PRODUCTIVITY IN U.S. RAILROADS
1951-1974

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1. Introduction

Based on conventional methodology, postwar productivity growth in the U.S. railroad industry has exceeded that of most other U.S. industries. This is true for both the Bureau of Labor Statistics' (1977) estimates of output per hour worked and for Kendrick's (1973) estimates of total factor productivity using output and an index of labor and capital input. Recently Meyer and Morton (1975), drawing on research performed for the Task Force on Railroad Productivity (1973), have questioned the validity of estimates of U.S. rail productivity based on conventional measurement techniques. Meyer and Morton suggested some important improvements which could be made in the measurement of rail productivity. They showed that implementation of these improvements would result in substantial downward revisions in the estimated growth of U.S. railroad productivity. Unfortunately, however, their implementation employed index number procedures which severely misrepresented the structure of production in the railroad industry. The result was productivity estimates which remained seriously flawed.

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The purpose of this paper is to provide new estimates of growth in U.S. railroad productivity. Our estimates reflect: (1) the improvements suggested by Meyer and Morton, (2) a disaggregated treatment of inputs, including a correction for the "betterment" accounting techniques used by railroads in reporting to the Interstate Commerce Commission (ICC), and (3) indexing procedures which are consistent with the structure of production in the railroad industry. We employ a data base which is considerably more comprehensive than those used in previous railroad productivity studies. We make use of detailed cost data from a large sample of Class I railroads to obtain information on the structure of cost and production in this industry.

Index number procedures represent production processes.[1] Hence it is desirable to choose a procedure which is capable of representing a diversity of possible production structures, i.e., one which is free of a priori restrictions. We use recent developments in duality theory to derive a procedure which avoids restrictive assumptions implicit in several widely-used indexing procedures. These assumptions include constant returns to scale, separability of outputs and inputs, predetermined elasticities of substitution and transformation, homogeneity or homotheticity of the input structure, and Hicks neutral technical change. Our approach begins with a general transformation function and its corresponding multiproduct cost function. Total differentiation of the cost function leads to an index of productivity which is a function of the rates of growth of the individual

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[1]For discussion see Samuelson and Swamy (1974) and Diewert (1976).

outputs and inputs. The weights for the input growth rates are the elasticities of total cost with respect to the corresponding input prices. The weights for the output growth rates are the elasticities of total cost with respect to the output levels.

Cost elasticities with respect to input prices and output levels are not directly observable. Nevertheless, since markets for railroad inputs are unregulated, and there is no binding rate of return regulation, input cost shares provide defensible estimates of the input weights. The relative prices for all outputs reflected their relative marginal costs of production, and if constant returns to scale prevailed for U.S. railroads, then revenue shares would provide defensible estimates of the output weights. However, all indications are that rate regulation has resulted in the cross-subsidization of passenger service by freight service. Furthermore, it is not clear that the relationship between long and short haul rates reflects their relative marginal costs. Therefore, it is necessary to obtain alternative estimates of the output cost elasticities to use as weights for the output growth rates. We obtain estimates of the cost elasticities from three cross-sectional cost function regressions using data from Class I U.S. railroads.

Our estimates of growth in U.S. railroad productivity differ substantially from estimates obtained using conventional methods. When conventional methods are applied to our data set, railroad productivity is estimated to have grown at the average rate of 3.6% per year, 1951-1974. Our methodology reveals that this high rate of growth of productivity is illusory. We find that railroad productivity increased at the substantially lower rate of 1.7% per year. The impact of our methodological improvements is even more dramatic for the recent peak-to-peak growth cycle, 1966-1973. Conventional methods indicate that rail productivity grew at the average annual rate of 3.3%. Our estimate of productivity growth for this same period is only 0.8% per year.

Meyer and Morton implicitly assume that the structure of railroad production exhibits constant returns to scale, as well as separability of outputs and inputs. Furthermore their indexing procedures specify a priori that the elasticity of transformation between passenger and freight service is infinite, and that the elasticity of substitution between any pair of inputs is unity. These specifications do not realistically reflect the structure of production for railroad services, and consequently result in errors in measured railroad productivity. We provide some illustrative estimates of railroad productivity using their procedures to demonstrate the importance of these unrealistic specifications.

2. Methodology

The efficient transformation of a vector of inputs X into a vector of outputs Y can be represented by an implicit function:

$$f(Y_1, Y_2, \ldots, Y_m; X_1, X_2, \ldots, X_n; T) = 0 \quad (1)$$

where T is time, representing shifts in the function due to changes in productivity. McFadden (1970) has shown that if the transformation function has a strictly convex input structure, then there exists a unique cost function which is dual to (1). The dual cost function can be written:

$$C = g(Y_1, Y_2, \ldots, Y_m; W_1, W_2, \ldots, W_n; T) \,, \tag{2}$$

where the W_i's are the prices at which the X_i's can be purchased, and C is total cost:

$$C = \sum_{i=1}^{n} W_i X_i \,. \tag{3}$$

The cost function (2) is homogeneous of degree plus one, nondecreasing, and concave in the factor prices (W_i). The first partial derivatives of the cost function with respect to the W_i's are equal to the cost minimizing input levels. This convenient property of the cost function is known as Shepherd's (1953) lemma,[2] which can be written in logarithmic form as

$$\frac{\partial \ln g}{\partial \ln W_i} = \frac{W_i X_i}{C} = S_i \,, \tag{4}$$

where S_i is the share of factor i in total cost.

Total differentiation of the log of the cost function with respect to time yields:

$$\frac{d \ln C}{dT} = \sum_{i=1}^{m} \frac{\partial \ln g}{\partial \ln Y_i} \frac{d \ln Y_i}{dT} + \sum_{i=1}^{n} \frac{\partial \ln g}{\partial \ln W_i} \frac{d \ln W_i}{dT} + \frac{\partial \ln g}{\partial T} \,. \tag{5}$$

The total derivative $\frac{d \ln C}{dT}$ can be interpreted as the rate of growth of total cost. The right hand side of (5) shows how the rate of growth of cost can be allocated among changes in output levels, changes in factor prices, and shifts in the cost function (changes in productivity).

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[2]Further discussion of the properties of the multiproduct cost function can be found in Hall (1973).

Total differentiation of (3) with respect to time yields

$$\text{(6)} \qquad \frac{d\,\ell n\,C}{dT} = \sum_{i=1}^{n} (W_i X_i/C)\left(\frac{d\,\ell n\,W_i}{dT} + \frac{d\,\ell n\,X_i}{dT}\right)$$

$$= \sum_{i=1}^{n} S_i \frac{d\,\ell n\,W_i}{dT} + \sum_{i=1}^{n} S_i \frac{d\,\ell n\,X_i}{dT} .$$

Expressions (4) and (6) can be substituted into (5) to obtain:

$$\text{(7)} \qquad -\frac{\partial\,\ell n\,g}{\partial T} = \sum_{i=1}^{m} \frac{\partial\,\ell n\,g}{\partial\,\ell n\,Y_i} \frac{d\,\ell n\,Y_i}{dT} - \sum_{i=1}^{n} S_i \frac{d\,\ell n\,X_i}{dT} .$$

The $\frac{\partial\,\ell n\,g}{\partial\,\ell n\,Y_i}$ are the cost elasticities of the outputs. If the outputs are priced at marginal cost, and if the production structure exhibits constant returns to scale, then the cost elasticities are equal to the shares of the outputs in total revenue $R_i = P_i Y_i / \Sigma P_i Y_i$. In this case (7) becomes:

$$\text{(8)} \qquad -\frac{\partial\,\ell n\,g}{\partial T} = \sum_{i=1}^{m} R_i \frac{d\,\ell n\,Y_i}{dT} - \sum_{i=1}^{n} S_i \frac{d\,\ell n\,X_i}{dT} .$$

Expression (8) is the Divisia Index of productivity discussed by Jorgenson and Griliches (1967).

Since output prices in the U.S. railroad industry are regulated by the ICC, these prices do not necessarily reflect marginal costs. Furthermore, it is not desirable to assume a priori that the railroad industry exhibits constant returns to scale. Therefore, rather than use (8), we use the concept of productivity defined by (7), which does not require competitive output pricing or constant returns to scale. This entails the use of cost elasticities with respect to outputs, rather than revenue shares, to weight the output growth rates. However, cost shares provide satisfactory estimates of cost elasticities with respect to factor prices, since railroads purchase inputs in unregulated factor markets.

The index of productivity (7) is defined in continuous time. Empirical implementation requires a discrete approximation to (7). We use first differences in natural logarithms to approximate the logarithmic derivatives, and we use arithmetic averages of the weights at the beginning and end of the period to approximate the instantaneous weights:

$$(9) \qquad -(\ln g_T - \ln g_{T-1}) = \sum_{i=1}^{m} \left\{ \frac{1}{2}\left[\frac{\partial \ln g}{\partial \ln Y_i}\right]_T + \frac{1}{2}\left[\frac{\partial \ln g}{\partial \ln Y_i}\right]_{T-1} \right\} \left\{ \ln Y_{i,T} - \ln Y_{i,T-1} \right\}$$

$$- \sum_{i=1}^{n} \left\{ \frac{1}{2} S_{i,T} + \frac{1}{2} S_{i,T-1} \right\} \left\{ \ln X_{i,T} - \ln X_{i,T-1} \right\}.$$

All the variables in (9) are observable except for the elasticities of cost with respect to the outputs; we estimate these from cross-section cost function regressions on a representative sample of railroads.

Diewert (1976) has criticized the use of formulas such as (9) for productivity measurement on the grounds that they result from separable transformation functions in which only neutral shifts in the functions are permitted. He proceeded to recommend an alternative measurement procedure based on a transformation function in which the outputs are treated asymmetrically

$$(10) \qquad Y_1 = h(Y_2, \ldots, Y_m;\ X_1, X_2, \ldots, X_n;\ T).$$

Diewert acknowledged that his recommended procedure suffered from two disadvantages: (i) the procedure is computationally more difficult, and (ii) the first output, Y_1, is asymetrically singled out.

The motivation for Diewert's procedure was to obtain a method of productivity measurement which did not require the separability of outputs and inputs. The fact that (9) approximates (7), which was derived from (1), reveals that it does not require separability of outputs and inputs, nor does it require that shifts in the transformation function be neutral. These specifications are required only if one wishes to interpret the two terms on the right hand side of (9) as "aggregate output" and "aggregate input," in which case (1) must be rewritten as:

$$f(Y(Y_1,\ldots,Y_m),X(X_1,\ldots,X_n),T) = 0. \tag{11}$$

3. Data

The Data Appendix provides a detailed description of the sources and methods used in the construction of our data set. In this section we provide a brief description of the data set, along with tables of the most important variables. Our principal data source is Transport Statistics of the United States. The most recent edition contains data for 1974.[3] Years prior to 1951 are excluded due to difficulties of data comparability. Our coverage is restricted to Class I railroads, which produced over 99% of U.S. railroad revenue ton-miles and passenger-miles in recent years.

In principle it would be desirable to treat as distinct outputs all railroad services which have different cost elasticities. In practice,

[3] Interstate Commerce Commission, Bureau of Accounts, Transport Statistics in the United States, Government Printing Office, Washington, D.C.

however, it is not possible to distinguish more than a few relatively homogeneous output categories. The most important distinction is between freight and passenger services. It is also important to recognize that the cost of providing freight and passenger services depends on the distance over which service is provided. It would also be desirable to allow for different cost levels associated with hauling different commodities. Unfortunately, it is not possible to do so with any assurance based on available data.[4] Thus we limit our output categories to freight and passenger services distinguished by length of haul.

There are two possible ways to account for length of haul. One way would be to decide upon discrete mileage bands, such as zero to two hundred, two hundred to four hundred, etc., and treat ton-miles or passenger-miles falling within the various bands as distinct outputs. The other way would be to allow for a continuous relationship between distance and cost. We adopt the latter approach for three reasons: First, data are readily available to estimate average length of haul. Second, it avoids the arbitrary selection of mileage bands. Third, it is a more workable approach, since the number of output cost elasticities to be estimated is much smaller.

The four output indexes which we employ are presented in Table 1: (1) Revenue freight ton-miles; (2) average length of freight haul, computed as the ratio of revenue ton-miles to revenue tons; (3) revenue passenger-miles; and (4) average length of passenger trip, computed as the ratio of revenue passenger-miles to revenue passengers.

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[4]The only data which could be used to address this issue are the Carload Waybill Statistics collected by the ICC until 1966 and by the U.S. Department of Transportation since 1969. We have been informed by industry sources that these statistics are not reliable. This has been confirmed by our detailed study of the waybills of a major Class I railroad.

Table 1

INPUT AND OUTPUT QUANTITY INDEXES

(1967 = 1.000)

	Input Indexes					Output Indexes			
Year	Labor	Way and Structures	Equipment	Fuel	Materials	Freight Ton-miles	Average Length of Freight Haul	Passenger Miles	Average Length of Passenger Trip
1951	2.077	1.093	.610	3.451	1.093	.899	.828	2.277	1.398
1952	1.967	1.113	.652	2.663	1.032	.854	.836	2.238	1.416
1953	1.907	1.080	.725	2.152	1.034	.842	.828	2.083	1.354
1954	1.683	1.085	.764	1.532	.915	.763	.854	1.926	1.304
1955	1.715	1.089	.784	1.515	.977	.867	.854	1.876	1.292
1956	1.693	1.086	.795	1.372	1.010	.899	.854	1.854	1.285
1957	1.586	1.081	.812	1.159	.993	.859	.865	1.703	1.230
1958	1.374	1.079	.844	.935	.894	.767	.898	1.529	1.199
1959	1.343	1.072	.848	.924	.932	.800	.900	1.451	1.223
1960	1.283	1.060	.852	.910	.923	.795	.896	1.399	1.275
1961	1.188	1.046	.826	.887	.906	.783	.918	1.335	1.252
1962	1.172	1.037	.819	.909	.884	.824	.932	1.309	1.248
1963	1.143	1.026	.826	.927	.920	.864	.941	1.217	1.167
1964	1.131	1.015	.836	.946	1.009	.915	.940	1.200	1.139
1965	1.078	1.012	.891	.972	.991	.970	.981	1.144	1.137
1966	1.057	1.002	.941	1.015	1.029	1.026	.997	1.125	1.112
1967	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1968	.980	.997	1.041	1.006	1.007	1.034	1.026	.863	.867
1969	.961	.993	1.055	1.003	1.082	1.067	1.033	.801	.804
1970	.959	.993	1.102	.966	1.122	1.063	1.044	.709	.741
1971	.884	.987	1.138	.970	1.163	1.028	1.075	.553	.602
1972	.824	.986	1.188	1.034	1.086	1.080	1.091	.563	.641
1973	.849	.977	1.248	1.051	1.187	1.184	1.126	.612	.714
1974	.841	.975	1.215	1.066	1.254	1.178	1.115	.680	.736

We distinguish five categories of inputs, which are constructed from much finer input classifications. The input indexes are: (1) labor, (2) way and structures, (3) equipment, (4) fuel, and (5) materials. These indexes are also presented in Table 1.

The labor quantity index is based on data from the annual A-300 reports of rail carriers to the ICC. It is computed as a log-change index of straight- and over-time hours, using the adjacent year average of compensation shares for seven occupational groups. The quantity indexes for structures and equipment are based on capital stock estimates derived by the perpetual inventory method. Our structures estimate capitalizes track and track materials, rather than expensing them (a procedure mandated by the ICC and followed by most U.S. railroads). The quantity index for fuel reflects BTU's of energy consumed. Finally, the materials quantity index is computed by deflating the remainder of operating expenses by a price index for railroad materials and supplies.

The most dramatic figures in Table 1 are the sharp declines in fuel usage in the early 1950's and the decline in passenger output throughout the period. The sharp reductions in fuel consumption reflect the rapid replacement of steam locomotives by more fuel efficient diesel locomotives. In 1951 54% of the locomotives in service were steam-driven; by 1954 this figure had fallen to 26%. During this three year period the BTU's used to produce steam fell from 1532 to just 391. Meanwhile BTU's consumed by all other locomotives only increased from 321 to 439.[5] The decline in

[5]These BTU data, expressed in trillions (10^{12}), are computed from Association of American Railroads, Statistics of Railroads of Class I, Washington, D.C., selected years.

passenger miles is principally due to lower demand for service. The large drop in 1971 reflects the formation of Amtrak. All but three railroads opted to have Amtrak take over their passenger service, which resulted in the elimination of a substantial amount of existing passenger service.

Annual estimates of total cost for Class I railroads are presented in Table 2, along with the shares of cost accounted for by the five inputs which we distinguish. The cost estimates for labor, fuel, and materials are closely related to the accounting costs reported to the ICC. The annual costs of using structures and equipment in the rail industry were imputed using procedures similar to those proposed by Christensen and Jorgenson (1969).

4. Estimation of the Elasticities of Cost with Respect to the Output Indexes

The use of (9) to estimate productivity growth requires estimates of the output cost elasticities. Our procedure for obtaining these elasticities is to estimate the structure of cost for the U.S. railroad industry with a cross section regression technique. This yields estimates of the elasticities of cost with respect to the four output indexes for individual railroads. Industry average cost elasticities can then be computed as weighted averages of the individual railroad elasticities.

It would be possible to estimate cost elasticities for each year in our sample, but this would require an enormous data development effort. We have chosen to estimate cost functions for three years in the postwar period: 1955, 1963, and 1974. The number of firms included in our samples

Table 2

COST SHARES, TOTAL COST OF INPUTS, AND LABOR'S SHARE IN NATIONAL INCOME

Year	Labor's Share in RR National Income	Cost Shares					Total Cost (Billions of $)
		Labor	Way and Structures	Equipment	Fuel	Materials	
1951	.825	.547	.133	.109	.067	.145	8.88
1952	.817	.548	.136	.118	.058	.140	8.95
1953	.840	.541	.135	.126	.054	.143	9.03
1954	.902	.535	.133	.143	.050	.139	8.45
1955	.858	.541	.131	.128	.051	.149	8.60
1956	.870	.541	.142	.116	.048	.153	9.25
1957	.883	.516	.166	.124	.045	.150	9.78
1958	.905	.494	.186	.142	.038	.140	9.57
1959	.895	.496	.179	.141	.038	.147	9.73
1960	.912	.474	.200	.148	.035	.143	10.05
1961	.889	.428	.236	.169	.034	.134	10.57
1962	.911	.440	.236	.162	.034	.128	10.66
1963	.884	.432	.235	.166	.034	.133	10.71
1964	.892	.425	.235	.167	.032	.141	11.12
1965	.877	.427	.230	.173	.033	.138	11.30
1966	.863	.417	.228	.184	.033	.139	11.84
1967	.938	.404	.231	.199	.032	.133	12.41
1968	.941	.401	.224	.212	.032	.132	12.99
1969	.937	.400	.218	.211	.032	.139	13.60
1970	.951	.405	.218	.205	.030	.142	14.35
1971	.967	.420	.183	.213	.032	.153	14.30
1972	.939	.457	.153	.202	.034	.155	13.76
1973	.963	.475	.138	.190	.040	.158	15.33
1974	.975	.466	.101	.188	.070	.175	16.85

for these years were 58, 56, and 40, respectively.[6] The methodology used to construct data for the individual railroads followed closely our methodology for the full industry, as described in the Data Appendix.

We have used the generalized translog multiproduct cost function, proposed by Caves, Christensen, and Tretheway (1978), to estimate cost elasticities. This cost function has the same form as the translog except for output levels, where the Box-Cox metric is substituted for the natural log metric.[7] This generalization permits the inclusion of firms with zero output levels for some products. In the current application it permits the inclusion in the sample of firms with no passenger output.

We use y_i to denote the output indexes, and Y_i to denote the Box-Cox transformations of y_i: $Y_i = (y_i^{\lambda} - 1)/\lambda$. With this convention the generalized translog multiproduct cost function can be written:

$$(12) \quad \ln C = \alpha + \sum_i^m \alpha_i Y_i + \sum_i^n \beta_i \ln W_i + \frac{1}{2} \sum_i^m \sum_j^m \delta_{ij} Y_i Y_j + \frac{1}{2} \sum_i^n \sum_j^n \gamma_{ij} \ln W_i \ln W_j + \sum_i^m \sum_j^n \rho_{ij} Y_i \ln W_j ,$$

where C is total cost, the W_i's are the prices of the input indexes, and $\delta_{ij} = \delta_{ji}$, $\gamma_{ij} = \gamma_{ji}$. Any cost function must be homogeneous of degree one

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[6] To arrive at a relatively homogeneous sample, some Class I railroads were excluded in each year. First, we excluded some Eastern railroads which exhibited very heavy commutation passenger traffic relative to other passenger and freight traffic. Second, we excluded several small carriers which primarily haul raw materials to the steel industry, and which are wholly-owned by steel producers. Missing data resulted in the exclusion of a third group of firms.

[7] The translog multiproduct cost function is discussed in Burgess (1974) and Brown, Caves, and Christensen (1979).

in factor prices; this requires that $\Sigma\beta_i = 1$, $\sum_j^n \gamma_{ij} = 0$ $(i=1,\ldots,n)$, and $\sum_i^n \gamma_{ij} = 0$ $(j=1,\ldots,n)$.

The estimation of (12) with pooled data from 1955, 1963, and 1974 would be undesirable because it would not allow for differences among the years in the structure of cost. We overcome this problem by introducing dummy variables for 1955 and 1974 (e.g. $D_{55} = 1$ in 1955, zero elsewhere) which allow the structure of cost to be different from that of 1963. These dummy variables are allowed to interact with the output indexes and the input prices. The cost function augmented by these dummy variables can be written:

$$\text{(13)} \quad \ell n\ C = \alpha + \alpha_{55}D_{55} + \alpha_{74}D_{74} + \Sigma\alpha_i Y_i + \Sigma\alpha_{55i}Y_i D_{55} + \Sigma\alpha_{74i}Y_i D_{74}$$
$$+ \Sigma\beta_i\ \ell n\ W_i + \Sigma\beta_{55i}\ \ell n\ W_i D_{55} + \Sigma\beta_{74i}\ \ell n\ W_i D_{74}$$
$$+ \frac{1}{2}\Sigma\ \Sigma\delta_{ij}Y_i Y_j + \frac{1}{2}\Sigma\ \Sigma\gamma_{ij}\ \ell n\ W_i\ \ell n\ W_j + \Sigma\ \Sigma\rho_{ij}Y_i\ \ell n\ W_j.$$

For (13) to be homogeneous of degree one in factor prices the following additional parameter restrictions must hold: $\Sigma\beta_{55i} = 0$, $\Sigma\beta_{74i} = 0$.

Given the large number of parameters in (13) to be estimated, it is desirable to make use of the following cost share equations implied by Shepherd's Lemma:

$$\text{(14)} \quad S_i = \beta_i + \beta_{55i} + \beta_{74i} + \sum_j \gamma_{ij}\ \ell n\ W_j + \sum_i \rho_{ij}Y_j$$

We treat (13) and (14) as a multivariate regression system and proceed to obtain efficient estimates of the unknown parameters using a modification of the technique proposed by Zellner (1962).[8] The estimated parameters for the generalized translog multiproduct cost function are presented in Table 3, along with their standard errors.[9]

The theory of cost and production requires that the estimated cost structure satisfy certain regularity conditions. These conditions are that the own-price elasticities of demand for each input be negative and that the Hessian matrix, $[\partial^2 C/\partial W_i \partial W_j]$, be negative semi-definite. A limitation of flexible functional forms is that these requirements cannot be satisfied globally.[10] We have computed the own price demand elasticities and the Hessian matrix of the cost function at each point in our sample, and we find that the estimated cost structure satisfies the regularity conditions at most of the sample points. However, the range of input prices and output levels in the sample is so large that the regularity conditions cannot be satisfied for all firms. The estimated cost function is well-behaved in the neighborhood of the average firm. It is this behavior which we use to represent the structure of cost for the industry.

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[8] Zellner's technique cannot be applied to (13) and (14) because the contemporaneous covariance matrix is singular. Our modification is to delete one of the share equations prior to carrying out the second stage of Zellner's technique. It can be shown that the resulting estimates are asymptotically equivalent to maximum likelihood estimates, as well as being invariant to which equation is deleted at the second stage. The procedure could be iterated to actually obtain maximum likelihood estimates, but the large increase in computer expenses cannot be justified by any improvement in the properties of the estimates.

[9] The y_i and W_i were normalized such that the mean of the 1963 values is equal to unity.

[10] See Caves and Christensen (1978) for discussion of the global properties of flexible functional forms.

Table 3

ESTIMATED COEFFICIENTS FOR THE GENERALIZED TRANSLOG MULTIPRODUCT COST FUNCTION

Coefficient	Estimate	Standard Error	Coefficient	Estimate	Standard Error	Coefficient	Estimate	Standard Error
α	19.1333	.0401	δ_{HP}	.0268	.0427	ρ_{RL}	-.0066	.0025
α_{55}	.0892	.0446	δ_{HR}	-.0163	.0343	ρ_{RE}	.0013	.0005
α_{74}	-.0575	.0874	δ_{PR}	.0018	.0134	ρ_{RQ}	.0055	.0025
α_T	.7798	.0515	β_L	.3926	.0080	β_{L55}	.0998	.0101
α_H	-.0575	.0870	β_E	.0291	.0016	β_{L74}	-.1276	.0203
α_P	.1627	.0323	β_Q	.5784	.0082	β_{E55}	.0148	.0023
α_R	-.0439	.0250	γ_{LL}	.2044	.0279	β_{E74}	.0131	.0042
α_{T55}	-.0468	.0575	γ_{EE}	-.0061	.0040	β_{Q55}	-.1146	.0102
α_{T74}	.0246	.0798	γ_{QQ}	.2474	.0280	β_{Q74}	.1144	.0208
α_{H55}	-.0032	.1052	γ_{LE}	.0246	.0056			
α_{H74}	.0188	.1245	γ_{LQ}	-.2290	.0275			
α_{P55}	.0457	.0287	γ_{QE}	-.0185	.0051			
α_{P74}	-.0558	.0341	ρ_{TL}	.0152	.0065			
α_{R55}	-.0253	.0207	ρ_{TE}	.0027	.0013			
α_{R74}	.0438	.0264	ρ_{TQ}	-.0179	.0066			
δ_{TT}	-.0613	.0591	ρ_{HL}	-.0401	.0118			
δ_{HH}	.0124	.1967	ρ_{HE}	.0059	.0024			
δ_{PP}	.0165	.0159	ρ_{HQ}	.0342	.0120			
δ_{RR}	-.0048	.0275	ρ_{PL}	.0056	.0031			
δ_{TH}	.0064	.0958	ρ_{PE}	-.0013	.0006			
δ_{TP}	-.0027	.0244	ρ_{PQ}	-.0043	.0032			
δ_{TR}	-.0078	.0168						

Subscripts:

T - ton-miles
H - length of haul
P - passenger-miles
R - length of trip
L - labor
E - fuel
Q - capital and materials
55 - year 1955
74 - year 1974

We now proceed to derive the elasticities of cost with respect to the output price indexes from the estimated cost functions. Since $\partial\, \ell n\, C/\partial\, \ell n\, y_i =$ $\frac{\partial\, \ell n\, C}{\partial\, \ell n\, Y_i}\, \frac{\partial Y_i}{\partial y_i}\, Y_i = \frac{\partial\, \ell n\, C}{\partial Y_i}\, y_i$, we can write the cost elasticities as:

$$(15) \qquad \frac{\partial\, \ell n\, C}{\partial\, \ell n\, y_i} = y_i(\alpha_i + \alpha_{55i}D_{55} + \alpha_{74i}D_{74} + \sum_i \delta_{ij}Y_j + \sum_i \rho_{ij}\, \ell n\, W_j).$$

These elasticities can be evaluated for each railroad in each of the three cross section years. We obtain the industry averages as cost-weighted averages over the individual railroads:

$$(16) \qquad \sum_j \left[\frac{\partial\, \ell n\, C}{\partial\, \ell n\, y_i}\right]_j \frac{C_j}{\Sigma C_j} \;,$$

where the subscript j indicates the individual railroads. Finally, these industry average elasticities for 1955, 1963, and 1974 are interpolated and extrapolated to the remaining sample years.[11] The annual estimates of the cost elasticities are presented in Table 4.

Meyer and Morton (1975) conjectured that the ratio of passenger to freight marginal cost was within the range of "five to nine." We can assess the validity of their conjecture by computing the ratios of marginal costs which are implicit in our estimated cost elasticities. We take the annual ratios of the passenger and ton-mile cost elasticities in Table 4; multiplying these ratios by the annual ratios of industry ton-miles to industry passenger-miles yields the annual marginal cost ratios. We present these ratios in Table 4. These figures indicate that the Meyer-Morton conjecture

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[11]The elasticity for each year is taken to be the point on the quadratic function determined by the 1955, 1963, and 1974 elasticities.

Table 4

AVERAGE COST ELASTICITIES OF RAIL OUTPUT INDEXES,
IMPLIED RATIO OF MARGINAL COSTS,
AND FREIGHT REVENUE SHARE

Year	Elasticities of Total Cost With Respect to:				Ratio of Passenger Mile to Ton-Mile Marginal Costs	Freight Revenue as a Share of Total Operating Revenues
	Ton-Miles	Average Length of Freight Haul	Passenger Miles	Average Length of Passenger Trip		
1951	.704	-.012	.294	-.082	7.8	.906
1952	.712	-.015	.284	-.080	7.2	.907
1953	.719	-.018	.274	-.077	7.3	.914
1954	.726	-.021	.264	-.075	6.8	.910
1955	.734	-.023	.255	-.072	7.6	.920
1956	.741	-.026	.245	-.070	7.6	.922
1957	.748	-.028	.236	-.067	7.5	.924
1958	.754	-.030	.228	-.065	7.2	.923
1959	.761	-.032	.219	-.062	7.5	.927
1960	.768	-.033	.210	-.059	7.4	.926
1961	.774	-.034	.202	-.057	7.3	.925
1962	.780	-.035	.194	-.054	7.4	.928
1963	.787	-.036	.186	-.051	8.0	.933
1964	.793	-.037	.179	-.048	8.1	.936
1965	.799	-.038	.171	-.045	8.6	.941
1966	.804	-.038	.164	-.042	8.8	.945
1967	.810	-.038	.157	-.039	9.2	.950
1968	.816	-.038	.150	-.035	10.5	.956
1969	.821	-.038	.144	-.032	11.0	.959
1970	.826	-.037	.137	-.029	11.8	.963
1971	.831	-.036	.131	-.025	13.9	.969
1972	.836	-.035	.125	-.022	13.6	.969
1973	.841	-.034	.119	-.019	13.0	.969
1974	.846	-.033	.114	-.015	11.0	.967

was valid through 1966, but that the ratio of passenger to freight marginal cost has exceeded nine since 1967.

5. Productivity Estimates

The estimation of productivity growth requires computation of the log-differences of the five input and four output indexes. When multiplied by one hundred, these differences can be interpreted as percentage growth rates. In Table 5 we present yearly log-differences times one hundred for each input and output. Using the figures in Tables 2, 4, and 5 to compute (9) yields annual estimates of the rate of productivity change in the U.S. railroad industry. With 1967 as the basis for comparison, these annual rates of change can be used to construct an index of productivity. The index of railroad productivity and its annual rate of change are presented in Table 6. Table 7 contains average annual growth rates, average cost shares and output elasticities, and the average annual growth of productivity.

In productivity analysis it is common practice to specify a structure of production in which inputs and outputs are separable and technical change is Hicks neutral. Under this specification there exist consistent aggregate indexes of total input and total output; thus, the first and second lines of the right hand side of (9) can be interpreted respectively as aggregate output and aggregate input.[12] The implied indexes and their rates of growth are presented in Table 8. The average annual rates of growth of input and output are -1.7% and +0.0% respectively.

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[12]Note that this interpretation of (9) does not result in a different estimate of productivity growth. See Berndt and Christensen (1973) for a discussion of consistent aggregate indexes.

Table 5

ANNUAL PERCENTAGE GROWTH RATES OF INPUT AND OUTPUT INDEXES

	Input Indexes					Output Indexes			
Year	Labor	Way and Structures	Equipment	Fuel	Materials	Freight Ton-miles	Average Length of Freight Haul	Passenger Miles	Average Length of Passenger Trip
1952	-5.4	1.8	6.6	-25.9	-5.7	-5.1	1.0	-1.8	1.2
1953	-3.1	-3.0	10.7	-21.3	.2	-1.5	-1.0	-7.2	-4.4
1954	-12.5	.5	5.2	-34.0	-12.2	-9.8	3.0	-7.8	-3.8
1955	1.8	.4	2.5	-1.1	6.5	12.7	.1	-2.6	-.9
1956	-1.3	-.3	1.5	-9.9	3.2	3.7	.0	-1.2	-.5
1957	-6.5	-.4	2.0	-16.9	-1.7	-4.6	1.3	-8.5	-4.4
1958	-14.4	-.2	3.9	-21.4	-10.5	-11.4	3.7	-10.8	-2.6
1959	-2.3	-.7	.5	-1.2	4.2	4.2	.2	-5.3	2.0
1960	-4.5	-1.2	.4	-1.5	-1.0	-.6	-.4	-3.6	4.2
1961	-7.7	-1.3	-3.1	-2.6	-1.9	-1.6	2.4	-4.7	-1.8
1962	-1.4	-.9	-.8	2.5	-2.4	5.1	1.5	-1.9	-.4
1963	-2.5	-1.0	.8	1.9	4.0	4.8	1.0	-7.3	-6.7
1964	-1.0	-1.1	1.2	2.1	9.2	5.8	-.1	-1.4	-2.5
1965	-4.8	-.3	6.3	2.7	-1.7	5.8	4.2	-4.8	-.2
1966	-1.9	-1.0	5.5	4.3	3.8	5.6	1.7	-1.7	-2.2
1967	-5.6	-.2	6.0	-1.5	-2.9	-2.6	.3	-11.7	-10.6
1968	-2.0	-.3	4.0	.6	.7	3.4	2.5	-14.7	-14.3
1969	-2.0	-.3	1.3	-.3	7.1	3.2	.7	-7.5	-7.6
1970	-.2	-.0	4.3	-3.8	3.6	-.4	1.1	-12.2	-8.1
1971	-8.1	-.6	3.3	.4	3.6	-3.3	2.9	-24.8	-20.8
1972	-7.0	-.1	4.3	6.4	-6.9	4.9	1.5	1.9	6.3
1973	2.9	-1.0	4.9	1.7	8.9	9.2	3.2	8.3	10.8
1974	-.9	-.2	-2.7	1.4	5.5	-.5	-1.0	10.6	3.1

Table 6

ESTIMATES OF RAILROAD PRODUCTIVITY

Year	Railroad Productivity		Alternative Indexes of Railroad Productivity					
	Rate of Change %	Index	Constant Returns to Scale (CRTS)	CRTS and Zero Length of Haul and Trip Elasticities	CRTS and Revenue Share Output Weights	National Income Input Weights	CRTS, Revenue Share Weights and National Income Weights	Weights Based on 1951 Cost Shares and Rate of Output Transformation
1951		.734	.740	.743	.652	.613	.545	.684
1952	.2	.736	.738	.745	.650	.620	.548	.684
1953	-.7	.731	.731	.737	.650	.620	.552	.679
1954	.5	.734	.727	.738	.649	.639	.565	.681
1955	6.4	.783	.783	.787	.711	.680	.618	.732
1956	3.0	.807	.809	.812	.739	.703	.645	.758
1957	-.9	.800	.797	.802	.735	.706	.649	.751
1958	-1.8	.785	.772	.785	.719	.718	.658	.737
1959	2.5	.805	.794	.807	.750	.740	.689	.757
1960	1.1	.814	.801	.817	.763	.755	.708	.765
1961	2.4	.834	.818	.837	.785	.785	.738	.786
1962	4.8	.875	.862	.879	.831	.825	.783	.829
1963	3.2	.904	.894	.905	.870	.855	.823	.862
1964	3.6	.937	.932	.938	.909	.885	.859	.899
1965	4.8	.983	.982	.987	.969	.949	.935	.959
1966	3.7	1.020	1.024	1.025	1.015	.993	.988	1.006
1967	-2.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1968	.8	1.008	1.009	1.004	1.025	1.021	1.037	1.025
1969	1.3	1.022	1.025	1.016	1.049	1.039	1.067	1.051
1970	-3.0	.991	.992	.983	1.028	1.015	1.052	1.030
1971	-3.4	.958	.953	.943	1.009	1.009	1.063	1.019
1972	7.2	1.030	1.029	1.017	1.092	1.118	1.185	1.111
1973	4.8	1.080	1.088	1.074	1.154	1.168	1.248	1.177
1974	.8	1.088	1.098	1.083	1.152	1.172	1.240	1.180

Table 7

AVERAGE ANNUAL RATES OF GROWTH OF INDEXES OF INPUTS, OUTPUTS, AND PRODUCTIVITY; AVERAGE COST SHARES AND OUTPUT COST ELASTICITIES (1951-74)

Labor	Way and Structures	Equipment	Fuel	Materials	Ton-Miles	Average Haul	Passenger Miles	Average Trip	Productivity
				Average Annual % Rate of Growth					
-3.9	-0.5	2.8	-5.1	0.6	1.2	1.3	-5.3	-2.8	1.7
Average Cost Shares					Ave. Output Cost Elasticities				
.468	.184	.164	.041	.144	.780	-.031	.195	-.051	

6. Comparisons

We proceed to compare our estimates of productivity growth with those obtained using conventional measurement techniques. The alternatives explored are (a) specification of constant returns to scale (CRTS), (b) CRTS and zero length of haul and trip elasticities, (c) CRTS and revenue shares as output weights, (d) use of national income input weights for shares of labor and capital, and (e) the use of index number procedures which place unwarranted a priori restrictions on the structure of production.

The cost elasticities in Table 5 sum to less than unity in every year. This reflects scale economies in the structure of production of railroad services. Using unity minus the sum of the cost elasticities to indicate the degree of scale economies yields .096, .114, and .088 respectively for

Table 8

INDEXES OF AGGREGATE INPUT AND OUTPUT UNDER ASSUMPTIONS OF INPUT-OUTPUT SEPARABILITY AND HICKS NEUTRAL TECHNICAL CHANGE

Year	Aggregate Input		Aggregate Output	
	Index	% Annual Growth Rate	Index	% Annual Growth Rate
1951	1.470		1.079	
1952	1.406	-4.4	1.035	-4.2
1953	1.379	-1.9	1.008	-2.7
1954	1.255	-9.4	.921	-9.0
1955	1.284	2.3	1.005	8.7
1956	1.276	-.6	1.030	2.5
1957	1.223	-4.3	.978	-5.2
1958	1.116	-9.2	.876	-11.0
1959	1.109	-.6	.893	1.9
1960	1.081	-2.6	.880	-1.5
1961	1.032	-4.6	.861	-2.2
1962	1.020	-1.2	.892	3.6
1963	1.014	-.6	.916	2.6
1964	1.022	.8	.958	4.4
1965	1.010	-1.2	.993	3.6
1966	1.016	.6	1.036	4.3
1967	1.000	-1.6	1.000	-3.6
1968	1.001	.1	1.009	.9
1969	1.004	.4	1.026	1.7
1970	1.016	1.2	1.008	-1.8
1971	.994	-2.2	.952	-5.6
1972	.964	-3.1	.992	4.1
1973	1.000	3.6	1.079	8.4
1974	1.000	.0	1.088	.8

1955, 1963, and 1974.[13] Constant returns to scale can be imposed on our methodology by restricting the output weights to sum to unity. We accomplish this by dividing the elasticities in Table 5 by their sum. The resulting productivity index is presented in Table 6. It is very similar to our preferred index. The revised index increases at an average annual rate which is slightly higher than that of the preferred index. However, to one decimal place the growth rate is the same as that of the preferred index, 1.7%. Thus our results are not sensitive to the imposition of constant returns to scale.[14]

Most rail productivity studies do not attempt to adjust for scale economies or distinguish ton-miles and passenger-miles by length of haul. The effect of this specification can be seen by recomputing productivity

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[13] Christensen and Greene (1976) proposed unity minus the cost elasticity as the measure of scale economies in the single output case. Brown, Caves, and Christensen (1976) generalized this measure to the multiple output case. Panzar and Willig (1977) have proposed a very similar measure -- unity divided by the sum of the cost elasticities. Both the Panzar and Willig measure and that of Brown, Caves and Christensen are based upon the discrepancy between costs and revenues arising from marginal cost pricing.

[14] Our use of the sum of all four cost elasticities as a measure of scale economies implies that cost increases are proportional to increases in ton-miles and passenger-miles which stem entirely from increases in average length of haul and average length of trip. This concept of scale economies is particularly relevant, since the output growth pattern of the industry has been dominated by changes in length of haul and length of trip. (See Table 1). As an alternative, however, we could consider a measure of scale economies which implies that cost increases are proportional to increase in ton-miles and passenger-miles holding length of haul and length of trip fixed. Imposing constant returns to scale in this case would require that only the ton-mile and passenger-mile elasticities be normalized to sum to one. Imposing constant returns to scale in this fashion has less of an impact since the sum of the ton-mile and passenger mile elasticities is closer to one than is the sum of all four elasticities.

growth with the following restrictions: (1) Set the cost elasticities which are specific to length of haul and length of trip equal to zero. (2) Normalize the ton-miles and passenger miles elasticities to sum to unity. The resulting productivity index is presented in Table 6. Its average annual rate of growth is 1.6%. Thus our results would be little changed by not considering length of haul.

Following Bureau of Labor Statistics practice, Kendrick (1973, p. 187) weighted freight ton-miles and passenger-miles by ". . . their proportionate shares in total operating revenues . . ." We present the share of freight revenues in total operating revenue in Table 5, for comparison with the freight and passenger output elasticities. The freight revenue share is substantially greater than the sum of the freight cost elasticities for all years in the sample. Conversely, the passenger revenue share is substantially smaller than the sum of the passenger cost elasticities for all years. We use Kendrick's procedure on our data set by setting the length of haul and trip cost elasticities to zero and substituting the passenger and freight revenue shares for the passenger-mile and ton-mile cost elasticities. The resulting index is shown in Table 6. This adjustment increases the average annual rate of productivity change from 1.7% to 2.5%.[15]

Kendrick's (1973) productivity estimates used labor and capital shares in "national income originating in the railroad industry" as weights for

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[15] Because the average haul and average trip elasticities are so close to zero, the increase in measured productivity from 1.7 to 2.5 percent per year arises almost entirely from the use of revenue share output weights -- not from the setting of the average haul and average trip elasticities to zero.

labor and capital inputs. These weights provide poor estimates of the relative cost shares of labor and capital. National income attributable to capital includes only profits and net interest paid. It markedly understates the full cost to railroad firms of utilizing capital in the production of rail services. Depreciation charges and property taxes are omitted. In addition the opportunity cost of capital is understated due to low railroad profitability. The share of labor compensation in national income originating in the rail industry is presented in the first column of Table 2. We have recomputed rail productivity with the labor and capital portions of national income substituted for labor and capital costs.[16] This adjustment results in an increase in the average annual rate of growth of productivity from 1.7% to 2.8%. The revised productivity index is presented in Table 6.

Next, we demonstrate the impact on the productivity index of using both conventional output weights and conventional input weights. The resulting index increases at an average annual rate of 3.6%, as opposed to 1.7% for the preferred index. It is clear that substituting conventional weights substantially changes our perception of productivity in the railroad industry. The impact of using such weights is even more dramatic for recent years than for the full sample period. During the peak-to-peak growth cycle of 1966-1973 our preferred productivity index grows at the average annual rate of 0.8%, while the "conventional" index grows at the average annual rate of 3.3%.

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[16]We allocated the capital portion of national income between equipment and structures such that their relative shares were the same as the relative cost shares.

Finally, we assess the sensitivity of our estimates to the use of the indexing procedures followed by Meyer and Morton (MM). They used two different indexing procedures for inputs and outputs, which we discuss in turn. The MM input index is a weighted average of the rates of growth of the inputs, the weights being fixed cost shares. The difference from our procedure is only in the fixity of the weights, but this is an important difference. Fixed cost shares rule out non-unitary elasticities of substitution and non-neutral technical change. The dramatic shifts in cost shares during the postwar period (Table 2 above) reveal that this assumption is not tenable. The choice of period in which to fix the weights is arbitrary, but the most common practice is to use the initial period weights. Use of the 1951 cost shares from Table 2 results in an index of aggregate input which grows at the average annual rate of -2.1%. The comparable rate of growth for the input index from Table 8 is -1.7%.

The MM output index is based on the assumption that passenger and freight outputs are perfect substitutes in production, with a rate of transformation of one passenger-mile per five freight ton-miles. Our estimates of the relative marginal cost of freight and passenger output are at odds with the assumption of perfect substitution. The rate of transformation implied by our estimates varies with the relative output levels from a low of 6.8 ton-miles per passenger mile in 1954 to a high of 13.9 in 1971. Fixing the rates of transformation among all four output indexes at their 1951 estimates results in an index of aggregate output which grows at the rate of 0.2% per year. The comparable rate of growth for the output index from Table 8 is +0.0%.

The use of the 1951 cost shares and the 1951 rate of output transformation for all years result in errors which are cumulative rather than offsetting. The productivity index derived from this approach is presented in Table 6. It grows at an average rate of 2.4% per year, substantially above the estimate of 1.7% per year derived from an unrestricted structure of production.

6. Concluding Remarks

We have developed estimates of U.S. railroad productivity using methods based on the neoclassical theory of production. This theory implies that elasticities of total cost with respect to outputs and factor prices are the appropriate weights for combining rates of growth of outputs and inputs, respectively, to obtain an estimate of productivity growth. Our estimates indicate that railroad productivity, grew at the average rate of 1.7% per year during the 1951-1974 period. This rate is substantially lower than most previous estimates of growth in rail productivity. For comparison we have also obtained estimates of productivity growth using conventional input and output weights. The resulting productivity index grows considerably faster, 3.6% per year.

Approximately half of the discrepancy between the growth rates of the productivity indexes is attributable to the difference in output weights. The conventional procedure is to use shares in total revenue. The revenue share from passenger service greatly understates its cost elasticity. Similarly the revenue share from freight service greatly overstates its cost elasticity.

The remainder of the discrepancy between the growth rate of the productivity indexes is attributable to differences in input weights. The conventional procedure is to use labor and capital shares in national income to represent their relative weights in the productivity index. These shares substantially understate the importance of capital and overstate the importance of labor in the production of railroad services.

Use of appropriate input and output weights is important, but it is also important to use annual estimates for the weights rather than fixing them in the base period. Meyer and Morton's approach of fixing the cost shares and the rate of output transformation in a base period can lead to substantial errors in productivity estimates. Using the 1951 rate of transformation between passenger and freight output and the 1951 cost shares has the effect of increasing estimated annual rail productivity growth from 1.7% to 2.4%.

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DATA APPENDIX

This appendix provides a detailed description of the primary data sources and methods used to develop our estimates of U.S. railroad inputs, outputs, and productivity. Most of our data were taken from Transport Statistics of the U.S., an annual compilation of data submitted to the Interstate Commerce Commission (ICC) by the railroads.[1] The format of Transport Statistics has changed over time; unless otherwise noted, specific table numbers refer to the 1970 edition.

I. Inputs

A. Labor

There are extensive data on employment and earnings for the railroad industry. The basic source is Wage Statistics of Class I Railroads in the United States, published by the ICC. It provides data on hours worked and compensation for the following seven labor classifications:

(1) Executives, officials and staff

(2) Professional, clerical, and general

(3) Maintenance of way and structures

(4) Maintenance of equipment and stores

(5) Transportation -- control functions

(6) Transportation -- yard and terminals

(7) Transportation -- train and engine.

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[1] Interstate Commerce Commission, Bureau of Accounts. Prior to 1953 Transport Statistics was published as Statistics of Railways of the U.S.

Some of the labor reported in the above categories is not viewed by the railways as a current expense, but is capitalized. The component of labor compensation which is viewed as a current expense is referred to as "employee compensation chargeable to operating expenses," and is reported in the railroad expense accounts (Transport Statistics, Table 161, line 456A). We use the ratio of operating labor compensation to total labor compensation to adjust the hours worked and compensation of each labor category. In addition to the labor capitalized by the railroads, there is labor in category (3) which should be capitalized because it represents investment in way and structures. An estimate of the additional amount of compensation which should be capitalized is given by the account "track laying and surfacing." We remove this amount from the compensation of labor in category (3) and reduce the hours worked in category (3) by the same proportion.

The compensation figures reported by the ICC do not include the full cost of labor to the railroads. Therefore, we add the following costs which are directly attributable to the employment of labor services: employees' health and welfare benefits, payments to the Railroad Retirement Plan, and unemployment insurance taxes. Data on these items are available in Transport Statistics, Tables 159 and 161. We allocate these costs to the seven employee classifications in proportion to wages and salaries.

Having adjusted the seven categories of hours worked and compensation, we proceed to compute an index of real labor input. In Wage Statistics hours and compensation are given separately for straight-time and over-time work. This permits us to consider fourteen types of labor input. We combine the fourteen types using the weighted log-change index number procedure.[2] We compute the index of the price of labor services as the ratio of total compensation to the index of real labor input. This index is shown in Table A1.

B. Fuel

Table 72 of Transport Statistics contains data on fuel used in the provision of motive power. Eight types of fuel are included. They are listed below along with the factors which we used to convert usage to British Thermal Units (BTU's):

	BTU's
1 ton anthracite coal	25,400,000
1 ton bituminous coal	26,200,000
1 cord hard wood	24,025,400
1 cord soft wood	20,522,460
1 gallon fuel oil	149,690
1 gallon diesel oil	138,000
1 gallon gasoline	125,000
1 kwh electricity	3,413

We add BTU's from all types of fuel to obtain an index of fuel consumed.

Our fuel index includes line haul, switching, and work train operations. A portion of work train operations is devoted to track laying and surfacing. In principle the fuel used for these operations should be

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[2] $\ell n\ (X_1/X_0) = \sum_{i=1}^{n} \bar{W}_i\ \ell n\ (X_{i1}/X_{i0})$, where $\bar{W}_i = (W_{i1} + W_{i0})/2$, and $W_{ij} = P_{ij}X_{ij}/\sum_{k=1}^{n} P_{kj}X_{kj}$.

Table A1

INPUT PRICE INDEXES FOR LABOR, FUEL AND MATERIALS

Year	Labor	Fuel	Materials
1951	.467	.430	.710
1952	.497	.491	.734
1953	.511	.569	.756
1954	.536	.692	.774
1955	.541	.717	.791
1956	.589	.814	.846
1957	.634	.941	.892
1958	.686	.967	.907
1959	.716	1.010	.926
1960	.740	.970	.941
1961	.760	.996	.942
1962	.799	.983	.936
1963	.807	.984	.934
1964	.833	.940	.942
1965	.892	.955	.949
1966	.931	.962	.965
1967	1.000	1.000	1.000
1968	1.059	1.036	1.026
1969	1.130	1.075	1.055
1970	1.210	1.130	1.094
1971	1.354	1.177	1.135
1972	1.521	1.129	1.187
1973	1.710	1.443	1.229
1974	1.864	2.763	1.421

capitalized along with the labor compensation discussed above. However, total work train fuel is less than one-half of one percent of total fuel for all years since 1961. Since no data are available on fuel used in track laying and surfacing, we have not attempted to make this minor adjustment in fuel.

Expenditures on fuel are reported in Transport Statistics, Table 161. The figures reported include fuel used in line haul and switching operations but exclude work train operations. To obtain total fuel expenditures we multiply the reported figures by the ratio of total BTU's to BTU's net of work train operations. The price index of fuel, given in Table A1, is obtained as the ratio of fuel expenditures to total BTU's consumed.

C. Capital

The ICC estimated stocks of equipment and way and structures for Class I railroads for the period 1914-63. The estimates are available in unpublished ICC working documents known as Elements of Value of Class I Line Haul Railways.[3] The ICC's asset accounting approach was the perpetual inventory method. However, the ICC periodically adjusted their estimates based upon field inspections of the actual physical stocks of the railroads. For most railroads the last of these inspections was conducted in the late 1940s.

We have used the Elements of Value for January 1, 1951 as an initial observation to construct our own perpetual inventory estimates of railroad

[3] A description of the ICC estimates is contained in Conference on Income and Wealth (1964).

capital stocks for the full 1951-1975 period.[4] Our methodology can be represented by the formula

$$\text{(A1)} \qquad K_{it} = I_{it} + (1-\delta_i)K_{i,t-1} ,$$

where K_{it} is the end of year real capital stock, I_{it} is the quantity of real investment occurring during the year, and δ_i is the rate of replacement, all for the i^{th} type of capital good. We estimate separate stocks of (1) equipment and (2) way and structures (hereafter referred to as structures).

Investment expenditures, as defined by the ICC, are published in Table 138 of Transport Statistics. Minor amounts of investment are not directly identified as equipment or structures. We have allocated these expenditures proportionately to equipment and structure investment. We augment the total of structures investment by the addition of the following items from the maintenance expense accounts: (1) ties, (2) rails, (3) other track material, (4) ballast, and (5) labor engaged in track laying and surfacing.

The Bureau of Economic Analysis (BEA), U.S. Department of Commerce, estimates price indexes for investment in rail equipment and structures. The equipment price index is published in the July issue of the Survey of Current Business. The structures index is unpublished. It was provided to us by the BEA staff. Table A2 contains the BEA investment price indexes

[4] We have not used any of the Elements of Value estimates after 1951 because they were not validated by field inspections and because the ICC's definition of investment used in constructing the Elements of Value excludes large amounts of investment which were expensed under ICC accounting conventions.

Table A2

PRICE AND QUANTITY INDEXES OF INVESTMENT EXPENDITURES

Year	Price Indexes		Quantity Index (billions of 1967 dollars)		
	Way and Structures	Equipment	Way and Structures	ICC Way and Structures	Equipment
1951	.734	.784	1.30	.41	1.34
1952	.763	.788	1.36	.48	1.20
1953	.793	.826	1.36	.46	1.05
1954	.793	.819	1.15	.42	.65
1955	.814	.831	1.10	.38	.71
1956	.875	.913	1.11	.45	.90
1957	.913	.969	1.05	.41	1.06
1958	.935	.998	.76	.28	.50
1959	.958	1.021	.71	.23	.57
1960	.960	1.016	.71	.27	.62
1961	.954	1.012	.61	.22	.44
1962	.955	1.012	.62	.22	.60
1963	.952	1.005	.61	.19	.75
1964	.958	.998	.70	.25	1.11
1965	.969	1.000	.71	.26	1.31
1966	.982	1.000	.80	.32	1.59
1967	1.000	1.000	.78	.32	1.19
1968	1.050	1.029	.86	.34	.80
1969	1.115	1.083	.87	.35	1.02
1970	1.211	1.149	.80	.28	.91
1971	1.312	1.206	.87	.29	.79
1972	1.397	1.275	.81	.24	.69
1973	1.485	1.348	.82	.25	.72
1974	1.801	1.475	.80	.24	.81

and estimates of real investment for Class I railroads. For structures investment we show the ICC estimates in addition to our revised estimates.

The final items needed to construct railroad capital stocks are estimates of the rates of replacement, δ_1, for equipment and structures. We have used .03 for structures and .06 for equipment. Our estimate of .06 for equipment is taken from Swanson (1968), who derived it from the Elements of Value equipment series.[5] Swanson's procedure would underestimate the structures replacement rate, since a substantial amount of actual investment is excluded under ICC accounting conventions. We have obtained information which indicates that .03 is a good estimate for the replacement rate of structures.[6] The stocks resulting from application of the perpetual inventory formula (A1) are presented in the first two columns of Table A3.

Estimation of railroad productivity requires estimates of shares in total cost for all inputs. Thus it is necessary to compute the annual cost attributable to the use of railroad stocks of equipment and structures. We follow the approach of Christensen and Jorgenson (1969) to impute annual costs for owned capital stocks. We use their formula, given on p. 304, for the annual cost per unit of stock for equipment and structures:

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[5]For a sample of 38 railroads, Swanson computed the rate of replacement which would yield the 1963 equipment stock given the 1945 stock and intervening investments.

[6]Arthur Andersen & Co. has studied structures service lives for railroads which are replacing the old accounting system with standard depreciation accounting rules. Accountants from this firm confirmed that service lives for rails and track materials are consistent with our estimate.

Table A3

CAPITAL STOCKS AND CAPITAL SERVICE PRICES

Year	Railroad Owned Capital Stocks (billions of 1967 $)		Imputed Price of Capital Services Per Unit of Stock		Rented Capital Stocks (billions of 1967 $)	
	Structures	Equipment	Structures	Equipment	Structures	Equipment
1951	29.37	8.22	.036	.098	3.08	1.62
1952	29.79	9.06	.037	.100	3.25	1.45
1953	30.26	9.72	.038	.097	1.80	1.97
1954	30.71	10.18	.035	.098	1.50	2.14
1955	30.94	10.22	.035	.087	1.39	2.41
1956	31.11	10.32	.041	.084	1.13	2.50
1957	31.28	10.60	.051	.092	.81	2.49
1958	31.39	11.02	.055	.100	.65	2.59
1959	31.21	10.85	.055	.100	.61	2.82
1960	30.98	10.77	.064	.108	.47	2.97
1961	30.76	10.75	.080	.134	.29	2.57
1962	30.45	10.54	.082	.131	.32	2.67
1963	30.16	10.51	.083	.134	.30	2.81
1964	29.86	10.63	.087	.137	.28	2.85
1965	29.67	11.10	.086	.136	.37	3.26
1966	29.49	11.74	.091	.143	.24	3.43
1967	29.40	12.63	.096	.153	.28	3.49
1968	29.30	13.06	.098	.164	.28	3.72
1969	29.29	13.08	.101	.169	.20	3.93
1970	29.28	13.31	.106	.165	.20	4.45
1971	29.20	13.42	.089	.166	.10	4.93
1972	29.19	13.41	.072	.145	.07	5.75
1973	29.12	13.29	.073	.145	-.14	6.83
1974	29.07	13.22	.059	.161	-.15	6.37

$$P_i = \left[\frac{1 - uz_i - k + ykuz_i}{1 - u}\right]\left[q_{i,t-1}r + q_i\delta_i - (q_i - q_{i,t-1})\right] + q_iT$$

where i is either equipment or structures,

P_i is the annual cost per unit of stock,

q_i is the replacement cost per unit of stock,

u is the rate of corporate income taxation,

z_i is the present value of depreciation (per dollar of investment) which is deductible from corporate income for tax purposes,

r is the opportunity cost of capital,

δ_i is the rate of economic depreciation,

T is the rate of property taxation,

k is the rate of investment tax credit, and

y is a binary variable which is unity in 1962-3 and zero in all other years.

All values are for the current year except those subscripted with t-1, which are lagged one period. Following is a brief summary of our treatment of each of these variables:

q_i - The BEA investment price indexes.

u - The statutory rate of federal corporate income taxation.

z_i - Formulas for z_i are given in Christensen and Jorgenson (1969). Prior to 1954 straight line depreciation was required. Beginning in 1954 railroads could choose among several accelerated depreciation formulas. We have used the double declining balance formula (with switchover to straight line at the optimal point) to represent depreciation practices from 1954 to 1975. We have used Moody's composite average of yields on railroad bonds to discount future depreciation allowances.

For the 1951-1961 period service lives used in depreciation accounting were established by agreements between the IRS and individual firms. Over this period the average service life for capital equipment was 28 years: the average for structures was 60 years.[6] In 1962 tax lifetimes were reduced to 14 years for equipment and 30 years to structures, and in 1971 a further reduction resulted in lifetimes of 11 and 24 years. Two corrections to the general computation of the z_i were required: (1) Expensed investment was assigned a z_i of unity. (2) Defense related investment in the early 1950s qualified for five year straight line depreciation. The z_i for these special cases were averaged in with those arising from the standard depreciation practices.

r - Moody's composite average of yields on railroad bonds.

δ_i - The perpetual inventory formulas for equipment and structures are based on geometric decline in efficiency. For this case the rate of depreciation is equal to the rate of replacement. Thus we have used .03 for structures and .06 for equipment.

T - We have estimated the effective property tax rate as the ratio of non-federal taxes to the value of the stocks of equipment and structures.

k - Most of railroad capital expenditures, including expenditures for those items referred to as structures under ICC accounting

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[6]Reported in Transport Statistics, Table 96, 1951-1961.

conventions, are eligible for the investment tax credit. We therefore utilize the same tax credit rate in computing the service prices of equipment and structures. This rate is computed as the ratio of actual tax credits claimed (provided to us by the Association of American Railroads) to investment expenditures.

y - This variable reflects the fact that in 1962-3 tax credits had to be excluded from the depreciation base.

$q_i - q_{i,t-1}$ - Some of the year to year differences in the q_i are extremely volatile. They did not appear to provide a good measure of the railroads' perceived revaluation of their assets. We have substituted a five year trailing average of the rate of capital gains to better represent expected asset price changes.

Our estimates of the imputed prices of equipment and structures owned by Class I railroads are presented in the third and fourth columns of Table A3.

The capital stocks in Table A3 do not represent the full amount of capital used by railroads. In addition to the capital which they own, the railroads rent and lease substantial amounts of capital. Rental receipts and expenditures are presented in Table 159 of Transport Statistics. The net expenditures indicate payments for use of capital not owned by Class I railroads. By far the largest item is for freight car rentals, but other categories are substantial as well. Unfortunately no further information is available on price or quantity indexes of leased equipment and structures.

It is reasonable to presume that the cost of leasing equipment is similar to the imputed cost of owning equipment. Thus we use the price indexes of services from railroad owned capital to deflate net rental payments for capital. The resulting estimates of rented capital stock are presented in the fifth and sixth columns of Table A3. The total capital stock of equipment and structu_es can be computed by summing the railroad owned and rented capital stocks.

D. Materials

All rail inputs not classified as capital, labor or fuel are included under the broad heading of materials. Expenditures for materials are computed as the difference between Grand Total Operating Expenses (Transport Statistics, Table 161, line 452) and those items in the expense accounts which are included in our estimates of capital, labor, or fuel. In Indexes of Railroad Materials Prices and Wage Rates (Series QMPW), the Association of American Railroads publishes several price indexes. We use the index for "other materials and supplies" to deflate materials expenditures to 1967 dollars. This index is presented in Table A1.

II. Outputs

A. Freight Service

We use total freight revenue ton-miles, reported in Table 162 of Transport Statistics, as our quantity index of ton-miles. Dividing freight revenue ton-miles by freight revenue tons, taken from the same table, produces average length of haul.

B. Passenger Service

The Association of American Railroads annually reports total revenue passengers and total revenue passenger miles.[7] We divide revenue passenger miles by revenue passengers to produce average length of passenger trip.

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[7] Association of American Railroads, Statistics of Railroads of Class I, Washington, D.C.

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