Selected Productivity Comparisons in Surface Freight Transportation: Inland Water, Rail, and Truck, 1955-1979

SAMUEL EWER EASTMAN

Aggregate productivity measurements for surface freight transportation are made, limited to a single measure of output—net ton-miles of transportation produced—for measured inputs of labor, capital, and energy. The ton-mile output measure was selected because it is shown that inland barge carriers and railroads, the principal comparison made, carry cargoes that average out to nearly the same density, 60-65 lb/ft^3. In addition, equipment use by rail and barge is compared. Barges are shown to be more productive than railroads by all measures studied. The analysis shows that labor productivity for water, measured in ton-miles per employee year, is four to five times greater than for rail for selected periods beginning in 1955. An average annual aggregate labor productivity growth rate of about 10 percent is shown for both water and rail. In contrast, truck productivity shows little gain over the period. Inland water capital productivity, measured in ton-miles per dollar of investment, is two to three times that of rail. Comparisons of water and truck show that investments in water transportation have been four to seven times more productive in recent years. On a route-mile basis, barging ranges from more than twice as energy efficient to nearly four times as energy efficient as rail. When circuity is taken into account—for example, for shipments between Minneapolis and New Orleans—barges continue to outperform railroads in energy productivity, the extent depending on which of the many available rail routes is used. In comparisons of barge use and rail freight-car use, rail freight-car use is found to be substantially lower and to have declined in recent years.

The operation of a transportation organization can be viewed as a blending of various scarce resources into an efficient and effective combination to provide a service to the user public. The chief scarce resources used in this type of service are labor, capital, and energy. These particular classes of resources can also be viewed as major expense items that go into the provision of transportation services for the general population.

When one views the use of scarce resources, the concept of productivity becomes a useful focus because it provides a definition of efficiency for comparative purposes. Thus, one can compare the productivity of competing services; the most productive service--i.e., that which uses less resources to produce the same service--may be regarded as the more efficient.

Productivity is traditionally defined as the ratio of output to input. In order to properly capture the total perspective of a firm's operation, the total output of the firm should be related to the combination of the partial inputs--i.e., labor, capital, and energy. The traditional view of productivity, largely effected by the Bureau of Labor Statistics, is the ratio of output to labor hours (1). The more modern view attempts to relate the entire spectrum of scarce resources as they are marshaled to produce the required level of service (2-5). This type of total factor productivity analysis is difficult to do at the aggregate industry level in the transportation field due to lack of data. However, at the individual transportation organization level, the total factor productivity perspective shows great promise of providing an understanding of the use of the various scarce economic resources as they are combined to produce a service to the public. A recent study conducted in the environment of a single motor-carrier firm showed the feasibility of this type of analysis (6).

This paper addresses the relative trends in productivity of the waterway mode of transportation as it compares with the two main competitive modes, truck and rail. All three of the major dimensions--labor, capital, and energy--are considered. Capital productivity is considered both on an aggregate basis and in terms of equipment use.

It is important to exercise considerable care in the manner in which outputs and inputs are defined prior to the combination within the productivity relation. If dollars of revenue are used as an indicator of the output of a transportation organization, the impact of inflation will readily confuse and distort the analysis. To use the productivity concept properly, the output should be in quantities and the input should also be in a relevant quantity unit.

The output of a transportation organization is a service. This service contains several key dimensions:

1. Efficiency in the movement of freight,
2. Timely delivery to the destination, and
3. Quality of service in terms of frequency, reliability, lack of damage, and supply of information en route.

This analysis concentrates on the efficiency dimensions. The first basic question to be addressed is the nature of the physical unit that will be used to represent the output of the transportation service. Obviously, a transportation organization is in the business of moving freight from origin to destination in a timely manner with minimal damage. One could address as a unit of output several different quantity units:

1. Number of customers served,
2. Number of individual bills of lading transported,
3. Number of tons moved through the system,
4. Number of ton-miles transported through the system, and
5. Value of goods transported.

The unit chosen must be the one that has the most meaning and can be derived from normal information systems within the organizations and within the industries. The first two units of output listed above could be extremely misleading as one tried to perform trend analysis to ascertain whether an industry was becoming more or less productive. Tons of freight moved can also be misleading, especially if the average length of a shipment changes over time, which appears to be the case in the transportation industries. For example, in the period from 1950 to 1975, the average length of haul for a Class 1 motor common carrier increased from 235 to 286 miles. In the rail system, an increase from 416 to 518 miles was exhibited. For water transportation on rivers and canals, in 1955 the average length of a shipment was 256 miles and in 1975 it had increased to 358 miles (7).

The ton-mile appears to be the most relevant indicator of output for a transportation organization,

but even this concept can be misleading (8-14). If the average density of freight moves from the heavier level to a lighter level, the productivity of the freight movement could be affected solely because of the nature of the freight density. The space occupied on the transportation equipment and the labor necessary to move the freight might remain stationary while the ton-mile figure decreased. This would indeed show a decrease in productivity, which might not be substantial when one looked deeper. One other useful aspect of the ton-mile concept is that it indicates the ability of the transportation organization to properly use and schedule its fleet. If traffic can only be maintained in a one-way mode, a great deal of deadhead traveling back to origin will be needed, which would use all of the input resources while providing no ton-miles of service. Thus, the effectiveness with which the transportation network is managed will be partly captured with the ton-mile concept.

AGGREGATE PRODUCTIVITY COMPARISONS: LABOR AND CAPITAL

Labor and capital productivity estimates that use ton-miles as the measure of output are given in Tables 1 and 2 at the aggregate level for water, rail, and truck and at the individual organizational level for water and truck. These productivity estimates are given for several time periods beginning in 1955. Measured in thousands of ton-miles per employee year, water labor productivity shows a relatively stable relation 4-5 times more productive than rail over the time period. In contrast, water labor productivity triples in comparison with truck productivity over the period: Water is about 10 times more productive in 1955 and about 40 times more productive in the late 1970s. This is reflected in an average annual labor productivity growth rate of 10 percent for both water and rail over the years considered but a much smaller, even negative, average annual labor productivity growth rate for trucking.

As noted earlier, caution must be exercised in drawing hard and fast conclusions from these comparisons because of differences in cargo densities and the different services offered by the three modes. This is particularly true of water and truck comparisons, which include, for truck but not for water, labor-intensive pickup, delivery, and consolidation services that involve the handling of low-density freight. A productivity comparison of water and truck, limited to line-haul service, is given later in this paper.

Aggregate capital productivity for the three modes measured in ton-miles per dollar of property and equipment and per dollar of total assets is given in Table 2 for the years 1955-1979. Again, the water-rail comparison is relatively stable: Water capital productivity is about twice that of rail based on property and equipment investment (rail right-of-way is included only in estimates based on total assets). Comparisons of water and truck capital productivity show investments in trucking to be about half as productive in the late 1950s but decreasing so as to be one-quarter or less productive than comparable investments in water in the late 1970s.

All of these capital productivity estimates are based on current dollars, and this during a period of substantial inflation. Since the useful life of trucking equipment (4-8 years) is substantially less than that of equipment used to produce water and rail transportation (20-30 years), the substantial decrease over the period of truck ton-miles per dollar of investment, compared with more stable values of water and rail ton-miles per dollar of investment, is partly a reflection of the inflation of the period. Truck transportation, using equipment of shorter life, shows the effect of inflation sooner. As the value of the dollar decreases, ton-miles produced per dollar invested in equipment will decline without any true change in capital productivity. By

Table 1. Aggregate labor productivity for water, rail, and truck: 1955-1979.

Year	Thousands of Ton-Miles per Employee Year: Water[a]	Rail[b]	Truck[c]	Water/Rail (%)	Water/Truck (%)
1955	2010	524	222	26	11
1960	2817	654	147	23	5.2
1965	5040	965	173	19	3.4
1970	9097	1230	162	13	1.8
1975	8627	1411	144	16	1.7
1976	9557	1515	155	16	1.6
1977	9718	1632	184	17	1.9
1978	8280	1622	140	19	1.7
1979	7805	1658	180	21	2.3

Note: Average annual growth is 12 percent for water, 9 percent for rail, and -0.1 percent for truck.

[a]Calculations based on tons carried and average number of employees from Interstate Commerce Commission (ICC) Transport Statistics in the United States: Part 5–Carriers by Water, Class A Carriers, for respective years. Average length of haul used was for that of all inland water carriers from U.S. Army Corps of Engineers' Waterborne Commerce of the United States: Part 5–National Summaries, Table 3, page 96, for respective years.

[b]Calculations based on ton-miles and average number of employees for Class I line-haul railroads (7, pp. 8 and 23).

[c]Calculations based on tons carried and average number of employees from ICC Transport Statistics in the United States: Part 2–Motor Carriers, Class I Common Carriers of General Freight Engaged in Intercity Service, for respective years. Average length of haul used was that for all intercity motor carriers (7, p. 15).

Table 2. Aggregate capital productivity for water, rail, and truck: 1955-1979.

Year	Property and Equipment: Ton-Miles per Dollar[a]: Water	Rail	Truck	Water/Rail (%)	Water/Truck (%)	Total Assets: Ton-Miles per Dollar: Water	Rail	Truck	Water/Rail (%)	Water/Truck (%)
1955	83.0	55.1	48.6	66.4	58.5	86.3	21.2	48.4	24.5	56.1
1960	73.0	43.8	25.8	60.0	35.3	79.7	19.3	27.6	24.1	34.5
1965	80.5	48.8	23.3	60.6	28.9	81.6	23.0	23.1	28.2	28.3
1970	130.2	46.2	17.1	35.5	13.1	144.4	23.0	15.5	15.7	10.7
1975	91.1	41.8	21.1	45.9	23.2	87.5	20.1	10.3	23.0	11.8
1976	99.1	44.7	21.8	45.1	22.0	88.1	22.2	10.5	25.2	11.9
1977	85.9	43.5	21.7	50.7	25.3	76.2	21.7	10.4	28.5	13.6
1978	85.7	44.2	20.7	51.6	23.8	74.6	22.3	9.95	29.9	13.3
1979	86.4	44.0	17.6	50.9	20.4	65.9	22.0	8.78	33.4	13.3

Note: Sources of ton-mile data same as in Table 1.
All financial data taken from ICC Transport Statistics in the United States: Part 5–Carriers by Water, Part 1–Railroads, and Part 2–Motor Carriers, for respective years.

[a]Excluding reserves for depreciation.

the same token, the relatively stable showing of these values by water and rail over this period suggests that capital productivity has increased markedly in these industries.

DATA BASE AND CARGO DENSITY

Railroads have been regulated by ICC since the turn of the century; they are required to report data on traffic and finances. The series Transportation Statistics in the United States, published annually by ICC, provides one complete and continuing source of data on railroads. The foregoing analysis is based on these data. A recent study confirms the finding above that there has been a substantial growth in rail aggregate productivity (15,16).

Such a complete data base is not available for the trucking industry or for water carriers, including carriers on the inland waterways, which are the focus here. Only the regulated water carriers and trucking companies are required to report traffic and financial information to ICC--estimated to be less than 10 and 50 percent, respectively, of the industry totals (7 and Waterborne Commerce). An overall check of the data given in Tables 1 and 2, based on statistics from ICC, can be made by comparison with a hypothetical line-haul operation (common-carrier truck).

For the waterway mode, one can relate the ton-miles transported for a given one-way trip to the cost of that capital as it is deployed. For comparison purposes, it is assumed that a 30-barge tow, each barge carrying 1500 tons, is driven by a single tow boat. New capital costs of these resources are $300 000/barge and $3.5 million/tow boat. The estimated life of these resources is taken at 25 years. The capital charge should be made up of two components: a depreciation component, which allows for capital recovery, and a return component, which represents a fair return for this initial investment. For the purposes of this analysis, straight-line depreciation is used along with a 20 percent annual return requirement on the initial investment.

Thirty barges at $300 000 each = $9 000 000.
One tow boat at $3.5 million = $3.5 million.
Total new investment = $12 500 000.
Depreciation charge (25-year straight-line basis) = $500 000/year.
Return = $12 500 000 x 0.20 = $2 500 000.
Total yearly capital charge = $3 000 000/30-barge tow.

For a tow from St. Louis to New Orleans, a distance of 1039 miles, the time in transit would be approximately five days. The capital productivity, ton-miles per dollar of capital, would be 46 755 000 ton-miles/$42 857 = 1091 ton-miles/$ [$3 000 000 x (5/350) = $42 857].

In terms of labor productivity for this hypothetical trip, the ton-miles per labor hour would be

Five days x 8 crew members per shift = 960 man-hours.
46 755 000 ton-miles/960 = 48 703 ton-miles/man-hour.

For the common-carrier truck mode, for a similar trip from St. Louis to New Orleans, a distance of 673 miles, a 40-ft tractor-trailer combination would exhibit the following productivity characteristics. At a speed of approximately 45 miles/h, the trip could be completed in one full day. The weight limit of 44 000 lb for the trailer would produce a total ton-mile output of 14 806 ton-miles. The initial cost of a trailer is approximately $11 500, and the initial cost for a tractor is approximately $38 000, which gives a total vehicle capital cost of $49 500. If one uses a five-year depreciation schedule and a 20 percent return, the annual capital charge for the trailer and tractor would be $19 800. Since this trip could be completed within a 24-h period, the capital charge for this activity would be $56.57. In terms of capital productivity, 14 806 ton-miles/$56.57 = 262 ton-miles/$. Labor productivity would be 14 806 ton-miles/24 man-hours = 617 ton-miles/man-hour.

A comparison of the results for the two modes shows the following:

		Productivity	
Mode	Data	Capital (ton-miles/$)	Labor (ton-miles/ man-hour)
Waterway	Line-haul	1091	48 703
	ICC	86.4	4 460
Truck	Line-haul	262	617
	ICC	17.6	103

One would expect the line-haul productivity to be substantially higher than that reported for all operations to the ICC, and this comparison shows clearly that it is. For inland waterway, the line-haul man-hour productivity is about 10 times that of all operations (48 703 versus 4460 ton-miles). For trucking, it is about 6 times greater (617 versus 103 ton-miles). The financial comparisons give line-haul an even greater advantage, more than 12 times in the case of water (1091 versus 86.4 ton-miles) and about 15 times in the case of trucking (262 versus 17.6 ton-miles).

Finally, there is the effect of cargo density on productivity comparisons that use ton-miles. The carrier of lower-density cargoes by one mode will, in comparison, understate true productivity. The data given in Table 3 show that inland barge carriers and railroads carry cargoes that average out to nearly the same density--60-65 lb/ft^3.

ENERGY EFFICIENCY OF BARGES AND RAILROADS

A third aggregate dimension of productivity is energy. Energy efficiency, or energy intensiveness as it is often called, is measured for moving freight by ton-miles of transportation produced per gallon of fuel burned and by British thermal units (Btu) per ton-mile. The Btu measures the quantity of energy input in the productivity equation. For example, 1 gal of No.2 diesel fuel contains 138 700 Btu.

In comparing the energy intensity of barges and railroads, careful attention must be paid to making "like comparisons". In addition, water and rail transportation route circuity must be taken into account.

Comparison of the energy efficiency of a 30-barge tow of 45 000 tons, line-haul downriver on the Mississippi, with the average for all railroads hauling all cargoes favors barging. Similarly, comparison of a 110-car unit train of 11 000 tons, line-haul down the mountain to a port, with the average for all barge companies hauling all cargoes favors rail. Studies show the following comparisons of "best" and "average" cases for both barge and rail (15):

	Btu per Ton-Mile		Ton-Miles per Gallon	
Case	Barge	Rail	Barge	Rail
Best	103	396	1347	350
Average	270	686	514	202

By barge, 1 gal of diesel fuel will move 1 ton 1347 miles in the best case and 514 miles in the average case and, by rail, 1 gal will move 1 ton 350 miles

Table 3. Tons of cargo carried and cargo density for rail and inland waterway: 1978.

Commodity Group	Rail: Tons Carried[a] (000 000s)	Rail: Percentage of Total	Rail: Cargo Density[b] (lb/ft^3)	Rail: Density Weighting[c]	Inland Waterway: Tons Carried[d] (000 000s)	Inland Waterway: Percentage of Total	Inland Waterway: Cargo Density[b] (lb/ft^3)	Inland Waterway: Density Weighting[c]
Farm products	128.7	9.66	40	3.86	50.303	10.13	40	4.05
Fresh fish and other marine products	-[e]	-[e]	-[e]	-[e]	8.892	1.79	30	0.54
Metallic ores	112.5	8.45	100	8.45	6.717	1.35	100	1.35
Coal and lignite	383.1	28.76	70	20.13	114.608	23.07	70	16.15
Crude petroleum	-[e]	-[e]	-[e]	-[e]	47.426	9.55	50	4.77
Nonmetallic minerals	134.7	10.11	100	10.11	71.737	14.44	100	14.44
Food and kindred products	95.4	7.16	30	2.15	10.576	2.13	30	0.64
Lumber and wood products	95.1	7.14	20	1.43	4.878	0.98	20	0.20
Pulp, paper, and allied products	41.4	3.11	32	0.99	2.720	0.55	32	0.18
Chemicals and allied products	106.7	8.01	43	3.44	34.295	6.90	43	2.97
Petroleum and coal products	44.4	3.33	49	1.63	123.563	24.88	49	12.19
Stone, clay, glass, and concrete products	59.9	4.50	80	3.60	5.245	1.06	80	0.85
Primary metal products	60.1	4.51	155	6.99	7.869	1.58	155	2.45
Transportation equipment	32.2	2.42	6	0.15	-[e]	-[e]	-[e]	-[e]
Waste and scrap materials	37.8	2.84	100	2.84	10.853	2.18	100	2.18
Total	1332.0	100.00		65.77	496.682	100.00		62.96

[a] From Association of Railroads (17).
[b] From American Trucking Associations, Inc. (18).
[c] Column 2 x column 3.
[d] From U.S. Army Corps of Engineers, Waterborne Commerce of the United States: Part 5–National Summaries, Table 10, page 30.
[e] Quantity is negligible.

in the best case and 202 miles in the average case. On a route-mile basis, barging ranges from more than two times as energy efficient as rail (average comparison) to nearly four times as energy efficient (best comparison).

Towboats follow winding rivers, and railroad tracks are built along easy grades. The resulting water or rail route is rarely the shortest distance between origin and destination. In addition, railroads usually offer a choice of routes, and studies show that rail freight does not always move over the shortest rail route (19).

To accommodate these variables, water and rail routes are compared with the "Great Circle" distance to obtain estimates of route circuity. For example, the inland water distance from Minneapolis to New Orleans is 1.6 times longer than the Great Circle distance. The rail route can be from 1.2 to 1.9 times the Great Circle distance, depending on which railroads carry the traffic and the routes selected on those railroads. Adjustments for circuity should be applied to route-ton-mile estimates of energy intensity when comparisons are made between specific points of origin and destination (19).

A comparison has been made of the relative energy efficiency to move grain from Minneapolis to the Gulf, taking rail and water circuity into account. It shows inland water is from 45.9 to 130.7 percent more energy efficient than rail, depending on which of the 10 different rail routes studied is actually used for shipment (19).

EQUIPMENT UTILIZATION

A popular measure of productivity that is less aggregate than labor, capital, and energy is equipment utilization. It is used by management within a single firm as a tool for control of the company's operations, and it is used to compare the relative productivity or efficiency of two or more firms producing the same transportation service or product. All else being equal, the firm with higher equipment utilization may be the more efficient.

Transportation equipment utilization is generally measured in two ways. One is the frequency with which the piece of equipment--barge, rail car, or truck trailer--is in motion producing transportation (hours per day, miles per year, etc.). The other relates to whether that piece of equipment, while in motion, is carrying a load, part of a load, or moving empty into position for a load (percentage of barges in a tow that are loaded, percentage of total rail car miles that are loaded, etc.). The two measurements are often related in a given market where fewer hours on the move may mean larger individual loads when movement does take place. In addition, of course, the nature of each market itself imposes constraints--for example, where only one-way loads are possible. Such would be the case of unit coal trains operated with dedicated equipment from a single mine. Efficient equipment utilization in this case depends on train turnaround time, since the cars will all be full in one direction and empty in the other.

The data given in Table 4 show that from 1947 to 1977 annual rail car miles decreased from 32.2 billion to 28.7 billion, about a 12 percent loss over the period. However, the percentage of total car miles for which cars were loaded decreased even more sharply, from 66.4 percent in 1947 to 58.6 percent in 1977, a nearly 17 percent loss over the period. These data show, for example, that in 1977, when rail cars moved, they were loaded only 56.8 percent of the time.

Comparable historical data on barging are not available, but a 1978 U.S. Army Corps of Engineers study based on vessel logs (20) measured the percentage of barges in the tows sampled that were loaded. The results are given in Table 5 for 11 major inland river systems. Equipment utilization measured in this manner shows that traffic characteristics vary from river system to river system. Thus, on the Cumberland River, the dominant traffic movement is upriver: The study shows that 91.5 percent of the upriver barges were loaded whereas only 50 percent of the barges moving downriver were loaded. On the other hand, on both the Lower Mississippi and the Ohio, traffic is more balanced: On the Lower Mississippi, 67 percent were loaded moving downriver and 63.5 percent moving upriver; on the Ohio, 59 percent were loaded moving downriver and 65.5 percent moving upriver. Equipment utilization is shown to be the most efficient on the Black Warrior-Tombigbee River system: 72.5 percent loaded moving downriver and 78.5 percent loaded moving upriver.

An average percentage of barges loaded for all 11 river systems was estimated by weighting the values shown for each river by the percentage of total ton-miles moved on that system. As presented in Table

Table 4. Measures of freight car use for Class I railroads: 1947-1977.

Year	Car Miles (billions) Loaded	Empty	Total	Percentage of Total Car Miles That Are Loaded
1947	21.4	10.8	32.2	66.4
1951	20.6	10.6	31.2	66.0
1955	20.1	11.1	31.2	64.5
1959	17.8	10.8	28.6	62.3
1963	17.1	11.0	28.1	60.9
1967	17.4	12.2	29.6	58.9
1968	17.8	12.3	30.1	59.3
1969	18.0	12.4	30.4	59.2
1970	17.3	12.6	29.9	57.8
1971	16.5	12.7	29.2	56.6
1972	17.1	13.2	30.3	56.5
1973	18.0	13.2	31.2	57.7
1974	17.6	13.1	30.7	57.2
1975	15.1	12.5	27.6	54.7
1976[a]	15.8	12.7	28.5	55.4
1977[a]	16.3	12.4	28.7	56.8

Note: Data from Transport Statistics in the United States and prior releases, reported in Modern Railroads, July 1980, page 55.

[a]Preliminary.

Table 5. Measures of barge use: 1978.

Waterway	Direction	Barges Loaded[a] (%)	Ton-Miles[b] (000 000)	Percentage of Total	Weighting
Allegheny River	Downriver	54			
	Upriver	55			
	Total	54.5	79.5	-[c]	0
Arkansas River	Downriver	66.5			
	Upriver	50			
	Total	55.5	1 694.9	0.9	0.499
Black Warrior-Tombigbee River System	Downriver	72.5			
	Upriver	78.5			
	Total	75.5	3 971.9	2.2	1.661
Cumberland River	Downriver	50			
	Upriver	91.5			
	Total	55.5	989.4	0.5	0.277
Illinois River	Downriver	50			
	Upriver	86			
	Total	66	7 683.9	4.3	2.838
Lower Mississippi River	Downriver	67			
	Upriver	63.5			
	Total	65	105 256.6	58.9	38.285
Missouri River	Downriver	88.5			
	Upriver	64			
	Total	75.5	1 528.6	0.8	0.604
Monongahela River	Downriver	50			
	Upriver	91			
	Total	61.5	1 223.8	0.7	0.430
Ohio River	Downriver	59			
	Upriver	65.5			
	Total	62.5	38 823.9	21.7	13.563
Tennessee River	Downriver	50			
	Upriver	88.5			
	Total	59.5	4 416.6	2.5	1.487
Upper Mississippi River	Downriver	86			
	Upriver	50			
	Total	67.5	12 908.4	7.2	4.860
Total			178 577.5	99.7	64.504

[a]Calculations based on data of U.S. Army Corps of Engineers (20).
[b]From American Waterways Operators, Inc. (21).
[c]Less than 0.1 percent.

5, this calculation shows that, for all rivers in the Corp of Engineers sample, an average of 64.5 percent of the barges moving are loaded. This is a substantially higher rate of equipment utilization than the 56.8 percent shown for rail based on loaded and unloaded car mileage.

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