COST FUNCTIONS FOR INLAND WATERWAYS TRANSPORT IN THE UNITED STATES

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Rightly or wrongly government plays an important role in the investment and operating decisions of transport firms. The Interstate Commerce Commission oversees a complicated structure of rates and a point-to-point system of operating licences. For inland waterway transport, additional complications stem from the fact that the construction and maintenance of navigable waterways are controlled by Congress through the Army Corps of Engineers. It is necessary for Congress, the ICC, and the Army Corps of Engineers to cooperate and to pursue the national interest rather than the interest of any particular industry or company. These agencies therefore require knowledge of the underlying cost and demand functions. This paper is designed to provide some information on waterway cost functions.

Two major trends have been evident in inland waterway transport over the last two or three decades. First, the cost per ton-mile has stayed about the same or fallen slightly, in contrast to the increase in most shipping costs. Second, a small number of firms have, through growth and merger, acquired a large share of the market. These trends, which are in contrast with those of other transport modes,[1] might be explained by increasing returns to scale. Thus our major hypothesis is that the long-run average cost of a firm declines as the size of the firm expands. In addition, we hypothesise that a firm's average cost also falls in the short run as output expands.

FORM OF THE FUNCTIONS

Our object is to estimate long and short-term relationships between cost, size of firm and output. We were able to obtain quarterly observations on five firms for the period 1962–66 (although 17 of the 100 potential observations were not available). The five firms in the sample are major inland waterway carriers with diverse barging operations. They operate on all the navigable tributaries of the Mississippi and Gulf Intercoastal Waterway systems, including the Missouri River, the Gulf of Mexico and Lake Michigan. They offer a complete range of water transport services, both in commodities handled and in equipment available for freight transport.

[1]Ocean-going vessels have become heavily subsidised over this period, and even so have experienced increasing rates. With the possible exception of airlines no other form of transport has seen so many mergers and such growth in the average size of firms.

Measures of Output

Several measures of output are available: tons, ton-miles (cargo or gross), and equivalent barge miles (EBM). None of these quantities is completely satisfactory in measuring output. Indeed, the output of a barge firm cannot be measured adequately by any single dimension. The cost of moving freight is dependent on the commodity handled, equipment used, length of haul, size of shipment, route travelled, time spent in transit, and many other variables. If a single measure is required, it should be calculated by weighting numerous aspects of the services performed; the conventional measures can be thought of as extremely simple weighting schemes. Since no compreprehensive weighting scheme exists, it is necessary to use one of the simple output measures.

One measure that has received considerable attention recently is the EBM (equivalent barge mile). An EBM is defined as "the movement of a fully loaded jumbo barge one mile."[2] An EBM is roughly 1350 cargo ton-miles for a fully loaded barge, or 760 for a half-empty barge. To be complete the definition should also specify the characteristics of the waterway over which the movement occurs.[3] In earlier work we discovered that the EBM provides a more homogeneous measure of output(for estimating cost and production functions) across firms and seasons than the ton or ton-mile.[4]

It would be convenient to assume that each observation of cost, output and size of firm gives the minimum possible cost of producing the specified output in a firm of the specified size. Unfortunately historical data rarely satisfy this assumption. Management is not as efficient as it might be, and the productive capacity of the firm resides in a stock of capital goods of various vintages and efficiencies. In addition, short-run adjustments are occurring continually, since the capital stock is changing and the level of output is fluctuating. It would be heroic to assume that these observations can be used to estimate the theoretical long-run cost function, *i.e.* the minimum possible cost of producing each level of output.

Another interpretation seems more acceptable. Each observation represents a level of efficiency achieved in the past. When these data are used, the estimated relationship will be regarded as a practical – not the theoretically optimal – function. The relationship might be used to draw conclusions about the expected effects of increasing firm size. The implicit assumption is that the level of efficiency obtained in the past is likely to persist in the future.

Measures of Firm Size

Four measures of firm size were available in the data: total towboat horsepower, number of towboats, total cargo tons of barge capacity, and number of barges. Each of these variables measures a slightly different aspect of the productive capacity of a firm. We have no way of knowing which is the best measure of size; possibly some combination of all of them would be best. All four variables were therefore tried separately in the estimated relationship to see whether they yielded significantly different results.

[2]This is the definition used by the ICC in barge form C.

[3]See Appendix.

[4]See: L. S. Case and L. Lave, "A Statistical Production Function for Inland Waterway Towboats," *Southeast Regional Science Association Papers*, 1968, 67-100.

Variations over Time

Since the observations range over a period of five years, it is of interest to note how costs changed over time. The period was one in which the industry made substantial efforts to improve efficiency. This gave rise to, among other things, the increasing use of cost accounting techniques, without which many of the data used in this study would not be available. To attempt to measure the effect of these cost-reducing activities, a linear time trend dummy variable has been included in the statistical model. (It must be pointed out, however, that factor prices, *e.g.*, for labour and equipment, have risen at the same time; no attempt has been made to identify this cost inflation, which naturally tends to offset the effect of increased efficiency.)

Both the cost function and the demand function shift seasonally. During some seasons there is ice or low water; at other times the waterways offer unimpeded navigation. To account for this seasonality we defined four dummy variables, one for each calender quarter.

Variation between Firms

We hypothesise that the cost function of each firm is the same, except for a difference in the constant term (which might indicate differences in average efficiency levels). Thus each firm will have the same cost of handling an additional unit of output and the same long-run cost function. To allow for differences in the intercept[5] of the cost function, we add five dummy variables, one for each firm.

Summary of Variables

Thus observations are quarterly across five firms and consist of: a measure of current output (EBM's); four measures of firm size (total towboat horsepower, size of towboat fleet, number of barges, and barge capacity measured in cargo tons); a linear annual time trend; a set of dummy variables to identify the quarter of the year; a set of dummy variables to allow for differences among companies; and three cost variables (total cost and its two components, direct operating expense or linehaul costs, and indirect operating expense.)

The Functions

Separate cost functions have been estimated for three categories of cost: indirect, direct, and total cost. The general form of the functions was:

$$\log \frac{\text{cost}}{\text{EBM}} = a_o + a_1 \log E_{ijt} + a_2 \log S_{ij\bar{t}} + a_3 C_i + a_7 t + a_8 Q_j + \varepsilon$$

where

E_{ijt} = output, measured in EBM's for the i^{th} firm, during the j^{th} quarter of the t^{th} year.

[5]As specified below, the cost functions are linear after a logarithmic transformation, and the cost function for each firm is allowed to differ by an additive term, which can be thought of as a change in the intercept or constant term. This implies that the firm cost functions are identical, save for a single factor. In other words, the cost function for company 1 is 12.8 per cent higher than that for company 5; if there were no differences in service, company 1 would have a 12.8 per cent cost advantage over company 5.

S_{ijt} = a measure of firm size (which may be total towboat horsepower, number of towboats, net tons of barge cargo capacity, or number of barges) for the i^{th} firm, during the j^{th} quarter of the t^{th} year.
C_i = firm dummy variables ($i = 1, \ldots 4$, since company 5's dummy variable is omitted).
t = annual time trend variable (1962 = 1, ... 1966 = 5).
Qj = quarterly dummy variables (fourth quarter omitted).
ε = residual.

The equation is linear in logarithms, since we hypothesise that the average cost function will be "L-shaped." The relation was calculated for all three measures of cost with the four measures of firm size. It was also calculated with the firm dummy variables omitted.

RESULTS

Results for the three cost categories are presented in tables I, II and III respectively. Four regressions are presented for each category of cost, one for each measure of firm size. There is little to distinguish between the four regressions for each cost category. Note that mean average cost per EBM is given in logarithms. Taking antilogs, mean indirect cost is \$0.3606 per EBM; mean direct cost is \$2.080 per EBM; mean total cost is \$2.489 per EBM. The amount of cargo in a barge must be specified if these figures are to be translated into costs per ton-mile. For example, a fully loaded jumbo barge would have ton-mile costs of 0.027c, 0.15c and 0.18c, respectively. A half-empty barge would have ton-mile costs of double these figures.

Indirect Cost Regressions

Indirect costs represent expenses not directly related to hauling freight, such as general office and management expenses, record keeping, sale of services, and the scheduling and coordination of shipments and equipment. Although it is difficult to connect these expenses with specific shipments, their level is related to the general level of output.

The indirect cost relationships for each of the four measures of firm size are shown in Table I. The four regressions are almost identical: individual coefficients change little, and the coefficients of determination show hardly any variation. Thus the first result to note is that the four measures of firms size give nearly identical results in the indirect cost regression; we can be confident of having captured the effect of firm size. The coefficient of determination is quite high. The estimated relation displays the predicted signs and explains over $\frac{3}{4}$ of the total variation; it is quite a satisfactory relation.

The coefficient of the time variable shows the annual geometric increase of average cost, controlling for quarter, company, output and firm size. The coefficient, though statistically insignificant, indicates that average indirect cost has been rising about 13 per cent per year. Apparently firms are spending more on scheduling, general level of service, and management.

The quarterly dummy variables indicate that the cheapest quarter in which to haul

TABLE I

Indirect Cost Regressions

	Mean	*Measures of Firm Size* 1	2	3	4
		(regression numbers)			
$\bar{R}^2$		.772	.772	.771	.772
Linear time		.134	.131	.122	.142
	.329	(.102)	(.097)	(.113)	(.108)
Quarter 1		.088	.087	.086	.088
	.250	(.031)	(.030)	(.030)	(.030)
Quarter 2		.051	.051	.051	.051
	.250	(.027)	(.027)	(.027)	(.027)
Quarter 3		.049	.049	.050	.050
	.250	(.027)	(.027)	(.027)	(.027)
Quarter 4	.250	0	0	0	0
Company 1		−.077	−.072	−.060	−.098
	.143	(.091)	(.082)	(.107)	(.129)
Company 2		−.176	−.195	−.162	−.196
	.238	(.099)	(.147)	(.093)	(.123)
Company 3		−.157	−.160	− .153	−.144
	.238	(.031)	(.036)	(.047)	(.041)
Company 4		−.268	−.274	−.254	−.268
	.143	(.077)	(.093)	(.059)	(.067)
Company 5	.238	0	0	0	0
Output (EBM)		−.765	−.778	−.789	−.771
	−.966	(.183)	(.161)	(.175)	(.163)
Size (HP)		−.059			
	−.456	(.223)			
Size (TB)			−.043		
	−1.024		(.164)		
Size (net tons)				−.009	
	−.373			(.378)	
Size (# barges)					−.144
	−.966				(.407)
Constant term		−1.171	−1.195	−1.176	−1.215
Indirect cost/EBM	−.443				

$\bar{R}^2$ is the coefficient of determination, adjusted for lost degrees of freedom. Just over 77 per cent of the variation in indirect cost/EBM is explained in each of the regressions. The other variables are defined earlier in the text. Note that output, size and cost are transformed into logarithms.

The first column shows the mean of each variable. The second column shows a complex regression, using one measure of firm size. In this regression just over 77 per cent of the variation in indirect cost is explained; indirect cost/EBM increased 13.4 per cent per year (the standard error of this coefficient is .102); the first quarter was 8.8 per cent costlier to operate in than the fourth quarter; and company 1's costs were 7.7 per cent less than those of company 5. A 1 per cent increase in output would lead to a .765 per cent decrease in indirect cost/EBM, and a 1 per cent increase in size would lead to a .059 per cent decrease in indirect cost/EBM. Finally, the constant term of the regression (which embodies the dummy variable for the fourth quarter and fifty company) is −1.171.

The remaining columns represent further regressions with different measures of firm size.

freight is the fourth, October to December. (The omitted dummy variable has an implicit coefficient of zero.) Quarters two and three are very similar, and the first quarter is the most costly. January to March is characterised by cold temperature, ice, bad visibility and low water; these conditions make extra work for management and keep output low. The second quarter also has a number of operating problems due to spring floods, fast currents and difficult navigation.

The coefficient of output is negative, large, and highly significant. It is not surprising that overhead costs per unit of output fall rapidly as output expands. Note that if total indirect costs were fixed and independent of the level of output, this coefficient would have a value of -1. Since the estimated value is -0.77, the implication is that about 23 per cent of indirect cost is variable with output (at the ouptut levels represented by these data). In other words, a 10 per cent increase in output would lead to a 2.3 per cent increase in total indirect cost.

The coefficients of the size variables are all negative, small and insignificant. One must be careful, however, in inferring the slope of the long-run average cost curve from the regression. The coefficient of size is interpreted as the partial derivative of average cost with respect to size; it indicates what happens to average cost as size expands, output held constant. The fact that the coefficient is negative indicates that, even at the present level of output, the firms could save money by purchasing additional towboats and barges. At first blush this result is implausible, since it implies that firms could achieve lower indirect costs by purchasing additional equipment. It could be argued, however, that substantial expenses are incurred in scheduling equipment and in moving empty equipment to the cargoes, and both these costs would fall if additional equipment were available. But in any case the coefficients are small.

To find the slope of the long-run cost curve, both output and size must be expanded simultaneously. As an approximation, we assume that the current size-output ratio is maintained as size is expanded.[6] If the size-output ratio is held constant, a 10 per cent increase in size leads to a decrease of approximately 8 per cent in average indirect cost. Stated another way, a 10 per cent increase in size would lead to only a 2 per cent increase in total indirect cost. Thus our hypothesis is confirmed: average indirect cost falls rapidly as size expands.

(In order to estimate the relation, one company dummy variable must be excluded and the estimated coefficients interpreted as the difference between the company in question and the company whose dummy variable is excluded. Discussion of these estimated company intercepts is postponed to the section on total costs.)

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[6]Thus, we want to determine $\left.\frac{\partial AC}{\partial S}\right|_{\frac{S}{EBM} = \text{constant}}$. We actually estimate the slope in elasticity terms; taking S and EBM in their geometric means

$$\left.\frac{\partial AC_T}{\partial S}\,\frac{S}{AC_T}\right|_{\frac{S}{EBM} = \text{constant}} = -0.81$$

Direct Cost Regressions

The direct cost relationships for each of the four measures of firm size are shown in Table II. Again the four regressions are almost identical and we can be confident that the effects of firm size have been estimated. These four regressions display high coefficients of determination and, with two exceptions, the predicted signs; about 84 per cent of the total variation is explained.

The time coefficient is positive when size is measured in terms of towboats and negative when barges are used. This inconsistency is difficult to explain. Possibly barges are used more intensively and reflect productive capacity better. It seems pointless to speculate very far, since the coefficients are very small and insignificant.

TABLE II

Direct Cost Regressions

	Mean	*Measures of Firm Size*			
		1	2	3	4
		(regression numbers)			
$\bar{R}^2$		.839	.842	.839	.838
Linear time		.009	.013	−.021	−.005
	.329	(.035)	(.033)	(.039)	(.037)
Quarter 1		.012	.012	.008	.010
	.250	(.010)	(.010)	(.101)	(.010)
Quarter 2		.012	.012	.012	.012
	.250	(.009)	(.009)	(.009)	(.009)
Quarter 3		.005	.005	.006	.006
	.250	(.009)	(.009)	(.009)	(.009)
Quarter 4	.250	0	0	0	0
Company 1		−.148	−.150	−.107	−.127
	.143	(.033)	(.028)	(.036)	(.044)
Company 2		−.193	−.234	−.162	−.175
	.238	(.034)	(.050)	(.032)	(.042)
Company 3		.015	.009	.010	.018
	.238	(.011)	(.012)	(.016)	(.014)
Company 4		−.130	−.149	−.108	−.114
	.143	(.026)	(.031)	(.020)	(.023)
Company 5	.238	0	0	0	0
Output (EBM)		−.576	−.582	−.624	−.606
	−.966	(.062)	(.055)	(.129)	(.056)
Size (HP)		−.068			
	−.456	(.076)			
Size (TB)			−.077		
	−1.024		(.056)		
Size (net tons)				.083	
	−.373			(.060)	
Size (# barges)					−.004
	−.966				(.140)
Constant term		−.197	−.239	−.187	−.202
Direct cost/EBM	.318				

The fourth quarter has the lowest unit cost for direct as well as indirect cost; as in the indirect cost regression, the third quarter is next lowest. This time the first and second quarters have nearly identical coefficients. These results seem consistent with expectations and with the indirect cost regressions.

As before, the coefficient of output is negative, large, and extremely significant. Total direct cost increases by only about 4 per cent when output increases by 10 per cent; *i.e.*, marginal cost is 40 per cent of average cost. In the short run it is important to keep equipment operating at peak utilisation, since the short-run marginal cost is quite small.

As in the indirect cost regressions, the coefficients of the size variables are negative, small, and not very significant. The only exception occurs when the total cargo capacity of the barge fleet is used as the size measure; for some reason, the coefficient is positive. Note that these size coefficients indicate what would happen to average direct cost if more towboats or barges were purchased, output being held constant. The slope of the long-run average direct cost curve is estimated on the assumption that output expands directly with size. A 10 per cent increase in size leads to approximately a 6.7 per cent decrease in direct cost per EBM. In other words, a 10 per cent increase in size leads to only a 3.3 per cent increase in total direct (line-haul) cost.

Total Cost Regressions

The total cost per EBM is the dependent variable in the regressions shown in Table III. Since direct costs make up about ¾ of total costs, the results of Tables II and III are similar. The coefficient of determination is higher for the total cost regressions than for either of the two components of cost; this suggests that the companies have no uniform procedure for dividing their expenses between direct and indirect categories.

The company dummy variables vary widely in two regressions, total costs versus indirect costs. For example, company 3 has low indirect costs but has the highest direct costs per EBM. One possible interpretation is that this company spends little on scheduling its equipment and making its operation more efficient, and so incurs higher operating costs. Company 5 has the highest indirect costs and the second highest direct costs. One might speculate that this company either is terribly inefficient or else offers a higher class of service than its competitors. Company 4, which has the lowest indirect costs and the second lowest direct costs, might either be relatively efficient or offer a low class of service. With only these data it is impossible to separate efficiency and level of service. Company 2 might be interpreted as having the most progressive management. Its relatively high indirect costs are more than offset by its low direct costs, and it is the company with the lowest total cost.

There are a number of possible hypotheses about the cost functions across firms: *e.g.* there is a different cost function for each firm, or one cost function adequately describes every firm, or one cost function adjusted for a difference in intercept can describe every firm. Since a more general cost function is to be preferred, a single cost function has been calculated for all firms and, for comparison, has been allowed to differ across firms by an intercept. The analysis of covariance provides a test of whether the explanatory power is significantly increased by allowing a different intercept for each firm. This test showed that the inclusion of different intercepts did increase the explanatory power of the regression. We did not go on to estimate

TABLE III
Total Cost Regressions

	Mean	Measurers of Firm Size 1	2	3	4
		(regression numbers)			
$\bar{R}^2$		.864	.865	.863	.862
Linear time		.029	.030	−.003	.014
	.329	(.036)	(.034)	(.039)	(.038)
Quarter 1		.021	.020	.017	.019
	.250	(.011)	(.010)	(.011)	(.011)
Quarter 2		.015	.015	.015	.009
	.250	(.009)	(.009)	(.009)	(.010)
Quarter 3		.010	.010	.010	.010
	.250	(.010)	(.009)	(.010)	(.010)
Quarter 4	.250	0	0	0	0
Company 1		−.128	−.126	−.085	−.107
	.143	(.034)	(.029)	(.037)	(.045)
Company 2		−.195	−.230	−.161	−.176
	.238	(.235)	(.051)	(.032)	(.043)
Company 3		.013	.008	.009	.017
	.238	(.011)	(.012)	(.016)	(.015)
Company 4		−.154	−.169	−.130	−.136
	.143	(.127)	(.033)	(.021)	(.023)
Company 5	.238	0	0	0	0
Output (EBM)		−.604	−.615	−.658	−.636
	−.966	(.064)	(.056)	(.061)	(.037)
Size (HP)		−.076			
	−.456	(.078)			
Size (TB)			−.074		
	−1.024		(.057)		
Size (net tons)				.079	
	−.373			(.133)	
Size (# barges)					−.015
	−.966				(.143)
Constant term		−.160	−.200	−.151	−.169
Total cost/EBM	.396				

separate functions for each firm, since, in addition to being less general, these functions could add little to the explanatory power of the general function. We concluded that the company cost functions did differ by a multiplicative constant. Economically, this difference could be ascribed to differences in efficiency or quality of service among companies.[7]

As with indirect and direct cost regressions, the coefficient of output is negative, large, and extremely significant. Short-run total cost rises by only 3.7 per cent when output rises 10 per cent. With marginal cost so much lower than average cost (in the

[7]When the company dummy variables are omitted, the coefficient of size becomes positive and extremely significant. Apparently the large companies happen to offer more service to customers, thereby incurring a higher cost. These service differences are removed by inserting dummy variables, and the coefficient of size takes on the expected negative sign.

short run), it is hardly surprising that firms are willing to cut rates to obtain additional business.

The slope of the long-run average total cost curve shows considerable returns to scale, as did the indirect and direct cost curves. Assuming that output expands in proportion to size, a 10 per cent increase in size will lead to a decrease in average cost of about 7.0 per cent. Thus, a 10 per cent increase in size will lead to only about a 3.0 per cent increase in total cost. The generally negative sign of the size coefficient indicates that total cost would fall (owing to savings in scheduling and in empty backhauls) if additional equipment were added, current output being unchanged.

SUMMARY AND CONCLUSION

Quarterly data were collected on five U.S. inland waterway firms for the period 1962–66. Indirect, direct and total costs were hypothesised to be a function of firm size, output, and the year and season of the observation. The cost functions were found to differ among firms by a multiplicative constant. Using quarterly data, indirect, direct, and total unit costs (output measured in EBMs) were regressed on firm size (measured four different ways), output, year and quarter. In all regressions the coefficient of determination exceeded 0.75, and the signs of the coefficients generally had the predicted signs. The slopes of both short and long-run cost functions were negative and significant. For example, a 10 per cent increase in output would raise indirect costs by 2.3 per cent, direct costs by 4 per cent and total costs by 3.7 per cent. A 10 per cent increase in firm size (together with an equal increase in output) would raise indirect costs by 2.0 per cent, direct costs by 3.3 per cent and total costs by 3.0 per cent. The increasing returns to scale, as indicated in this paper, are one possible reason for the wave of mergers in the industry.

APPENDIX

The EBM is based on the fact that towboat output is not proportional to the number of tons or ton-miles being pushed. Rather, considerable effort is required to move the towboat and a flotilla of empty barges. Adding cargo to the barges requires additional effort, but not in proportion to the cargo added. As draft increases, the amount of turbulence in the water also increases, thus requiring increasing marginal effort by the towboat to achieve any given speed. There is another interaction with waterway depth: in general, the deeper the water the less severe the turbulence for any draft.

In addition to this engineering phenomenon, two more factors alter the draft, or cargo load and output relationship: waterway congestion and locking time. If, for example, a large portion of the total time taken on any trip is spent navigating locks, an empty or partially loaded barge becomes just as difficult to push as does a fully loaded barge (for an analysis of waterway congestion, see L. Lave and J. DeSalvo, "Congestion, Tolls, and the Economic Capacity of a Waterway," *Journal of Political Economy*, 76, 1968, 375–91, and J. DeSalvo and L. Lave, "An Analysis of Towboat Delays", *Journal of Transport Economics and Policy*, II, 1968, 1–10). All these factors

are closely related to the waterway conditions which prevail for any movement (hence the insistence on including waterway characteristics in the EBM definition). The number of EBM's per hour produced by a given boat will vary with the physical conditions.

Since barge equipment comes in a wide variety of sizes and types, it is necessary to adjust EBM's for the carrying capacity of the barge. A standard barge-mile is, of course, not equivalent to a jumbo barge-mile. The EBM is of special interest since it has been adopted by the ICC as part of its cost-finding procedure for waterway firms. This procedure is embodied in Barge Form C. Barge Form C presents a method for calculating EBM's, based essentially on the arguments presented above. In particular, Barge Form C contains a system of weights that can be applied to barge movements. Two sets of weights are presented, reflecting the two factors discussed above: river district and barge size.

The EBM, then, is itself an output index, although it is still imperfect as an output measure. However, it does attempt to collapse certain features of waterway transport output into a single measure by recognising characteristics of waterway transport that have an important influence on the relationship between costs and output.

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