RAILROAD COST CONSIDERATIONS AND THE BENEFITS/COSTS OF MERGERS

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ABSTRACT

This study examines the cost conditions present in the Class I railroad industry. Recent mergers and merger proposals have brought forth questions regarding the desirability of maintaining competition in areas impacted by horizontal mergers and, similarly, the desirability of end-to-end mergers. As we consider the costs and benefits of various merger oversight policies, it is imperative that we understand the welfare effects of such policies. One essential element of such welfare effects is the effects on costs within the industry. In examining the cost conditions in the industry, the study finds that railroads are natural monopolies over current networks. That is, duplicate networks serving the same railroad markets would result in increased industry costs. This suggests that maintaining competition in markets impacted by horizontal mergers is not justified by railroad cost considerations. In examining the potential cost effects of end-to-end mergers, the study finds evidence to suggest that Class I railroads are natural monopolies as networks are expanded.

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

The late 1970's and early 1980's saw a wave of rail mergers. These mergers raised concern among many observers over the elimination of intramodal competition in the case of horizontal mergers, and over possible foreclosure of rail markets in the case of vertical mergers.

Recently, the effects of rail mergers on shippers and economic efficiency have drawn a renewed interest. The recent merger between two of the nation's largest railroads (Union Pacific and Southern Pacific) is responsible for much of this interest. Several observers (e.g. Levin - 1981, and Winston, Corsi, Grimm, and Evans - 1990) have suggested that the Interstate Commerce Commission should pursue policies which preserve some level of intramodal competition in the face of rail mergers because of its effectiveness at keeping rates low.

This study will revisit the issue of intramodal competition in the rail industry, attempting to sort out its benefits and costs. There are several issues involved in assessing the usefulness of intramodal competition. However, the two most important are:

1.) Are railroads natural monopolies in specific markets?

2.) If railroads are natural monopolies, what limits are imposed on rates by other (non-rail) forms of competition?

This study will address the first of these issues. The first issue will be addressed by directly testing for the condition for natural monopoly in specific markets - cost subadditivity. Moreover, the study will examine the potential for cost savings resulting from end-to-end mergers by testing for cost subadditivity as networks are expanded.

Review of Railroad Cost Studies

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

Keeler (1974), pointed out the problems present in most of these early cost studies. As Keeler pointed out, nearly all of 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. In order 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 having 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 the area of 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) the 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 the basic advantage over other functional forms in estimating costs in that it is very 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 that examined the potential impacts of railroad and trucking deregulation by Friedlaender and Spady (1980). 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, they were able to measure both 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).

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, the 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 3 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, they found significant differences resulting from using the full sample instead of only those with non-zero outputs for passenger and freight output.

At the same time as these other innovations in the translog cost function were taking place, two studies that 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. Namely, they showed that because there are many basic differences between railroad firms, the estimation of a cost function that fails to consider firm effects can lead to biases in the coefficients of important policy variables. They 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 as well as the amount invested in existing track above that required to offset normal depreciation. This was essentially 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.

All of the previously mentioned studies used data that was prior to railroad deregulation. Since the study by Braeutigam, 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 that were 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.[1] The study found significant increasing returns to density for rail freight services, but constant overall returns to scale. The study highlighted the importance of including the current replacement cost of capital in cost estimates, but the study still did not 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.

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

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

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 their 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 are certainly the relevant concepts.

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. Moreover, the study 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. In order to estimate the effects of deregulation on shippers they 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. In order to estimate the effects of deregulation on rail carriers they performed a counter factual projection of economic profits in 1977 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, they found that deregulation led to an increase in railroad profits. In order 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 their study that is perhaps 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. Moreover, they 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.

Cost Concepts and Natural Monopoly

With the great interest in removing economic regulations in the transport and telecommunications industries in the late 1970's and early 1980's, the notion of natural monopoly and the conditions for its existence have been discussed widely. However, as pointed out by Sharkey (1982) and Baumol, et. al (1988), the concept of natural monopoly has been defined imprecisely and been greatly misunderstood by many in the economics profession. Much of the literature has used economies of scale as the definition of natural monopoly, suggested a necessary link between natural monopoly and the inability of marginal cost pricing to be sustainable, and suggested that an industry where economies of scale have been exhausted is not a candidate for natural monopoly. While in the single product case, economies of scale are sufficient for the existence of natural monopoly and suggest that marginal cost pricing will generate losses for the firm, they are not necessary for natural monopoly. Moreover, in the multi-product case, economies of scale and economies of scope combined are not sufficient to ensure natural monopoly.

The necessary and sufficient condition for natural monopoly in the single product case or in the multi-product case is a condition known as strict cost subadditivity. Strict cost subadditivity can be defined as:

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

where, yi's are outputs produced by each of n firms in the single product case and output vectors in the multi-product case. This condition for the existence of natural monopoly merely shows that one will exist if the outputs can be produced at a lower cost by one firm than by any combination of firms. While the condition of strict cost subadditivity is conceptually simple, Sharkey (1982) and Baumol et. al define several sufficient conditions for subadditivity in the multi-product case, because verifying subadditivity empirically requires the examination of costs under all different output combinations. In practice, most empirical railroad cost studies have either aggregated output into a composite factor or have looked for the existence of economies of scale and scope. Neither approach will necessarily test for the presence of natural monopoly. The following paragraphs explain related cost concepts and show the sufficient conditions for subadditivity of costs in a multi-product firm.

In order to understand the sufficient conditions for strict cost subadditivity, several cost concepts must first be defined. The first important cost concept to be defined is ray average costs. In the single output case, we are able to obtain average costs by dividing total costs by total output. However, in the multi-product case, the units of each output are different (e.g. for a multiproduct firm producing beef and leather, one cow hide and one pound of beef are different outputs). Therefore, there is no common output measure to divide total costs by in order to get average costs. Ray average costs are obtained by examining cost behavior as relative output proportions are held constant (i.e. in the two product case, as one moves along a ray from the origin in the q1-q2 space). 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:

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

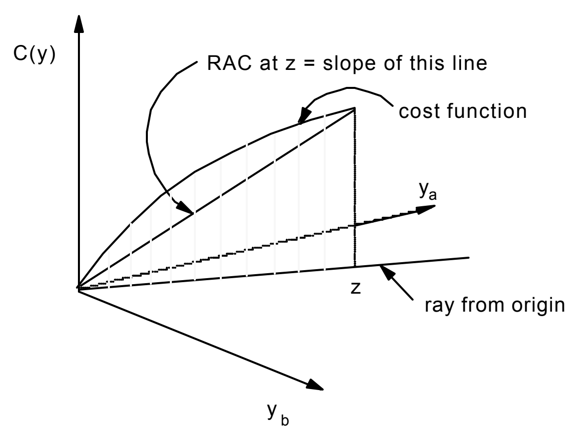

Figure 1

where:

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

The concept of ray average cost can be further understood by examining Figure 1. The figure shows that ray average costs are just those obtained when keeping output proportions constant. In the diagram, ray average costs are decreasing out to z.

Thus, the analogous concept to declining average costs for the multi-product firm is declining ray average costs. Declining ray average costs occur when expanding outputs in the same proportion leads to an increase in total cost by a smaller proportion.

Just as economies of scale imply declining average cost in the single product case, economies of scale imply declining ray average costs in the multi-product case. Economies of scale for the multi-product firm are defined as the inverse of the elasticity of cost with respect to output. Cost elasticity of output is shown by the following equation:

$$ec = \sum_i \frac{\delta C}{\delta y_i} * \frac{y_i}{C}$$

Returns to scale are then shown by:

$$S = \frac{C}{\sum_i \frac{\delta C}{\delta y_i} * y_i}$$

Returns to scale are increasing, constant, and decreasing as S is greater than, equal to, and less than 1. As shown by Baumol, et. al, this measure of returns to scale is the same as the traditional single product measure of returns to scale applied to a composite commodity.

Economies of scope are savings in unit costs resulting from a firm producing several different types of outputs concurrently. There are several intuitive examples of economies of scope, including the joint production of beef and leather, wool and mutton, or lawn service and compost. The concept of economies of scope can be formally defined as follows:

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

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

Another name for economies of scope is orthagonal subadditivity, since the condition for economies of scope is the same as the condition for cost subadditivity, except that the output vectors must be orthagonal to each other; i.e. they have no common outputs.

As shown by Baumol, et. al, the degree of economies of scope realized by producing two disjoint outputs a and b together is defined as the proportional increase in costs that would occur by producing the two products separately. That is:

$$DSE(y) = \frac{C(y^a) + C(y^b) - C(y)}{C(y)}; \quad y = y^a + y^b$$

where: DSE(y) = degree of scope economies realized at output y

Baumol, et. al also show that multiproduct scale economies depend on product specific economies and the degree of scope economies in the following way:

$$S_M = \frac{B^a PS^a(y) + (1-B^a) PS^b(y)}{1-DSE(y)}$$

where: $$B^a = \frac{\sum_{j\epsilon a} y_j \frac{\delta C}{\delta y_j}}{\sum_{j\epsilon(a+b)} y_j \frac{\delta C}{\delta y_j}}$$

PS^a = product specific scale economies for product set a at an output of y

PS^b = product specific scale economies for product set b at an output of y

This equation shows the roles played by product-specific and scope economies in the determination of overall multiproduct scale economies. Higher levels of individual product specific economies and scope economies both increase the degree of multiproduct scale economies realized. Moreover, multiproduct scale economies can be realized even with product specific scale diseconomies if large enough economies of scope are realized.

Product specific scale economies are defined as the average incremental cost of a product divided by the marginal cost of the product, where average incremental cost of a product is defined as the average change in the firm's total costs resulting from producing the given product at all. Similarly to the case of a single product firm, the definition is derived from the fact that if average incremental cost is higher than marginal cost, then average incremental cost must be decreasing. This suggests that increasing the production of the product will result in a less than proportional increase in cost.

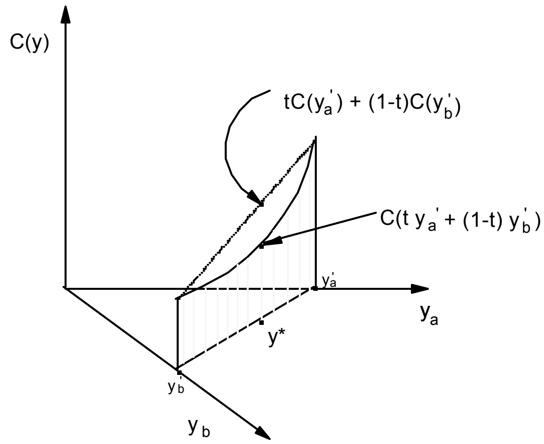

Figure 2

Two other important cost concepts that must be defined before exploring the sufficient conditions for cost subadditivity are trans-ray convexity and trans-ray supportability. Trans-ray convexity occurs at the point y* in the two product case, when a cross section of the cost function taken between any combination of the production of the two goods that cuts through the point y* is convex. This can best be explained diagrammatically. In Figure 2, the two-good case is illustrated. y_a' and y_b' are one possible output combination of y_a and y_b that intersects the point y* (there are an infinite number of other combinations of y_a and y_b that also intersect point y*). If the cost function displays convexity over the cross section taken over any of the combinations of y_a and y_b that intersect y*, then costs are trans-ray convex at point y*. Mathematically, the condition $C(ty_a' + (1-t)y_b') \leq tC(y_a') + (1-t)C(y_b')$ implies trans-ray convexity. While this is easily drawn for the two product case, the concept also applies to the case of any amount of products produced by one firm.

Trans-ray supportability is closely related to trans-ray convexity, but is a weaker condition. A trans-ray supportable cost function at y* can be defined as one where one of the cross sections of the cost function taken over any of the infinite combinations of the outputs that cross through y* has a support. The cost function has a support at y* if a flat plane drawn tangent to C(y*) is below the costs that would occur using any other combination of the outputs along the same cross section of the cost surface. This is again explained more fully by a diagram. Assume that Figure 3 represents the cross section taken from the cost function in Figure 2. The dotted strictly convex line is the cost function shown in Figure 2 displaying trans-ray convexity. Because the line z lies strictly below all other points on the strictly convex line, it is supported by z. Similarly, the solid line in the diagram is supported by z, although it is not convex. If any combination of y_a and y_b that intersects the point y* has such a support, then the cost function displays trans-ray supportability at y*.

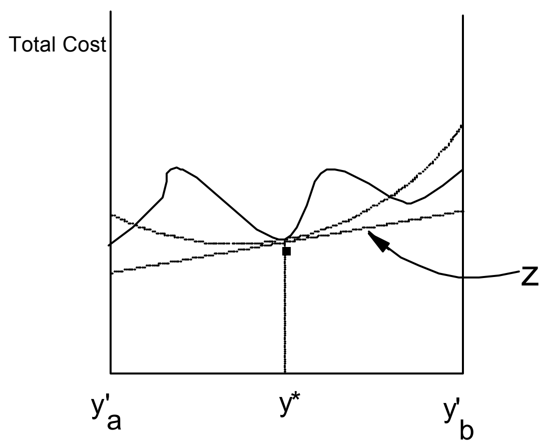

Figure 3

The final cost concept that must be explained is supportability. Supportability uses the same concept as trans-ray supportability, but imposes the much stronger condition that the entire cost surface must be supported for all outputs below y* in order to be supportable at y*. That is, if one were to draw a hyperplane from the origin through C(y*), the entire cost surface between the origin and y* would lie above that hyperplane. Formally, it is defined as a case where there is a vector $g(y^*)>0$ such that $g(y^*)\cdot y^* = C(y^*)$ and $g(y^*)\cdot y < C(y)\ \forall\ 0<y<y^*$.

Sharkey and Baumol, et. al both provide examples of cost functions satisfying the conditions of economies of scale and economies of scope to show that the existence of both is not sufficient to satisfy cost subadditivity. Thus, in the absence of testing for cost subadditivity directly, some stronger sufficient conditions are necessary. Sharkey (1982) and Baumol, et. al have shown sufficient conditions for cost subadditivity that strengthen either the economies of scale condition or the economies of scope condition (weak cost complementarity). These include:

1.) Decreasing average incremental costs of each product up to y* and economies of scope at y* imply cost subadditivity. - This condition is very intuitive. If each product has decreasing average incremental costs up to some output (y*), then producing k and (1-k) portions of any y_i* by two different firms results in a higher cost of production. Moreover, if producing y_i* and y_j* results in economies of scope, then producing each separately results in higher total costs of production. Thus, for an output of y*, the lowest cost is achieved by producing each output up to the level included in y* and by producing each output jointly $\Rightarrow$ subadditivity.

2.) Declining ray average costs up to the hyperplane crossing through y* and trans-ray convexity of costs on the same hyperplane crossing through y* imply cost subadditivity - This condition is also fairly intuitive, as explained in the two output case. We know from basic vector addition that the point y* can be represented by the addition of two rays, one containing relatively more of one output and the other containing relatively more of the other. Each of these rays will lie inside (towards the origin) of the cross section that cuts through y* and displays trans-ray convexity. Moreover, the two rays will lie on opposite sides of a ray drawn from the origin through y*. Because of the condition of declining ray average costs, expanding the rays out to the cross section that cuts through y* will result in a lower average cost for each. Further, because the two rays lie on opposite sides of a ray drawn from the origin to y* and because of the condition of trans-ray convexity, movement from the two points of the expanded rays towards y* will result in a further reduction in average costs. Thus, any segmentation of the output produced in y* (including completely separate production of outputs, or any combined production of outputs in smaller scales) will result in a higher total cost of production $\Rightarrow$ subadditivity.

3.) A weaker condition than the previous one is that trans-ray supportability at y* and decreasing ray average costs up to the hyperplane where trans-ray supportability is met imply subadditivity. The intuition is similar to the stronger case above.

4.) Supportability up to y* implies subadditivity there. This condition is also very intuitive. From the definition of supportability we know that if we multiply a vector of prices by the vector of outputs y*, we get our cost at y*. However if we multiply any other output vector that is below y* by the same vector of prices, we get a number that is below our cost at that vector of outputs. Thus, the cost per unit of output is higher for outputs below y*$\Rightarrow$ subadditivity.

5.) Strong cost complementarity implies cost subadditivity - cost complementarity can be defined as a situation where the marginal cost of any output declines whenever that output or any other output produced by the firm increases. When the cost function is twice differentiable, the condition is $\delta^2 C/\delta y_i \delta y_j < 0$; where i and j are the same output or different outputs.

6.) If the cost function is separated into variable and fixed costs, strict subadditivity of variable costs at y* implies strict subadditivity of total costs at y* even with product specific fixed costs as long as the total fixed costs associated with producing the products together are no higher than the total fixed costs associated with producing the products separately. This condition is presented, because the sufficient condition of trans-ray supportability along with declining ray average costs may not hold in the presence of product specific fixed costs even when variable costs meet these conditions. The condition merely combines a strict subadditivity condition on variable costs with a subadditivity condition on fixed costs. Similarly, if the variable costs are subadditive (not strictly) and fixed costs are strictly subadditive, then strict subadditivity of the cost function is met.

While these sufficient conditions for subadditivity of costs are useful for identifying cost subadditivity, a preferred approach would be to examine cost subadditivity directly because the necessary and sufficient condition for natural monopoly of cost subadditivity is a much weaker condition than any of the sufficient conditions highlighted above. Due to the advances in computer speed and capabilities, a direct approach to measuring cost subadditivity is no longer an insurmountable task. The following section reviews studies that have attempted to test for natural monopoly in other industries.

Empirical Tests of Natural Monopoly

Many studies have examined the cost structure of regulated industries in order 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. Moreover, 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, very 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), they find that subadditivity is rejected in all cases.

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

$$\tilde{C}_t < \tilde{C}_t^a(\phi,\omega) + \tilde{C}_t^b(\phi,\omega),\ \forall\ \phi,\omega \in (0,1)$$

$$\text{where: } \tilde{C}_t^a(\phi,\omega) = \tilde{C}(\tilde{q}_t^a) = \tilde{C}(q_z + \hat{q}_t^a)$$

$$\tilde{C}_t^b(\phi,\omega) = \tilde{C}(\tilde{q}_t^b) = \tilde{C}(q_z + \hat{q}_t^b)$$

$$\tilde{C}_t = \tilde{C}(\tilde{q}_t^a + \tilde{q}_t^b) = \tilde{C}(\tilde{q}_t)$$

$$\hat{q}_t^a = ((1-\phi)q_{1t}^*, (1-\omega)q_{2t}^*)$$

$$\hat{q}_t^b = (\phi q_{1t}^*, \omega q_{2t}^*)$$

$$q_{1t}^* + q_{2t}^* = \hat{q}_t - 2q_z$$

$$q_z = (\min_t q_{1t}, \min_t q_{2t})$$

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.

In order 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 very 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, they tested for the following condition on each observation:

$$C(q^M) < C(q^a) + C(q^b)$$

$$\textit{where}: q^a = (kq_1^M, \lambda q_2^M, \gamma q_3^M)$$

$$q^b = ((1-k)q_1^M, (1-\lambda)q_2^M, (1-\gamma)q_3^M)$$

$$k, \lambda, \gamma = (0.1, 0.2, \ldots, 0.9)$$

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 highlights the rationale for the translog cost specification.

The Translog Multiproduct Railroad Cost Function

In general, a firm's technology can be described with the use of a production function: Y=f(**x**), where **x** is a vector of inputs used in the production of Y. The production function shows the maximum output associated with the different combinations of inputs in the firm's production possibilities set.

However, the rail industry is truly a multi-product industry, where technology cannot be described by a production function. Analogous to the production function for a multi-product firm is the transformation function. The transformation function shows the set of technologically efficient production plans, where technologically efficient plans are those where the maximum output is produced with a given amount of inputs. The transformation function is shown as: T(**y, 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**.

The representative firm's cost function may be obtained by minimizing production costs for producing a given output as follows:

$$\min_{x} \; w \cdot x \quad s.t. \; T(y,x) = 0$$

The solution to this minimization problem will produce the conditional input demand functions for the representative firm. Conditional input demand functions show input demand as a function of input prices and output levels; e.g. **x**=**x(w,y)**.

In terms of neoclassical optimization, the representative firm's cost function is obtained by substituting the input demand functions into the expression C = **w·x**, to yield cost as a function of input prices, output, and the scale of operation in the short run, and cost as a function of input prices and output only in the long run.

In this study, the translog cost function is used to estimate railroad costs. The biggest advantage of the translog cost function is its flexibility. The translog allows the estimation of the structure of costs in the rail industry without imposing restrictions on costs, such as homogeneity and separable technologies for multiple outputs. Moreover, without knowledge of the structure of the cost function, the best way to estimate it is to formulate a function that is as general as possible. A generalized short-run cost function for the rail industry would show costs as a function of factor prices (w_i), outputs (y_j), capital stock (k), and technological conditions (t_n), as follows:

$$C = C(w_i, y_j, k, t_n)$$

One way to approximate an unknown function, such as the cost function above, is to perform a Taylor series expansion with a remainder. 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.[2] For the generalized railroad cost function shown above, the second order taylor series expansion around the mean values of outputs, factor prices, capital, and technological variables can be performed as follows:

$$
\begin{aligned}
C(w_i, y_j, k, t_n) = {} & \frac{C(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{0!} + \sum_i \frac{C_{w_i}(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{1!} (w_i - \bar{w}_i) + \\
& \sum_j \frac{C_{y_j}(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{1!} (y_j - \bar{y}_j) + \sum_n \frac{C_{t_n}(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{1!} (t_n - \bar{t}_n) + \\
& \frac{C_k(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{1!} (k - \bar{k}) + \sum_i \sum_m \frac{C_{w_i w_m}(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{2!} (w_i - \bar{w}_i)(w_m - \bar{w}_m) + \\
& \sum_i \sum_j \frac{C_{w_i y_j}(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{2!} (w_i - \bar{w}_i)(y_j - \bar{y}_j) + \sum_i \frac{C_{w_i k}(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{2!} (w_i - \bar{w}_i)(k - \bar{k}) + \\
& \sum_i \sum_n \frac{C_{w_i t_n}(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{2!} (w_i - \bar{w}_i)(t_n - \bar{t}_n) + \sum_j \sum_i \frac{C_{y_j w_i}(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{2!} (y_j - \bar{y}_j)(w_i - \bar{w}_i) + \\
& \sum_j \sum_l \frac{C_{y_j y_l}(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{2!} (y_j - \bar{y}_j)(y_l - \bar{y}_l) + \sum_j \frac{C_{y_j k}(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{2!} (y_j - \bar{y}_j)(k - \bar{k}) + \\
& \sum_j \sum_n \frac{C_{y_j t_n}(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{2!} (y_j - \bar{y}_j)(t_n - \bar{t}_n) + \sum_i \frac{C_{k w_i}(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{2!} (k - \bar{k})(w_i - \bar{w}_i) + \\
& \sum_j \frac{C_{k y_j}(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{2!} (k - \bar{k})(y_j - \bar{y}_j) + \frac{C_{kk}(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{2!} (k - \bar{k})^2 + \\
& \sum_n \frac{C_{k t_n}(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{2!} (k - \bar{k})(t_n - \bar{t}_n) + \sum_n \sum_i \frac{C_{t_n w_i}(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{2!} (t_n - \bar{t}_n)(w_i - \bar{w}_i) + \\
& \sum_n \sum_j \frac{C_{t_n y_j}(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{2!} (t_n - \bar{t}_n)(y_j - \bar{y}_j) + \sum_n \frac{C_{t_n k}(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{2!} (t_n - \bar{t}_n)(k - \bar{k}) + \\
& \sum_n \sum_o \frac{C_{t_n t_o}(\bar{w}_i, \bar{y}_j, \bar{k}, \bar{t}_n)}{2!} (t_n - \bar{t}_n)(t_o - \bar{t}_o) + R_n
\end{aligned}
$$

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[2]The translog cost function was first introduced by Christensen, Jorgenson, and Lau (1973).

By placing both sides of the taylor series equation in natural logarithms, replacing partial derivatives with parameters, imposing symmetry conditions (e.g. $C_{witn} = C_{tnwi}$), and placing the remainder term into the error term the translog short-run cost function can be obtained.

$$
\begin{aligned}
\ln C = {} & \alpha_0 + \sum_i \alpha_i \ln (w_i/\bar{w}_i) + \sum_j \beta_j \ln (y_j/\bar{y}_j) + \psi \ln (k/\bar{k}) + \sum_n \lambda_n \ln (t_n/\bar{t}_n) + \\
& \frac{1}{2}\sum_i \sum_n \gamma_{in} \ln (w_i/\bar{w}_i) \ln (w_n/\bar{w}_n) + \sum_i \sum_j \omega_{ij} \ln (w_i/\bar{w}_i) \ln (y_j/\bar{y}_j) + \\
& \sum_i \theta_i \ln (w_i/\bar{w}_i) \ln (k/\bar{k}) + \sum_i \sum_n \phi_{in} \ln (w_i/\bar{w}_i) \ln (t_n/\bar{t}_n) + \\
& \frac{1}{2}\sum_j \sum_l \zeta_{jl} \ln (y_j/\bar{y}_j) \ln (y_l/\bar{y}_l) + \sum_j \iota_j \ln (y_j/\bar{y}_j) \ln (k/\bar{k}) + \\
& \sum_j \sum_n \varsigma_{jn} \ln (y_j/\bar{y}_j) \ln (t_n/\bar{t}_n) + \frac{1}{2}\mu \, [\ln (k/\bar{k})]^2 + \\
& \sum_n \kappa_n \ln (k/\bar{k}) \ln (t_n/\bar{t}_n) + \frac{1}{2}\sum_n \sum_o \nu_{no} \ln (t_n/\bar{t}_n) \ln (t_o/\bar{t}_o) + \epsilon
\end{aligned}
$$

Given the Taylor series approximation interpretation of the translog cost function, one may ask why a third or fourth order Taylor series approximation is not used since it can be shown that the remainder term decreases in size as the order of approximation increases. While this would be desirable ideally, the additional number of parameters that would have to be estimated given a third or fourth order approximation would be too large to allow estimation with most data sets.

Data and Methodology

In examining the existence of subadditivity of costs in the railroad industry, this study uses the same type of methodology that was used by Shin and Ying in the telecommunications industry. Simulations based on an estimated translog multiproduct cost function are performed, to assess the proportion of the time that subadditivity holds.

A long-run translog multiproduct cost function is estimated for the Class I railroad industry. When applying the cost theory outlined above to the railroad industry, we can identify the relevant factor prices, outputs, and technological conditions. The generalized long-run cost function for the railroad industry can be defined as:

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

where: 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

$ITGTM$ = through train gross ton-miles

MOR = miles of road

ALH = average length of haul

$SPEED$ = train miles per train hour

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.[3] 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

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

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 two cities, A and B, it can adjust its capital stock in order 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 is also 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.[4] 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.

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[4]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.

The trains run regularly between the particular origin and destination. Because of the high volume nature of unit trains, and the smaller switching requirement, unit trains are typically 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 are typically considered the highest cost service provided by railroads. Through train services are those provided between two or more major freight terminals. The service is typically 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. Moreover, 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 is generally 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. In essence, 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.

In order to estimate the generalized cost function above, the translog cost functional form is used. As with other estimations of the trans-log cost function, use is made of Shephard's Lemma to obtain share equations for each input. The share equations are then estimated in a seemingly unrelated system with the cost function. This is done in order 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. The entire seemingly unrelated system can be defined as follows:[5]

$$
\begin{aligned}
\ln C = {} & \alpha_0 + \sum_i \alpha_i \ln(w_i/\bar{w}_i) + \sum_j \beta_j \ln(y_j/\bar{y}_j) + \psi \ln(k/\bar{k}) + \sum_n \lambda_n \ln(t_n/\bar{t}_n) + \\
& \frac{1}{2}\sum_i \sum_m \gamma_{im} \ln(w_i/\bar{w}_i) \ln(w_m/\bar{w}_m) + \sum_i \sum_j \omega_{ij} \ln(w_i/\bar{w}_i) \ln(y_j/\bar{y}_j) + \\
& \sum_i \theta_i \ln(w_i/\bar{w}_i) \ln(k/\bar{k}) + \sum_i \sum_n \phi_{in} \ln(w_i/\bar{w}_i) \ln(t_n/\bar{t}_n) + \\
& \frac{1}{2}\sum_j \sum_l \zeta_{jl} \ln(y_j/\bar{y}_j) \ln(y_l/\bar{y}_l) + \sum_j \iota_j \ln(y_j/\bar{y}_j) \ln(k/\bar{k}) + \\
& \sum_j \sum_n \varsigma_{jn} \ln(y_j/\bar{y}_j) \ln(t_n/\bar{t}_n) + \frac{1}{2}\mu \left[\ln(k/\bar{k})\right]^2 + \\
& \sum_n \kappa_n \ln(k/\bar{k}) \ln(t_n/\bar{t}_n) + \frac{1}{2}\sum_n \sum_o \nu_{no} \ln(t_n/\bar{t}_n) \ln(t_o/\bar{t}_o) + \epsilon
\end{aligned}
$$

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

where share equations are estimated for all inputs but one, to avoid perfect collinearity. 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 ($\sum \alpha_i = 1$). Finally, firm dummies are included to account for fixed effects.[6] 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

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[5]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.

[6]F-tests revealed that firm effects are significant at the 1% level.

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.

In order to estimate the translog multiproduct cost function 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 1994.[7] These data are the best available for the Class I 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 the variables used and their construction. Table 2 provides a list of the railroads and years used, according to the merger definitions of Dooley, et. al.

Before presenting the empirical results of the translog estimation, one other important feature of the translog cost function should be highlighted. As shown in the previous section, the derivation of the translog cost function from a Taylor series approximation suggests that each of the observations on independent variables should be divided by the overall sample mean of that independent variable. This is convenient for the interpretation of estimation results as well, since

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[7]The use of 1983-1994 data is superior to that used in most previous studies. Most previous studies used pre-1983 data, which used 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 superior.

the first order term parameter estimates will show the elasticity of costs with respect to those variables when all variables are estimated at their sample means.

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
OPERCOST	Railroad Operating Cost (R1, Sched. 410, ln. 620, Col F)
CAPEXP	Capital 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 (Uniform Rail Costing System)
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)
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
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 = TRNMLS/(TRNHR+TRNHS+TYSWH)
TRNMLS	Total Train Miles (R1, Sched 755, line 5, Col. B)
TRNHR	Train Hours in Road Service (R1, Sched 755, line 115, Col. B)
TRNHS	Train Hours in Train Switching (R1, Sched 755, line 116, Col. B)
TYSWH	Total Yard Switching Hours (R1, Sched 755, line 117, Col. B)
Average Length of Haul	RTM / REVTONS
REVTONS	Revenue Tons (R1, Sched 755, line 105, Col. B)

* *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)	1983-1994
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)	1983-1994
Chesapeake & Ohio (CO)	1983-1985 - merged with BO, SCL to form CSX
Chicago & Northwestern (CNW)	1983-1994
Consolidated Rail Corporation (CR)	1983-1994
CSX Transportation (CSX)	1986-1994 - 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)	1983-1994 - from 1984-1994 incl. merged GTW, DTI
Illinois Central Gulf (ICG)	1983-1994
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)	1985-1994 - 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)	1983-1994 - from 1985-1994 incl. merged SOO, MILW
Southern Railway System (SRS)	1983-1984 - merged with NW to form NS
Southern Pacific (SP)	1983-1994 - from 1990-1993 incl. merged SP, SSW - for 1994 incl. merged SP, SSW, DRGW
Saint Louis, Southwestern (SSW)	1983-1989 - merged into SP
Union Pacific (UP)	1983-1994 - from 1986-1987 includes merged UP, WP, MP system - from 1988-1994 includes merged UP, WP, MKT system

Western Pacific (WP)	1983-1985 - merged into UP

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

Empirical Results

Table 3 shows the estimated translog cost function.[8] As the table shows, all of the first order terms have the expected signs except one, and all but one are significant at conventional levels. Labor, road investment, and materials are shown to comprise the largest shares of total costs, accounting for approximately 35.6, 24.3, and 18.0 percent of total costs respectively.[9] Equipment and fuel account for approximately 15.3 percent and 6.8 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 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 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 is higher than that with respect to way train

[8]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 A1 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.

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

service. This apparently reflects the higher portion of line capacity being used on lines carrying unit trains than on lines carrying way trains.

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	21.4798* (0.0843)
ln Labor Price	0.3565* (0.0070)
ln Equipment Price	0.1532* (0.0055)
ln Fuel Price	0.0680* (0.0017)
ln Materials and Supply Price	0.1797* (0.0092)
ln Way and Structures Price	0.2427* (0.0065)
ln Unit Train Gross Ton-Miles (Adjusted)	0.1339* (0.0249)
ln Way Train Gross Ton-Miles (Adjusted)	0.1005* (0.0237)
ln Through Train Gross Ton-Miles (Adjusted)	0.4131* (0.0664)
ln Speed	0.1954*** (0.0994)
ln Miles of Road	0.2786* (0.0848)
ln Average Length of Haul	0.0429 (0.1106)
Time	-0.0399* (0.0090)
Second Order Terms	
½ $(\ln \text{Labor Price})^2$	0.1081* (0.0140)
½ $(\ln \text{Equipment Price})^2$	0.0180* (0.0049)
½ $(\ln \text{Fuel Price})^2$	0.0512* (0.0034)
½ $(\ln \text{Materials Price})^2$	0.0118 (0.0192)
½ $(\ln \text{Way and Structures Price})^2$	0.1337* (0.0098)
ln Labor Price*ln Equipment Price	-0.0164* (0.0055)

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

ln Labor Price*ln Fuel Price	-0.0127* (0.0034)
ln Labor Price*ln Materials Price	0.0070 (0.0133)
ln Labor Price*ln Way and Structures Price	-0.0860* (0.0087)
ln Equipment Price*ln Fuel Price	-0.0022 (0.0014)
ln Equipment Price*ln Materials Price	0.0166** (0.0073)
ln Equipment Price*ln Way and Structures Price	-0.0160* (0.0048)
ln Fuel Price*ln Materials Price	-0.0120* (0.0050)
ln Fuel Price*ln Way and Structures Price	-0.0163* (0.0024)
ln Materials Price*ln Way and Structures Price	-0.0154 (0.0103)
½ (ln Unit Train GTM)^2	0.0701* (0.0093)
½ (ln Way Train GTM)^2	0.0100 (0.0212)
½ (ln Through Train GTM)^2	0.2371* (0.0788)
ln Labor Price*ln Unit Train GTM	-0.0017 (0.0024)
ln Labor Price*ln Way Train GTM	-0.0010 (0.0041)
ln Labor Price*ln Through Train GTM	0.0257* (0.0081)
ln Equipment Price*ln Unit Train GTM	0.0072* (0.0018)
ln Equipment Price*ln Way Train GTM	0.0153* (0.0032)
ln Equipment Price*ln Through Train GTM	0.0277* (0.0061)
ln Fuel Price*ln Unit Train GTM	0.0039* (0.0006)
ln Fuel Price*ln Way Train GTM	-0.0024** (0.0009)

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

ln Fuel Price*ln Through Train GTM	0.0041**
	(0.0020)
ln Materials Price*ln Unit Train GTM	-0.0177*
	(0.0031)
ln Materials Price*ln Way Train GTM	-0.0212*
	(0.0053)
ln Materials Price*ln Through Train GTM	-0.0286*
	(0.0108)
ln Way and Structures Price*ln Unit Train GTM	0.0082*
	(0.0022)
ln Way and Structures Price*ln Way Train GTM	0.0093**
	(0.0038)
ln Way and Structures Price*ln Through Train GTM	-0.0289*
	(0.0081)
ln Unit Train GTM*ln Way Train GTM	-0.0037
	(0.0096)
ln Unit Train GTM*ln Through Train GTM	-0.0666**
	(0.0255)
ln Way Train GTM*ln Through Train GTM	-0.0002
	(0.0193)
½ (ln Speed)^2	-0.5250***
	(0.2646)
½ (ln Miles of Road)^2	0.3465*
	(0.1110)
½ (ln Average Length of Haul)^2	-0.4984
	(0.3612)
½ (Time)^2	-0.00008
	(0.0011)
ln Labor Price*ln Speed	-0.0383*
	(0.0130)
ln Labor Price*ln Miles of Road	-0.0098
	(0.0107)
ln Labor Price*ln Average Length of Haul	-0.0364*
	(0.0126)
ln Labor Price*Time	-0.0050*
	(0.0010)
ln Equipment Price*ln Speed	0.0221**
	(0.0103)
ln Equipment Price*ln Miles of Road	-0.0502*
	(0.0080)

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

ln Equipment Price*ln Average Length of Haul	-0.0447* (0.0100)
ln Equipment Price*Time	-0.0061* (0.0007)
ln Fuel Price*ln Speed	0.0144* (0.0029)
ln Fuel Price*ln Miles of Road	-0.0123* (0.0026)
ln Fuel Price*ln Average Length of Haul	0.0267* (0.0030)
ln Fuel Price*Time	0.0002 (0.0003)
ln Materials Price*ln Speed	-0.0093 (0.0168)
ln Materials Price*ln Miles of Road	0.0556* (0.0142)
ln Materials Price*ln Average Length of Haul	0.0523* (0.0162)
ln Materials Price*Time	0.0066* (0.0012)
ln Way and Structures Price*ln Speed	0.0112 (0.0120)
ln Way and Structures Price*ln Miles of Road	0.0167 (0.0105)
ln Way and Structures Price*ln Average Length of Haul	0.0021 (0.0116)
ln Way and Structures Price*Time	0.0042* (0.0009)
ln Unit Train GTM*ln Speed	-0.0744** (0.0331)
ln Unit Train GTM*ln Miles of Road	-0.0195 (0.0359)
ln Unit Train GTM*ln Average Length of Haul	0.0914** (0.0374)
ln Unit Train GTM*Time	-0.0020 (0.0022)
ln Way Train GTM*ln Speed	0.0128 (0.0488)
ln Way Train GTM*ln Miles of Road	0.0426 (0.0301)

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

ln Way Train GTM*ln Average Length of Haul	-0.0492 (0.0454)
ln Way Train GTM*Time	-0.0085* (0.0026)
ln Through Train GTM*ln Speed	0.2865* (0.0955)
ln Through Train GTM*ln Miles of Road	-0.3006* (0.0858)
ln Through Train GTM*ln Average Length of Haul	-0.0842 (0.1333)
ln Through Train GTM*Time	-0.0125** (0.0057)
ln Miles of Road*ln Average Length of Haul	0.3805** (0.1686)
ln Speed*ln Average Length of Haul	0.3868 (0.2628)
ln Speed*Time	-0.0392* (0.0111)
ln Average Length of Haul*Time	0.0387* (0.0128)
ln Miles of Road*ln Speed	-0.3041** (0.1241)
ln Miles of Road*Time	0.0255* (0.0071)

System Weighted R^2 = .9965
System Weighted MSE =1.22
Number of Observations = 188
DW =2.152
*significant at the 1% level
**significant at the 5% level
***significant at the 10% level
firm specific dummies are also 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 all previous studies have done may distort the relationships between costs and outputs. In order 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. Moreover, the subadditivity simulations performed in the next section are also performed with the homogeneous output cost function. The following F-Test is used to assess the validity of such a restriction.

$$F = \frac{(RSS_R - RSS_U) \;/\; num.\ of\ restrictions}{RSS_U \;/\; d.f._U}$$
$$= 4.49$$

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 are also positive and significant, and suggest that a one percent increase in mileage will result in about a .28 percent increase in costs. Speed has a positive sign and is significant at the 10 percent level, reflecting the increased maintenance of way and capital costs associated with maintaining a higher quality road. Average length of haul has an unexpected sign, but is not significant at conventional levels. Finally, the time trend suggests that total railroad costs have been declining at approximately 3.9 percent per year.

Further, the estimated cost function 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.[10]

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

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[10]In order to test for concavity at the point of means, the following transformation of translog parameters is used to obtain the Hessian matrix.

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

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

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

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.

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, multiproduct economies of scale are shown to be strong. The parameter estimates suggest that in 1983 the elasticity of short-run total costs with respect to output was approximately .65, providing strong preliminary evidence that Class I railroads are natural monopolies in local markets. Furthermore, the elasticity of total costs with respect to output has been decreasing over time as shown by the output-time interaction variables.[11] However, this finding does not guarantee subadditivity. Evidence of economies of scope between unit train and through train

[11]Remember that time is not normalized by its mean.

service and way train and through train service is also shown in the interaction terms. In order 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 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 also evidence of economies of scope in serving different markets, with the elasticity of costs with respect to output and miles of road of approximately .93.

Tests of Cost Subadditivity

Two separate tests of cost subadditivity are performed in this study. 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 a fixed network (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 miles to vary and allowing network size to vary. 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 subadditivity is most relevant for considering the potential benefits of mergers that increase the overall size of rail networks.

In order to assess cost subadditivity, both simulations test directly for the subadditivity condition, as was done by Shin and Ying (1992). The subadditivity condition for localized markets is:

$$C(q^{m}) < C(q^{a}) + C(q^{b}),$$
$$C(q^{m}) = C(q_1, q_2, q_3)$$
$$C(q^{a}) = C(\lambda q_1, \gamma q_2, \phi q_3)$$
$$C(q^{b}) = C((1-\lambda)q_1, (1-\gamma)q_2, (1-\phi)q_3)$$
$$\lambda, \gamma, \phi = (0.1, 0.2, 0.3 \ldots, 0.9)$$
$$q_1, q_2, q_3 = \textit{unit train, way train, and through train GTM}$$

The parameter estimates obtained from the translog 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.[12] For each of the 188 observations with non-zero unit train gross ton-miles simulations are performed by splitting outputs into the 365 unique vector combinations. Thus, a total of 68,620 simulations are performed for the case where network size is held constant.

Table 4 summarizes the simulations for cost subadditivity with a fixed network. As the table shows, the condition of strict cost subadditivity is met for all 188 observations. Thus, it is

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[12]Subadditivity is evaluated using both the 1983 and the 1994 cost structures.

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 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 is performed in the same fashion, except miles of road are split between two firms as well. With four variables, there are now a total of 3,281 unique vector combinations, meaning that a total of 616,828 simulations are performed. The simulations are performed using the 1983 cost structure and the 1994 cost structure. This will allow an assessment of natural monopoly shortly after railroad deregulation and nearly 15 years after deregulation. Table 5 summarizes the results of the simulations for both 1983 and 1994 using the multiple output model introduced in this study and using the single output model used in previous studies. As the table shows, while the condition of strict cost subadditivity is not met for any of the 188 observations in either year using the multiple output model, monopoly costs are lower than two firm costs for approximately 69 percent of all simulations in which network size is allowed to vary. A strict interpretation of these results would suggest that while the monopoly realizes lower costs than many two firm configurations, for all observations there is at least one two firm configuration with lower costs than the monopoly firm. However, a strict interpretation of these simulation results is probably not appropriate when analyzing the railroad industry. Because of the nature of railroad operations, many hypothetical network/output combinations are not possible. For example, a 5,000 mile railroad with uniform traffic density over its network could not be split into two 2,500 mile networks with one carrying 90 percent of the traffic and the other 10 percent. Thus, in using these results to interpret the likelihood that railroads are natural monopolies over current networks, more weight should be placed on the proportion of simulations where monopoly firm costs are lower than two firm costs than on the percentage of simulations where strict cost subadditivity is met. Therefore, based on the 69 percent of simulations where monopoly costs are lower than two firm costs, it appears that railroads are natural monopolies over current network sizes.

Table 5 also highlights the major differences between the multiple output model and the single output model in terms of the implications each makes for subadditivity. While the multiple output model shows monopoly costs that are lower than two-firm costs for approximately 69 percent of the observations, the single output model shows monopoly costs to be lower than two-firm costs for only 46 percent of the observations in 1983 and 52 percent of the observations in 1994. Moreover, the average savings from monopoly are negative in the single output case in 1983. When viewed from the single output model, the case for railroads being a natural monopoly over multiple markets is much weaker.

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

		Monopoly Costs Lower Than Two-Firm Costs		Percent Savings from Monopoly (over all 68,620 simulations)				Cost Subadditivity Condition Met	
Year	Number of Simulations	Number	Pct.	Average	Maximum	Minimum	Number of Obs.	Number	Pct.
1983	68,620	68,620	100	25.3	286.6	3.2	188	188	100
1994	68,620	68,620	100	48.6	432.4	8.0	188	188	100

Table 5: Summary of Subadditivity Simulations While Allowing Network Size to Vary*

		Monopoly Costs Lower Than Two-Firm Costs		Percent Savings from Monopoly (over all 616,828 simulations)				Cost Subadd. Cond. Met		Cost Superadd. Cond. Met	
Cost Model	Year	Number	Pct.	Avg.	Max.	Min.	# of Obs.	Number	Pct.	Number	Pct.
Multiple Outputs	1983	422,996	68.6	8.04	310.9	-35.0	188	0	0	0	0
Multiple Outputs	1994	428,590	69.5	5.52	183.9	-33.1	188	1	0.01	0	0
Single Output	1983	3,552	46.1	-0.51	125.4	-45.5	188	60	31.9	59	31.4
Single Output	1994	3,991	51.8	4.10	120.6	-40.1	188	80	42.6	36	19.2

*Cost subadditivity is met when the monopoly cost is less than the combined two-firm cost for all two-firm combinations. Cost superadditivity is when all two-firm costs are less than the monopoly cost.

SUMMARY AND CONCLUSIONS

Recently, there has been a great deal of discussion over mergers in the U.S. railroad industry. This discussion has focused on the appropriate role for the Surface Transportation Board (STB) in merger oversight, the need for preserved competition in the face of mergers of railroads serving the same markets, and the impacts of end-to-end mergers on railroad costs.

This study sheds some light on each of these issues. First, the study finds evidence to suggest that railroads are natural monopolies over a fixed network size. That is, duplicate networks serving the same markets would result in increased industry costs. This suggests that maintaining competition in markets impacted by horizontal mergers is not justified by railroad cost considerations. However, more study is needed to assess the impacts of such competition on rates to make a full welfare assessment of competition. Second, the study finds evidence that suggests that railroads are natural monopolies over multiple markets as well. Thus, it appears on a cost basis that the recent mega-mergers that have been occurring have had some real benefits. Moreover, while not addressed in this study, service quality may also improve as a result of mergers. Third, the study highlights the importance of cost considerations in considering the potential benefits of mergers. The STB cannot make intelligent decisions regarding the desirability of mergers without some understanding of their potential impacts on industry costs.

Finally, the study highlights the importance of modeling the multi-product nature of railroads. Subadditivity simulations using a homogeneous output produce much weaker support for the notion of railroads being natural monopolies over multiple markets. This may partially explain the finding in previous studies of a lack of cost benefits resulting from increased railroad size.

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Appendix

Table A1: 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	21.3955* (0.0821)
ln Labor Price	0.3562* (0.0057)
ln Equipment Price	0.1403* (0.0045)
ln Fuel Price	0.0616* (0.0016)
ln Materials and Supply Price	0.2115* (0.0075)
ln Way and Structures Price	0.2305* (0.0052)
ln Unit Train Gross Ton-Miles (Adjusted)	0.0112 (0.0093)
ln Way Train Gross Ton-Miles (Adjusted)	0.1166* (0.0170)
ln Through Train Gross Ton-Miles (Adjusted)	0.4240* (0.0597)
ln Speed	0.1951** (0.0853)
ln Miles of Road	0.3120* (0.0608)
ln Average Length of Haul	0.0262 (0.0894)
Time	-0.0372* (0.0079)
Second Order Terms	
½ (ln Labor Price)^2	0.1265* (0.0142)
½ (ln Equipment Price)^2	0.0143* (0.0051)
½ (ln Fuel Price)^2	0.0496* (0.0038)
½ (ln Materials Price)^2	0.0537** (0.0205)
½ (ln Way and Structures Price)^2	0.1398* (0.0094)
ln Labor Price*ln Equipment Price	-0.0142** (0.0057)

Table A1: 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 Fuel Price	-0.0104* (0.0035)
ln Labor Price*ln Materials Price	-0.0175 (0.0139)
ln Labor Price*ln Way and Structures Price	-0.0844* (0.0085)
ln Equipment Price*ln Fuel Price	-0.0033** (0.0016)
ln Equipment Price*ln Materials Price	0.0184** (0.0076)
ln Equipment Price*ln Way and Structures Price	-0.0152* (0.0049)
ln Fuel Price*ln Materials Price	-0.0252* (0.0054)
ln Fuel Price*ln Way and Structures Price	-0.0108* (0.0024)
ln Materials Price*ln Way and Structures Price	-0.0294* (0.0104)
½ (ln Unit Train GTM)^2	0.000002 (0.000002)
½ (ln Way Train GTM)^2	-0.0099 (0.0200)
½ (ln Through Train GTM)^2	0.0901 (0.0704)
ln Labor Price*ln Unit Train GTM	0.000003** (0.000001)
ln Labor Price*ln Way Train GTM	-0.0017 (0.0041)
ln Labor Price*ln Through Train GTM	0.0262* (0.0079)
ln Equipment Price*ln Unit Train GTM	-0.000004* (0.000001)
ln Equipment Price*ln Way Train GTM	0.0175* (0.0033)
ln Equipment Price*ln Through Train GTM	0.0220* (0.0060)
ln Fuel Price*ln Unit Train GTM	0.0000009* (0.0000003)
ln Fuel Price*ln Way Train GTM	-0.0020*** (0.0010)

Table A1: Seemingly Unrelated Regression of Translog Cost Function and Share Equations - Controlling for Firm Effects (Box Cox Transformation Applied to Outputs - lambda = .0001)	
ln Fuel Price*ln Through Train GTM	-0.0011 (0.0021)
ln Materials Price*ln Unit Train GTM	0.000002 (0.000002)
ln Materials Price*ln Way Train GTM	-0.0256* (0.0055)
ln Materials Price*ln Through Train GTM	-0.0109 (0.0108)
ln Way and Structures Price*ln Unit Train GTM	-0.000002** (0.000001)
ln Way and Structures Price*ln Way Train GTM	0.0118* (0.0038)
ln Way and Structures Price*ln Through Train GTM	-0.0362* (0.0077)
ln Unit Train GTM*ln Way Train GTM	-0.00001 (0.000009)
ln Unit Train GTM*ln Through Train GTM	0.00008* (0.00001)
ln Way Train GTM*ln Through Train GTM	-0.0259 (0.0194)
½ (ln Speed)^2	0.1109 (0.2419)
½ (ln Miles of Road)^2	0.0360 (0.0847)
½ (ln Average Length of Haul)^2	-0.1644 (0.3140)
½ (Time)^2	0.0007 (0.0010)
ln Labor Price*ln Speed	-0.0385* (0.0131)
ln Labor Price*ln Miles of Road	-0.0123 (0.0096)
ln Labor Price*ln Average Length of Haul	-0.0421* (0.0124)
ln Labor Price*Time	-0.0051* (0.0009)
ln Equipment Price*ln Speed	0.0264** (0.0104)
ln Equipment Price*ln Miles of Road	-0.0384* (0.0074)

Table A1: Seemingly Unrelated Regression of Translog Cost Function and Share Equations - Controlling for Firm Effects (Box Cox Transformation Applied to Outputs - lambda = .0001)	
ln Equipment Price*ln Average Length of Haul	-0.0332* (0.0098)
ln Equipment Price*Time	-0.0052* (0.0007)
ln Fuel Price*ln Speed	0.0192* (0.0032)
ln Fuel Price*ln Miles of Road	-0.0027 (0.0025)
ln Fuel Price*ln Average Length of Haul	0.0261* (0.0031)
ln Fuel Price*Time	0.0008** (0.0003)
ln Materials Price*ln Speed	-0.0280 (0.0173)
ln Materials Price*ln Miles of Road	0.0217 (0.0131)
ln Materials Price*ln Average Length of Haul	0.0552* (0.0161)
ln Materials Price*Time	0.0038* (0.0012)
ln Way and Structures Price*ln Speed	0.0209*** (0.0120)
ln Way and Structures Price*ln Miles of Road	0.0317* (0.0093)
ln Way and Structures Price*ln Average Length of Haul	-0.0060 (0.0114)
ln Way and Structures Price*Time	0.0057* (0.0009)
ln Unit Train GTM*ln Speed	-0.00004** (0.00002)
ln Unit Train GTM*ln Miles of Road	-0.00007* (0.00001)
ln Unit Train GTM*ln Average Length of Haul	0.00002 (0.00002)
ln Unit Train GTM*Time	-0.000003** (0.000001)
ln Way Train GTM*ln Speed	0.0576 (0.0423)
ln Way Train GTM*ln Miles of Road	0.0924* (0.0277)

Table A1: Seemingly Unrelated Regression of Translog Cost Function and Share Equations - Controlling for Firm Effects (Box Cox Transformation Applied to Outputs - lambda = .0001)

ln Way Train GTM*ln Average Length of Haul	-0.0507 (0.0434)
ln Way Train GTM*Time	-0.0098* (0.0022)
ln Through Train GTM*ln Speed	0.0554 (0.0860)
ln Through Train GTM*ln Miles of Road	-0.2038* (0.0646)
ln Through Train GTM*ln Average Length of Haul	0.0838 (0.1106)
ln Through Train GTM*Time	-0.0119** (0.0048)
ln Miles of Road*ln Average Length of Haul	0.3005** (0.1328)
ln Speed*ln Average Length of Haul	0.0346 (0.2472)
ln Speed*Time	-0.0354* (0.0099)
ln Average Length of Haul*Time	0.0320* (0.0106)
ln Miles of Road*ln Speed	-0.1543 (0.1081)
ln Miles of Road*Time	0.0218* (0.0057)

System Weighted R^2 = .9959
System Weighted MSE = 1.35
Number of Observations = 200
DW = 2.014
*significant at the 1% level
**significant at the 5% level
***significant at the 10% level
firm specific dummies are also included in the cost function estimation (parameter estimates for firm dummies are not shown)