm Operation[1]	Miles of Road
Florida East Coast	0.5939	99.97	24.83	442
Grand Trunk & Western	0.5664	99.09	18.98	959
Kansas City Southern	0.8176	90.19	10.19	1,681
Denver, Rio Grande & Western	0.8998	87.02	7.92	2,246
Illinois Central Gulf	0.8772	57.21	-0.27	2,887
Saint Louis, Southwestern	1.0274	74.43	3.31	2,898
Chicago & Northwestern	0.9389	31.36	-4.00	5,650
Soo Line	1.0990	14.93	-5.22	5,770
Southern Pacific	1.3609	0	-15.42	9,879
Atchison, Topeka, & Sante Fe	1.3917	0	-16.47	11,266
Consolidated Rail Corporation	1.2436	0	-18.12	13,068
Norfolk Southern	1.2372	0	-20.11	15,955
CSX Transportation	1.2751	0	-22.80	19,565
Union Pacific	1.4684	0	-23.85	21,882
Burlington Northern	1.4431	0	-21.12	23,356

[1]Negative numbers indicate an average decline in costs from two firm operation.

Table A2: Measures of Returns to Scale while Network Size Varies

1990 Railroads	Elast. of Cost with Respect to Ton-Miles and Miles of Road	% of Sim. where Two-Firm Cost Exceeds Monopoly Cost	Average Percentage Cost Increase above Monopoly from Two-firm Operation[1]	Miles of Road
Florida East Coast	0.5646	100	27.90	442
Grand Trunk & Western	0.5673	99.51	19.80	927
Kansas City Southern	0.8230	89.97	9.65	1,681
Denver, Rio Grande & Western	0.9064	87.17	7.93	2,246
Illinois Central Gulf	0.8992	58.76	-0.21	2,773
Soo Line	1.1246	11.58	-5.99	5,293
Chicago & Northwestern	0.9445	27.16	-4.23	5,624
Atchison, Topeka, & Sante Fe	1.3583	0	-15.30	10,650
Southern Pacific	1.3649	0	-17.63	12,600
Consolidated Rail Corporation	1.2426	0	-18.01	12,828
Norfolk Southern	1.2573	0	-19.73	14,842
CSX Transportation	1.2842	0	-22.70	18,943
Union Pacific	1.4680	0	-23.92	21,128
Burlington Northern	1.4301	0	-20.63	23,212

[1]Negative numbers indicate an average decline in costs from two firm operation.

Table A2: Measures of Returns to Scale while Network Size Varies

1991 Railroads	Elast. of Cost with Respect to Ton-Miles and Miles of Road	% of Sim. where Two-Firm Cost Exceeds Monopoly Cost	Average Percentage Cost Increase above Monopoly from Two-firm Operation[1]	Miles of Road
Florida East Coast	0.5069	100	31.44	442
Grand Trunk & Western	0.5872	99.63	20.52	925
Kansas City Southern	0.8236	90.28	9.85	1,682
Denver, Rio Grande & Western	0.9077	90.06	9.87	2,246
Illinois Central Gulf	0.8937	61.23	0.45	2,766
Soo Line	1.1112	11.09	-5.81	5,045
Chicago & Northwestern	0.9378	32.28	-3.74	5,573
Atchison, Topeka, & Sante Fe	1.4115	0	-17.46	9,639
Southern Pacific	1.3573	0	-17.11	12,143
Consolidated Rail Corporation	1.2460	0	-17.78	12,454
Norfolk Southern	1.2754	0	-20.50	14,721
CSX Transportation	1.2800	0	-22.10	18,854
Union Pacific	1.4780	0	-23.66	20,261
Burlington Northern	1.4246	0	-20.10	23,088

[1]Negative numbers indicate an average decline in costs from two firm operation.

Table A2: Measures of Returns to Scale while Network Size Varies

1992 Railroads	Elast. of Cost with Respect to Ton-Miles and Miles of Road	% of Sim. where Two-Firm Cost Exceeds Monopoly Cost	Average Percentage Cost Increase above Monopoly from Two-firm Operation[1]	Miles of Road
Grand Trunk & Western	0.6183	1.00	20.11	925
Denver, Rio Grande & Western	0.9068	0.89	9.16	2,247
Illinois Central Gulf	0.8868	0.65	1.18	2,732
Soo Line	1.0875	0.10	-5.93	5,033
Chicago & Northwestern	0.9395	0.31	-3.88	5,419
Atchison, Topeka, & Sante Fe	1.4294	0	-17.87	8,750
Southern Pacific	1.3517	0.000305	-17.09	12,142
Norfolk Southern	1.2840	0	-20.63	14,703
CSX Transportation	1.2917	0	-22.43	18,905
Union Pacific	1.4899	0	-23.72	19,020
Burlington Northern	1.4406	0	-20.69	22,750

[1]Negative numbers indicate an average decline in costs from two firm operation.

Table A2: Measures of Returns to Scale while Network Size Varies

1993 Railroads	Elast. of Cost with Respect to Ton-Miles and Miles of Road	% of Sim. where Two-Firm Cost Exceeds Monopoly Cost	Average Percentage Cost Increase above Monopoly from Two-firm Operation[1]	Miles of Road
Grand Trunk & Western	0.6403	99.30	19.15	925
Denver, Rio Grande & Western	0.9130	87.78	8.45	2,179
Illinois Central Gulf	0.9216	59.74	0.19	2,717
Soo Line	1.0908	11.92	-5.32	5,062
Chicago & Northwestern	0.9541	26.49	-4.17	5,337
Atchison, Topeka, & Sante Fe	1.4484	0	-18.49	8,536
Consolidated Rail Corporation	1.2395	0	-17.30	11,831
Southern Pacific	1.3576	0	-17.24	11,920
Norfolk Southern	1.2994	0	-20.91	14,589
Union Pacific	1.4837	0	-23.36	17,835
CSX Transportation	1.2877	0	-21.78	18,779
Burlington Northern	1.4500	0	-20.81	22,281

[1]Negative numbers indicate an average decline in costs from two firm operation.

Table A2: Measures of Returns to Scale while Network Size Varies

1994 Railroads	Elast. of Cost with Respect to Ton-Miles and Miles of Road	% of Sim. where Two-Firm Cost Exceeds Monopoly Cost	Average Percentage Cost Increase above Monopoly from Two-firm Operation[1]	Miles of Road
Grand Trunk & Western	0.6287	98.99	18.38	925
Illinois Central Gulf	0.9064	66.90	1.50	2,665
Soo Line	1.0570	25.60	-3.03	5,139
Chicago & Northwestern	0.9482	17.92	-4.89	5,211
Atchison, Topeka, & Sante Fe	1.4652	0	-18.73	8,352
Consolidated Rail Corporation	1.2550	0	-17.71	11,349
Southern Pacific	1.3915	0	-20.05	13,715
Norfolk Southern	1.3180	0	-21.01	14,652
Union Pacific	1.5073	0	-24.18	17,499
CSX Transportation	1.3041	0	-22.30	18,759
Burlington Northern	1.4532	0	-20.77	22,151

[1]Negative numbers indicate an average decline in costs from two firm operation.

Table A2: Measures of Returns to Scale while Network Size Varies

1995 Railroads	Elast. of Cost with Respect to Ton-Miles and Miles of Road	% of Sim. where Two-Firm Cost Exceeds Monopoly Cost	Average Percentage Cost Increase above Monopoly from Two-firm Operation[1]	Miles of Road
Grand Trunk & Western	0.6454	99.30	18.88	916
Illinois Central Gulf	0.9293	69.43	1.97	2,642
Soo Line	1.0454	32.03	-3.23	5,130
Atchison, Topeka, & Sante Fe	1.4504	0	-19.01	9,126
Consolidated Rail Corporation	1.2666	0	-17.77	10,701
Norfolk Southern	1.3257	0	-21.09	14,407
Southern Pacific	1.3919	0	-20.30	15,388
CSX Transportation	1.3009	0	-21.91	18,645
Burlington Northern	1.4670	0	-20.81	22,200
Union Pacific	1.5007	0	-26.72	22,785

[1]Negative numbers indicate an average decline in costs from two firm operation.

Table A2: Measures of Returns to Scale while Network Size Varies

1996 Railroads	Elast. of Cost with Respect to Ton-Miles and Miles of Road	% of Sim. where Two-Firm Cost Exceeds Monopoly Cost	Average Percentage Cost Increase above Monopoly from Two-firm Operation[1]	Miles of Road
Grand Trunk & Western	0.6779	98.45	18.19	918
Illinois Central Gulf	0.9183	71.44	2.56	2,623
Soo Line	1.0462	31.12	-3.16	4,980
Consolidated Rail Corporation	1.2625	0	-17.53	10,543
Norfolk Southern	1.3223	0	-21.05	14,282
Southern Pacific	1.3984	0	-20.19	14,404
CSX Transportation	1.2869	0	-21.36	18,504
Union Pacific	1.5670	0	-26.44	22,266
Burlington Northern	1.6116	0	-27.99	35,208

[1]Negative numbers indicate an average decline in costs from two firm operation.

Table A2: Measures of Returns to Scale while Network Size Varies

1997 Railroads	Elast. of Cost with Respect to Ton-Miles and Miles of Road	% of Sim. where Two-Firm Cost Exceeds Monopoly Cost	Average Percentage Cost Increase above Monopoly from Two-firm Operation[1]	Miles of Road
Grand Trunk & Western	0.6581	1.00	19.15	659
Illinois Central Gulf	0.9127	0.82	2.99	2,598
Soo Line	0.9733	0.72	0.43	3,364
Consolidated Rail Corporation	1.2653	0	-17.47	10,801
Norfolk Southern	1.3357	0	-21.41	14,415
CSX Transportation	1.2959	0	-21.60	18,285
Burlington Northern	1.5932	0	-27.66	33,757
Union Pacific	1.6292	0	-29.28	34,946

[1]Negative numbers indicate an average decline in costs from two firm operation.

Table A3: Estimated Marginal Cost Revenues and Total Costs - 1997

Railroad	Weighted Average Marginal Cost per Ton-Mile[2]	Average Cost per Ton-Mile	Marginal Cost Revenues[3]	Total Costs
Burlington Northern	$0.0131	$0.0214	$5,551,911,916	$9,066,518,431
Consolidated Rail Corporation	$0.0237	$0.0389	$2,311,739,845	$3,805,165,864
CSX Transportation	$0.0180	$0.0315	$2,997,273,470	$5,236,970,156
Grand Trunk & Western	$0.0145	$0.0383	$141,682,944	$373,665,425
Illinois Central Gulf	$0.0088	$0.0265	$195,561,021	$587,307,353
Norfolk Southern	$0.0196	$0.0317	$2,663,239,245	$4,311,988,206
Soo Line	$0.0114	$0.0280	$243,722,144	$601,516,130
Union Pacific	$0.0166	$0.0255	$7,502,092,540	$11,532,060,304

[2]The marginal cost of unit, way, and through train services weighted by the amount of ton-miles of each service.

[3]The revenues that would be generated if price were set equal to marginal cost. Extreme caution must be used in interpreting the marginal cost revenues for the GTW, ICG, and Soo Line Railroads as each showed negative marginal costs of way train service.

Table A4. Seemingly Unrelated Regression of Translog Cost Function and Share Equations - Controlling for Firm Effects (Box Cox Transformation Applied to Outputs - lambda = .0001)

First Order Terms	
Intercept	21.9422*
	(0.0588)
ln Labor Price	0.3535*
	(0.0054)
ln Equipment Price	0.1334*
	(0.0043)
ln Fuel Price	0.0585*
	(0.0016)
ln Materials and Supply Price	0.2153*
	(0.0071)
ln Way and Structures Price	0.2393*
	(0.0049)
ln Unit Train Gross Ton-Miles (Adjusted)	0.0654*
	(0.0115)
ln Way Train Gross Ton-Miles (Adjusted)	0.0794*
	(0.0188)
ln Through Train Gross Ton-Miles (Adjusted)	0.4951*
	(0.0609)
ln Speed	0.1060
	(0.0694)
ln Miles of Road	0.5853*
	(0.0691)
ln Average Length of Haul	-0.0958
	(0.0809)
Time	-0.0235*
	(0.0048)
Second Order Terms	
½ (ln Labor Price)^2	0.1147*
	(0.0137)
½ (ln Equipment Price)^2	0.0202*
	(0.0048)
½ (ln Fuel Price)^2	0.0481*
	(0.0037)
½ (ln Materials Price)^2	0.0672*
	(0.0193)
½ (ln Way and Structures Price)^2	0.1513*
	(0.0084)
ln Labor Price*ln Equipment Price	-0.0146*
	(0.0054)
ln Labor Price*ln Fuel Price	-0.0121*
	(0.0036)
ln Labor Price*ln Materials Price	-0.0127
	(0.0134)

Table A4. Seemingly Unrelated Regression of Translog Cost Function and Share Equations - Controlling for Firm Effects (Box Cox Transformation Applied to Outputs - lambda = .0001)

ln Labor Price*ln Way and Structures Price	-0.0754*
	(0.0076)
ln Equipment Price*ln Fuel Price	-0.0023
	(0.0016)
ln Equipment Price*ln Materials Price	0.0155**
	(0.0071)
ln Equipment Price*ln Way and Structures Price	-0.0188*
	(0.0045)
ln Fuel Price*ln Materials Price	-0.0234*
	(0.0053)
ln Fuel Price*ln Way and Structures Price	-0.0104*
	(0.0023)
ln Materials Price*ln Way and Structures Price	-0.0467*
	(0.0095)
½ (ln Unit Train GTM)^2	0.00001*
	(0.000002)
½ (ln Way Train GTM)^2	-0.0144
	(0.0192)
½ (ln Through Train GTM)^2	0.1901*
	(0.0705)
ln Labor Price*ln Unit Train GTM	0.000003*
	(0.000001)
ln Labor Price*ln Way Train GTM	-0.00003
	(0.0039)
ln Labor Price*ln Through Train GTM	0.0196*
	(0.0075)
ln Equipment Price*ln Unit Train GTM	-0.000004*
	(0.0000008)
ln Equipment Price*ln Way Train GTM	0.0143*
	(0.0031)
ln Equipment Price*ln Through Train GTM	0.0162*
	(0.0058)
ln Fuel Price*ln Unit Train GTM	0.0000002
	(0.0000003)
ln Fuel Price*ln Way Train GTM	-0.0034*
	(0.0010)
ln Fuel Price*ln Through Train GTM	-0.0003
	(0.0021)
ln Materials Price*ln Unit Train GTM	0.000002
	(0.000001)
ln Materials Price*ln Way Train GTM	-0.0204*
	(0.0052)
ln Materials Price*ln Through Train GTM	0.0069
	(0.0102)

Table A4. Seemingly Unrelated Regression of Translog Cost Function and Share Equations - Controlling for Firm Effects (Box Cox Transformation Applied to Outputs - lambda = .0001)

ln Way and Structures Price*ln Unit Train GTM	-0.000002*** (0.0000009)
ln Way and Structures Price*ln Way Train GTM	0.0096* (0.0036)
ln Way and Structures Price*ln Through Train GTM	-0.0423* (0.0072)
ln Unit Train GTM*ln Way Train GTM	0.00002* (0.000004)
ln Unit Train GTM*ln Through Train GTM	0.00002* (0.000007)
ln Way Train GTM*ln Through Train GTM	-0.0422** (0.0210)
½ (ln Speed)^2	-0.5094* (0.1079)
½ (ln Miles of Road)^2	-0.0295 (0.0815)
½ (ln Average Length of Haul)^2	0.1408 (0.1948)
½ (Time)^2	-0.0011*** (0.0006)
ln Labor Price*ln Speed	-0.0172*** (0.0103)
ln Labor Price*ln Miles of Road	-0.0065 (0.0092)
ln Labor Price*ln Average Length of Haul	-0.0572* (0.0090)
ln Labor Price*Time	-0.0048* (0.0007)
ln Equipment Price*ln Speed	-0.0168** (0.0081)
ln Equipment Price*ln Miles of Road	-0.0328* (0.0071)
ln Equipment Price*ln Average Length of Haul	-0.0136*** (0.0073)
ln Equipment Price*Time	-0.0032* (0.0006)
ln Fuel Price*ln Speed	-0.0013 (0.0027)
ln Fuel Price*ln Miles of Road	-0.0022 (0.0025)
ln Fuel Price*ln Average Length of Haul	0.0377* (0.0024)
ln Fuel Price*Time	0.0008* (0.0003)

Table A4. Seemingly Unrelated Regression of Translog Cost Function and Share Equations - Controlling for Firm Effects (Box Cox Transformation Applied to Outputs - lambda = .0001)

ln Materials Price*ln Speed	0.0514* (0.0134)
ln Materials Price*ln Miles of Road	0.0044 (0.0125)
ln Materials Price*ln Average Length of Haul	0.0093 (0.0117)
ln Materials Price*Time	0.0021** (0.0009)
ln Way and Structures Price*ln Speed	-0.0162*** (0.0094)
ln Way and Structures Price*ln Miles of Road	0.0371* (0.0088)
ln Way and Structures Price*ln Average Length of Haul	0.0239* (0.0082)
ln Way and Structures Price*Time	0.0051* (0.0006)
ln Unit Train GTM*ln Speed	0.00005* (0.00002)
ln Unit Train GTM*ln Miles of Road	-0.00003* (0.000007)
ln Unit Train GTM*ln Average Length of Haul	-0.00002* (0.000006)
ln Unit Train GTM*Time	-0.000003** (0.000002)
ln Way Train GTM*ln Speed	-0.0411 (0.0312)
ln Way Train GTM*ln Miles of Road	0.1069* (0.0292)
ln Way Train GTM*ln Average Length of Haul	0.0299 (0.0333)
ln Way Train GTM*Time	-0.0015 (0.0022)
ln Through Train GTM*ln Speed	0.2271* (0.0673)
ln Through Train GTM*ln Miles of Road	-0.0540 (0.0665)
ln Through Train GTM*ln Average Length of Haul	-0.2267** (0.1051)
ln Through Train GTM*Time	-0.0066 (0.0043)
ln Miles of Road*ln Average Length of Haul	0.3957* (0.1272)
ln Speed*ln Average Length of Haul	0.1864 (0.1168)

Table A4. Seemingly Unrelated Regression of Translog Cost Function and Share Equations - Controlling for Firm Effects (Box Cox Transformation Applied to Outputs - lambda = .0001)

ln Speed*Time	-0.0270*
	(0.0075)
ln Average Length of Haul*Time	0.0264*
	(0.0067)
ln Miles of Road*ln Speed	-0.1690***
	(0.0907)
ln Miles of Road*Time	0.0073
	(0.0052)

System Weighted R^2 = .9955
System Weighted MSE = 1.19
Number of Observations = 231
DW = 1.92
*significant at the 1 percent level
**significant at the 5 percent level
***significant at the 10 percent level
firm specific dummies also are included in the cost function estimation (parameter estimates for firm dummies are not shown)

Table A5: Firm Dummy Parameter Estimates from the Seemingly Unrelated Estimation of Long-Run Total Costs (Table 3)	
Railroad Firm Dummies	
ATSF - ATSF 1983-1995, BNSF 1996-1997	-0.1901*** (0.1075)
BM	-0.1164 (0.1293)
BN - BN 1983-1995, BNSF 1996-1997	-0.7723* (0.1477)
BNSF	-0.2346** (0.0959)
BO - BO 1983-1985, CSX 1986-1997	0.1139 (0.0794)
CNW - CNW 1983-1994, UP 1995-1997	-0.0806* (0.0289)
CO - CO 1983-1985, CSX 1986-1997	0.0415 (0.0957)
CR	0.0444 (0.0924)
CSX	-0.3842** (0.1927)
DH	-0.4892* (0.1561)
DMIR	-1.4097* (0.3151)
DRGW - DRGW 1983-1993, SP 1994-1996, UP 1997	-0.2349* (0.0785)
DTI - DTI 1983, GTW 1984-1997	-0.6542** (0.2771)
FEC	-0.3649*** (0.2087)
GTW	0.1561 (0.1557)
GTW1 - Merged DTI GTW 1984-1997	0.7541** (0.3322)
KCS	-0.2982* (0.0636)
MILW - MILW 1983-1984, SOO 1985-1997	0.0236 (0.0565)
MKT - MKT 1983-1987, UP 1988-1997	-0.5168* (0.0626)
MP - MP 1983-1985, UP 1986-1997	-0.1868** (0.0844)
NS	-0.1129 (0.0997)

Table A5: Firm Dummy Parameter Estimates from the Seemingly Unrelated Estimation of Long-Run Total Costs (Table 3)

NW - NW 1983-1984, NS 1985-1997	0.0857 (0.0929)
PLE	-0.9213** (0.3574)
SOO	-0.2377* (0.0801)
SOO1 - Merged SOO-MILW 1985-1997	0.0161 (0.1092)
SRS - SRS 1983-1984, NS 1985-1997	-0.1725* (0.0649)
SP - SP 1983-1996, UP 1997	-0.0335 (0.0997)
SP1 - Merged SP-SSW, SP 1990-1996, UP 1997	-0.1508 (0.1344)
SP2 - Merged SP-SSW-DRGW, SP 1994-1996, UP 1997	-0.0208 (0.0944)
SSW - SSW 1983-1989, SP 1990-1996, UP 1997	-0.1529 (0.1151)
UP	-0.1756*** (0.0942)
UP1 - Merged UP-WP-MP, UP 1986-1997	-0.0622 (0.1966)
UP2 - Merged UP-MKT, UP 1988-1997	0.4351* (0.0741)
UP3 - Merged UP-CNW, UP 1995-1997	-0.0077 (0.0505)
UP4 - Merged UP-SP, UP 1997	0.3336* (0.0869)
WP - WP 1983-1985, UP 1986-1997	-0.2047 (0.1745)

ICG is the excluded firm dummy
BLE and SCL were deleted as both had zero unit train gross ton-miles in each year. For some other railroads, early years are not included because of zero unit train gross ton-miles.

APPENDIX B

Review of Industry Cost Studies for the Telecommunications and Electrical Utility Industries

Review of Electrical Utility and Telecommunications Studies

The electric utility and telecommunications industries are two network industries that have long been considered natural monopolies, and have recently begun to restructure. Because of the network characteristics these industries share with the railroad industry, it is useful to review findings that have examined the cost characteristics of these industries. This section provides a brief review of some of the studies performed in these industries that have attempted to determine whether the industry was a natural monopoly.

Several studies have examined the issues of economies of scale and the separability of production stages in the electrical utility industry. These issues have important implications for restructuring proposals in electricity provision. The issue of economies of scale addresses the sufficient condition for natural monopoly in the provision of electricity, since the electricity supply industry might be considered a single-product industry. The issue of separability of production stages addresses the desirability of vertical disintegration of the electric utility industry – a component of many restructuring proposals. Some of the studies reviewed here address both of these issues, while others address one or the other.

Studies that have examined economies of scale in the provision of electricity have done so either for a particular component of electricity production, such as generation, or for the entire vertically integrated electrical utility (i.e. the generation, transmission, and distribution of power). The first study to examine economies of scale in the provision of electricity using a flexible functional form was done by Christensen and Greene (1976). The authors examined economies of scale in generation using two cross sections of U.S. data – 1955 and 1970. They found significant economies of scale for firms of all sizes in 1955, but by 1970 many of the firms in the sample had exhausted economies of scale. This suggested that competition in the generation stage might be beneficial.

Another important study examining costs in electricity supply was performed by Roberts (1986), who examined economies of scale for the entire vertically integrated electricity supplying firm and examined the issue of separability of power distribution from transmission and generation. Using a cost function approach with a cross section of 1978 U.S. electrical utilities, he found increasing returns to scale as the number of customers and the size of the network was held fixed, and constant returns to scale when increased electricity output was the result of an increase in the number of customers or an increase in the size of the service area (measured in square miles). The author also rejected the notion of separability of power distribution from transmission and generation. This suggests that vertically disintegrating the industry, or separating the stages of production, could lead to efficiency losses.

Rushdi (1991) examined economies of scale in the electricity supply industry in Australia. Using time-series data for one utility that was involved in generation, transmission, and distribution, he estimated a cost function. He found an elasticity of cost with respect to output of much less than one, but was unable to separate out the effects of technological progress from economies of scale, since the utility's output grew over time. He concluded that since the same types of equipment could be purchased in 1991 as was used in the beginning of the study period, it was unlikely that much of the cost savings were due to technological improvement. Thus, he concluded that significant economies of scale existed in the Australian electricity supply industry. However, his analysis did not allow for consideration of the effects of a changing customer base or increased network size.

Another study that examined economies of scale for the entire vertically integrated electric utility was by Byung-Joo Lee (1995), who used a production function approach. Using a cross section of U.S. investor-owned utilities in 1990, the author found that returns to scale had been exhausted. Lee also performed an extensive evaluation of the separability of production stages, finding that neither transmission, generation, nor production could not be conducted independently of the others without losses in efficiency. One noteworthy aspect of the article is that the author estimated the efficiency losses attributable to vertically disintegrating the firm. He found that separating generation from transmission and distribution resulted in a 4.12 percent loss, separating distribution from the other two resulted in a 7.59 percent loss, and separating all three stages from each other resulted in a 18.63 percent loss.

In a study similar to that of Roberts, Thompson (1997) estimated the costs of electricity supply in the U.S. using a cross section of all major investor-owned utilities. He found significant economies of scale in electricity supply when the number of customers and the service area was held constant, slight economies of scale when increased power sales were the result of increased customers, and constant returns to scale when the increased power sales were the result of increased customers and increased service area. The author also rejected the separability of generation from transmission and distribution and the separability of distribution from supply and transmission.

Finally, Filippini (1998) examined economies of scale in electric power distribution in Switzerland. Using a panel data set of municipal utilities from 1988 through 1991, he found evidence that large economies of scale exist as network size is held fixed, suggesting that side-by-side electricity distribution networks would result in excess resource costs. In examining economies of scale as network size expands he found that only small and medium sized firms could gain from end-to-end mergers, but not large firms.

For the most part, these studies of the electrical utility industry are fairly consistent with the findings of the railroad industry. The idea that way and structures capital can be separated from other transportation inputs is rejected, suggesting that vertically disintegrating the railroads by allowing firms not owning the rail lines to operate over them would result in excess resource costs. This is consistent with the findings of the efficiency losses resulting from disintegrating electrical utilities.

Moreover, economies of scale are found as network size is held fixed and an exhaustion of scale economies is found as network size is varied for all but the smallest firms. This is consistent with the findings of the electrical utility industry that find economies of scale as the number of customers and network size is held fixed, but an exhaustion returns to scale if customers or network size varies. However, the implications are slightly different. Whereas a natural monopoly in local markets is implied by lower one-firm than two-firm costs as outputs are split between two firms and network size is held constant in the rail industry, this is not necessarily the case for the electrical utility industry. In the electricity supply industry, in contrast to the rail industry where more output can be supplied with a fixed network, more output in local markets often means an expansion of the network. Although service area (in square miles) remains fixed, providing more service often means serving more customers, which entails installing a whole new network of delivery equipment (lines, transformers, etc). Thus, the finding that economies of scale are not realized when increased power sales are the result of more customers suggests that electric utilities may not be natural monopolies in local markets.

A variety of studies also have examined the existence of economies of scale and natural monopoly in the telecommunications industry. Most of these studies examined these issues using data from the Bell system prior to divesture in 1984, making it difficult to separate the effects of scale economies from technological change on costs. Studies by Nadiri and Schankerman(1979), Eldor and Sudit (1979), Christensen Cummings, and Schoech (1983), and others all found significant scale economies for the Bell system.

More recently, the studies by Evans and Heckman (1983) and Shin and Ying (1992) recognized that scale economies were not sufficient for natural monopoly in a multi-product industry. Thus, these studies introduced the natural monopoly tests highlighted earlier in the study. Unlike previous studies, these studies found that telecommunications firms were not natural monopolies.

Another important difference of Shin and Ying's study from the previous studies was its use of local exchange carrier data rather than Bell system data. This allowed a separation of scale economies from technological improvements. Guldmann (1991) also examined local exchange carrier cost data and found constant returns to scale for medium to large firms when output was measured as number of telephone stations.

The general findings of the more recent telecommunications studies are consistent with those found in the electricity supply studies. That is, there are economies in providing more output, but more output usually is achieved through the installation of more access lines. When more output is achieved through installing more access lines, returns to scale are constant. Thus, unlike the railroad industry, telecommunications firms do not appear to be natural monopolies in local markets.