STATISTICAL COST FUNCTIONS FOR DRY BULK CARRIERS

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The object of this paper is to estimate sea transportation cost functions for dry bulk carriers on the basis of market data. Such functions are of help to port authorities in assessing the benefits of port investments intended to serve large vessels (see Goss, 1967). Cost functions may also be of interest to shipowners, shipbuilders and shippers, as they provide information on the relative importance of the effects on freight rates of economies of size, route length, and the general market situation.

The classic approach to quantifying sea transportation costs is to calculate the required revenue per ton, defined as the long-term price per ton covering all expenditures and yielding an adequate return on invested capital (see Goss and Jones, 1977; Heaver, 1970). This method requires explicit assumptions on various parameters such as ship life, technical conditions of ship exploitation, voyage characteristics, etc., and data on cost components such as purchase price, scrap value, and crew and other operating costs. This "engineering" method of deriving cost functions can be used to simulate the effects of size, route length, etc., on costs.

In this paper direct statistical estimates of the main determinants of sea transport costs (vessel size and route length) are presented for dry bulk carriers operating in the grain, iron ore and coal trades.

THEORY AND METHOD

It is clear that in order to distinguish the effects on costs of different vessel sizes and route lengths by using data on spot market freight rates one must allow for variations in market conditions.

Especially in the spot market for voyage charters, freight rates will respond in a volatile manner to shifts in demand as the short-run supply of tonnage for a particular trade is fairly inelastic (O'Loughlin, 1967). Short-term adjustments to an expanding demand are limited to, e.g., increasing from economic to maximum speed, switches between trades and, if a continuing boom in freight rates is expected, bringing vessels out of lay-up and switching long-term chartered capacity to the spot market. Finally new building may increase supply, but this may take months and even years. Probably the elasticity of supply if rates decrease is somewhat higher if rates are falling, as it is easier to contract supply by lay-up and scrapping than to expand.

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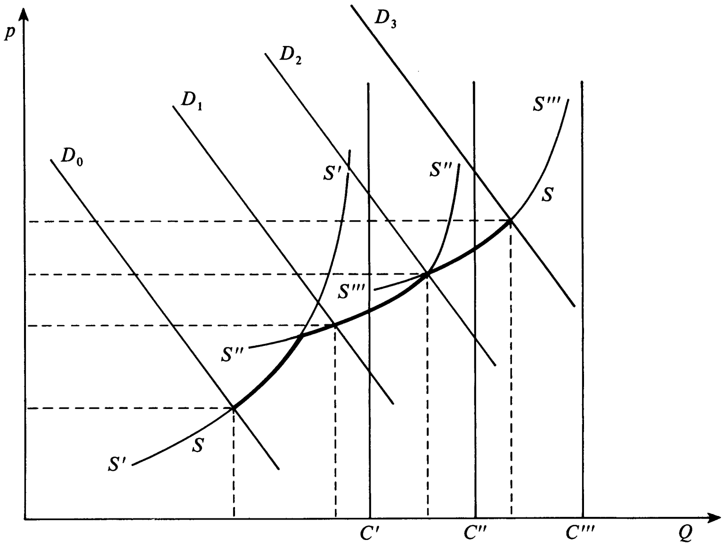

FIGURE 1

In the shipping market short-term variations of freight rates are due more to shifts in the demand curve than to shifts in the supply curve. For example, during 1979 the coefficient of variation of monthly supplied capacity for dry bulk was 2.4%, but the coefficient of variation of monthly capacity demanded was twice as high at 5.1% (*Lloyd's Shipping Economist*, 1979–1980).

Estimating a single equation regression on the level of freight rates versus observed sailings (or a proxy variable such as excess supply) identifies the supply curve, as can be seen from Figure 1. Curve *SS* is the long-term supply curve. Short-term supply curves (e.g. $S'S'$ $S''S''$) depend upon existing capacity (e.g. C' C'', etc.), and clearly are less elastic than long-run supply.

By controlling for changes in capacity the short-term effects on freight rates of excess supply may be separated from long-term effects of expansion or contraction of capacity.

The level of freight rates will be determined by equilibrating forces of demand and supply, while the structure of freight rates will be governed by the cost structure of different types of producers. Consequently, a model of the following type may be used:

$$P_{it} = F(S_i, NM_i, D_i, E_t, C_t)$$

where P_{it} is the freight rate for a particular voyage charter *i* in period *t*
S_i is vessel size for charter *i*
NM_i is the voyage length for charter *i*
D_i is a vector of other characteristics such as trade, multiple calls, etc. . . .
E_t is excess supply at time of chartering
C_t is capacity in service at time of chartering.

TABLE 1

Parameters of Vessel Size Distribution

	Average Size (in 000 dwt)	*Standard Deviation (in 000 dwt)*	*Number of Vessels*
Grain trade	33.9	15.7	271
Iron ore trade	91.3	37.0	87
Coal trade	56.1	21.2	55

TABLE 2

Averages and Standard Deviations

	Distance (nautical miles)	*Size*	*Price*	*Multiple Calls*
Heavy grain	*A* 6242.2	*A* 33.9	*A* 21.9	168
	SD 2974.3	*SD* 15.7	*SD* 9.2	
Iron ore	*A* 5331.1	*A* 91.3	*A* 8.3	14
	SD 2824.6	*SD* 37.0	*SD* 3.7	
Coal	*A* 6203.0	*A* 55.0	*A* 13.3	21
	SD 3159.8	*SD* 21.2	*SD* 5.2	

A = average; *SD* = standard deviation.

DATA

The data for this study were derived from fixtures for voyage charters published monthly by *Fairplay* during 1979. For most fixtures details are given on trade type, origin and destination, rate in $ per ton of cargo, vessel size and whether or not the charter specified multiple calls.

A complete set of observations was compiled on size (S in deadweight tons), price per ton cargo (P in $), voyage length ($NM$ in thousand nautical miles) and a dummy variable (1 if multiple calls, 0 otherwise) for 271 fixtures in the grain trade, 87 in iron ore and 55 in coal.[1]

Table 1 summarises the main parameters of the distribution of vessel size in the sample.

In Figure 2 the distribution of vessel size in this sample is compared with the profile of sailings from the principal exporting regions during 1979 as estimated by *Lloyd's Shipping Economist*, May 1980.

The general shape of the sample distribution corresponds with the estimated distribution of sailings. However, smaller vessels are over-represented in this sample for the grain trade and under-represented for coal and iron ore.

In Table 2 averages and standard deviations are listed for sailing distances and

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[1] Data are available on request from the author.

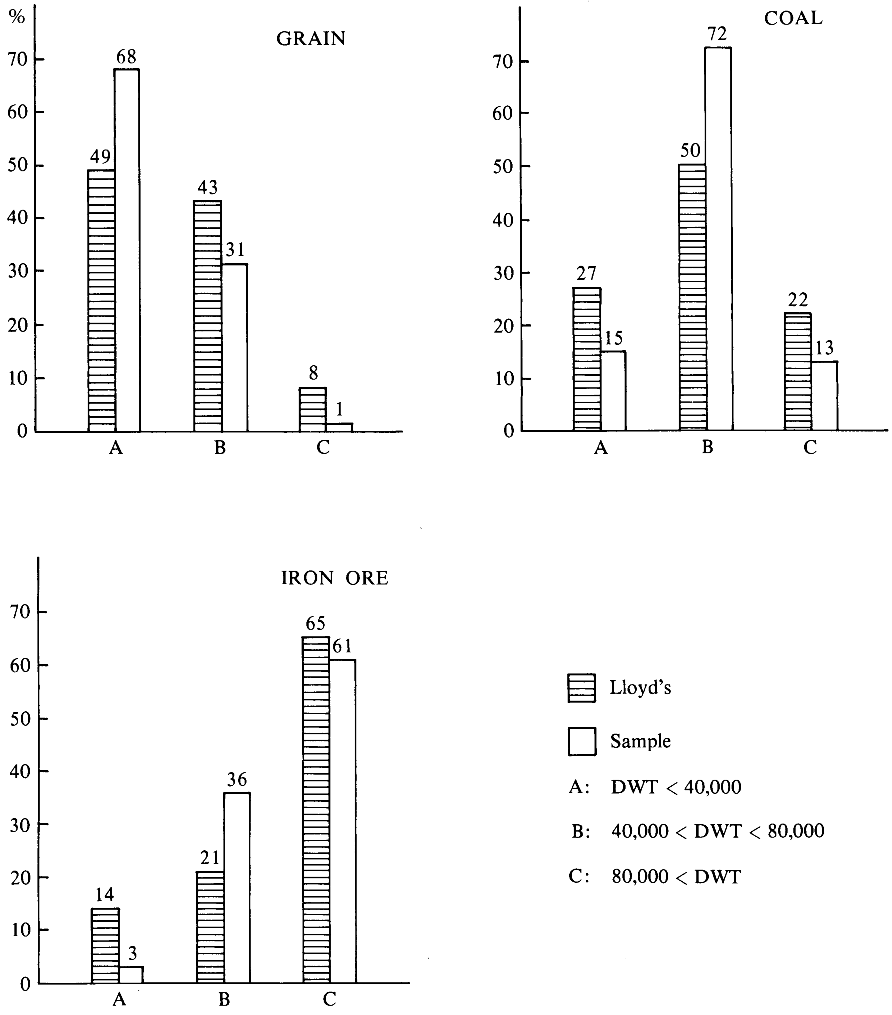

FIGURE 2

Vessel Size Distribution: Sample vs Sailings

dollar prices, as well as the number of voyage charters where calls had to be made at more than two ports. Especially in the grain trade, multiple calls are common, and they widen the variation in freight rates.

Single correlation coefficients between freight rate, vessel size and distance are given in Table 3. They confirm the expected negative relationship between freight rate and vessel size and the expected positive relationship between freight rate and distance. Vessel size and voyage length apparently are not closely related; this

TABLE 3

Correlation Coefficients

		Freight Rate	*Distance*	*Size*
Grain	Freight rate	—	0.445	–0.456
	Distance		—	0.107
	Size			—
Ore	Freight rate	—	0.592	–0.197
	Distance		—	0.341
	Size			—
Coal	Freight rate	—	0.659	–0.264
	Distance		—	0.204
	Size			—

confirms the shallow dip in theoretically derived relations between optimum ship size and voyage length (Kendall, 1972).

In addition to data derived from the monthly published fixtures an excess supply indicator was used. Figure 3a plots the monthly percentage of excess supply over demand for dry bulk carriers as published by *Lloyd's Shipping Economist*, 1979. Total capacity is plotted in Figure 3b.

RESULTS

Two specifications of the basic model were estimated by means of ordinary least squares for each trade. The first specification is a log-log equation for which coefficients are easily interpretable as elasticities. This functional form yielded the results presented in Table 4.

The statistical quality of these regressions is fairly good. On average two thirds of the variation in prices is explained by the equations (62% for grain, 75% for iron ore and 70% for coal). All estimated coefficients have the correct sign. They are highly significant, except the dummy variables for iron ore and coal and excess supply for grain trade.[2]

The average elasticity of voyage length is about 0.38; this means that a 1% increase in voyage length raises freight rates by slightly less than four tenths of 1%. These

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[2] When the insignificant dummy variables in the regressions on iron ore and coal trades were dropped from the equations, the following results were obtained:

$$\text{Iron ore} \quad \ln P = \underset{(6.204)^{\circ}}{-18.778} + \underset{(1.195)^{\circ}}{4.599} \ln C + \underset{(0.035)^{\circ}}{0.437} \ln NM - \underset{(0.057)^{\circ}}{0.419} \ln S - \underset{(0.108)^{\circ}}{0.496} \ln E$$

$$\text{Coal} \quad \ln P = \underset{(9.482)^{\circ\circ}}{-20.517} + \underset{(1.815)^{\circ}}{4.999} \ln C + \underset{(0.053)^{\circ}}{0.419} \ln NM - \underset{(0.102)^{\circ}}{0.535} \ln S - \underset{(0.186)^{\circ\circ}}{0.344} \ln E$$

The multiple coefficients of determination amounted to 0.740 and 0.686, respectively. These results show that the estimated coefficients remained stable after the insignificant dummy variables were dropped.

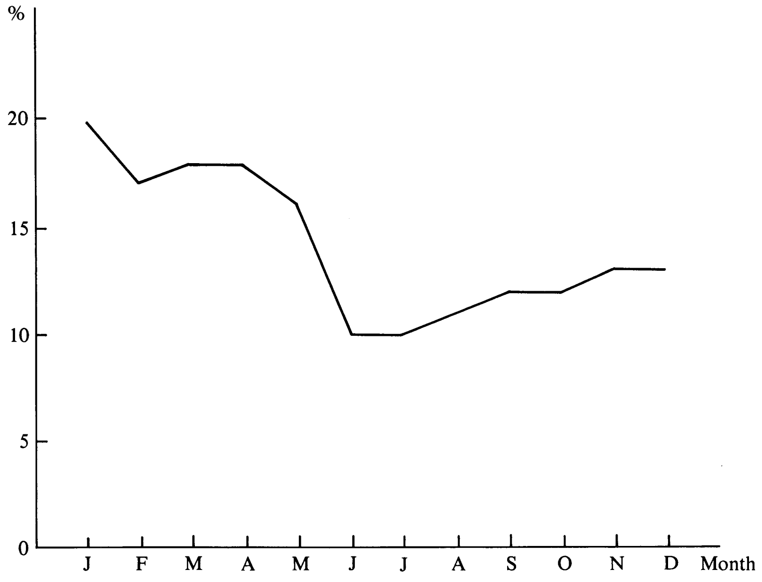

FIGURE 3a
Excess Supply 1979

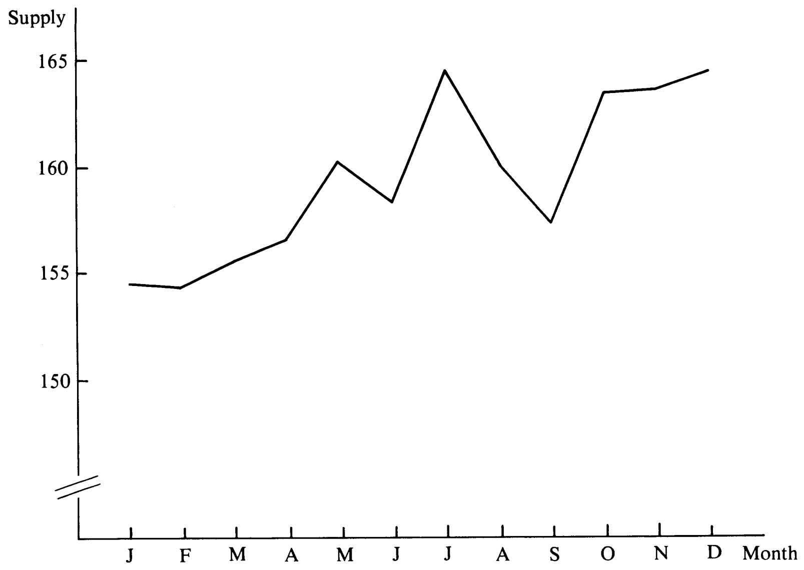

FIGURE 3b
Total Capacity 1979

TABLE 4

Regression Results Log-log Models

Dependent lnP	*Grain*		*Iron Ore*		*Coal*	
Variable	*Estimate*	*Standard Error*	*Estimate*	*Standard Error*	*Estimate*	*Standard Error*
Constant	−28.437	(5.015)°	−19.320	(6.184)°	−20.847	(9.364)°°
ln C	6.434	(0.953)°	4.705	(1.192)°	5.043	(1.792)°
ln NM	0.317	(0.026)°	0.420	(0.037)°	0.414	(0.053)°
ln S	−0.423	(0.044)°	−0.406	(0.058)°	−0.511	(0.102)°
ln E	−0.143	(0.096)	−0.512	(0.108)°	−0.353	(0.184)°°
ln D	0.173	(0.040)°	0.087	(0.064)	0.101	(0.067)
R^2	0.619		0.746		0.700	
Observations	271		87		55	

P is the U.S. dollar price per ton, NM the distance in nautical miles, S the vessel size in thousand deadweight tons, E the percentage excess supply. $D = 1$ for multiple calls and zero otherwise, and ln represents natural logarithms.

All coefficients marked by ° are significantly different from zero at the 1% level. Those marked by °° are significantly different from zero at the 5% level.

values are smaller than those obtained with "engineering cost functions". The elasticities implicit in the analysis of Heaver (1970) and Goss and Jones (1977) range between 0.6 and 1.

According to the above equations a 1% increase in vessel size results in a decrease of freight rates of about 0.45%. These elasticities are comparable with those found by Heaver and by Goss and Jones. Their absolute values of implicit elasticities range between 0.3 and 0.7.

Market conditions have an important effect on the level of freight rates. In 1979 the average excess supply was 14.2%; the lowest figure was 10% in June/July, and the highest 20% in January. The net effect of a drop in excess supply from 20% to 10% is an increase in freight levels varying between 10% (grain) and over 40% (iron ore). However, one should take into account the fact that at high (low) levels of excess supply capacity will contract (expand). High-cost (marginal) vessels will leave or enter the market, according to the level of excess supply. Consequently, periods of high excess supply tend to coincide with periods of low capacity (see Figure 3).[3] High-cost vessels will be taken out of service during such periods, and this will further depress freight rates.

In periods of low excess capacity high-cost vessels operating at the margin of the market will re-enter, as a tight market tends to coincide with high supply of capacity. This re-entering of marginal vessels will further increase freight rates.

The total effect of a change from a slack market with low capacity (January 1979) to a tight market with high capacity (July 1979) is an increase in prices of about 60% to 80%. This is illustrated in Table 5.

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[3] There were, however, no problems of multicollinearity. The zero order correlation coefficient between excess supply and total capacity ranged between −0.54 (coal) and −0.61 (grain).

TABLE 5

Rate Increase

	Due to a Drop in Excess Supply From 20% to 10%	*Due to an Increase in Capacity (from min. to max.)*	*Total*
Grain	10%	50%	60%
Iron ore	43%	35%	78%
Coal	28%	38%	66%

TABLE 6

Elasticity of Supply

	Excess = 10%	*Excess* = 14.1% (*average excess supply*)	*Excess* = 20%
Grain	0.79	1.02	1.32
Iron ore	0.39	0.46	0.54
Coal	0.46	0.55	0.67

Further, the elasticity of supply (E_s) of tonnage can be calculated in terms of the estimated coefficients of excess supply (α) and capacity (β) according to the following expression:

$$E_S = \frac{1}{(\alpha)} \cdot \frac{E}{100 + E} + \frac{1}{(\beta)}[4]$$

Relevant values for this sample are given in Table 6.

As is to be expected, the elasticity of supply of tonnage in the grain trade is higher than in iron ore and coal, as more specialised vessels are engaged in the latter trades. Furthermore, the tighter the market the smaller the elasticity of supply and the larger the effect on freight levels.

Finally, if multiple calls are required freight rates increase by 19% for grain, 7% for iron ore and 10% for coal. These values are merely averages for the present sample.

The second specification of the basic model was designed to maximise explanatory power and explicitly take into account a few important inferences from the Goss–Jones–Heaver engineering cost functions.

From their results it follows that required revenue per ton decreases with vessel size but at a decreasing rate and bounded below. Second, their analyses indicate that average costs per nautical mile decrease with distance and with vessel size. Finally,

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[4] The first part of the expression was obtained by calculating the supply elasticity $(\partial Q/\partial p)/(p/Q)$ (Q = observed quantity supplied), using the definition $E = 100\ [(C^\circ - Q)/Q]$ and considering capacity C° as fixed. The second part of the expression relates to the price elasticity of capacity $(\partial C/\partial p)(p/C)$.

TABLE 7

Regression Results of Modified Model, all Variables Included

	Grain		*Iron ore*		*Coal*	
Variable	*Estimate*	*Standard Error*	*Estimate*	*Standard Error*	*Estimate*	*Standard Error*
Constant	−125.718	(21.660)°	−23.020	(10.080)°	−64.907	(16.717)°
C	0.715	(0.138)°	0.159	(0.072)°°	0.274	(0.103)°
NM	2.812	(0.635)°	1.454	(0.203)°	0.982	(0.527)°°
NM^2	−0.046	(0.043)	−0.035	(0.013)°	0.029	(0.039)
$1/S$	173.800	(35.396)°	132.495	(28.496)°	350.576	(60.815)°
E	2.073	(1.219)°°	0.202	(0.673)	3.314	(1.032)°
E^2	−0.081	(0.043)°°	−0.019	(0.024)	−0.126	(0.036)°
D	4.155	(0.823)°	0.559	(0.536)	1.087	(0.586)°°
$NM \times S$	−0.0122	(0.0065)°°	−0.0025	(0.0007)°	−0.0022	(0.0024)
R^2	0.670		0.778		0.879	
Observations	271		87		55	

Coefficients marked ° are significantly different from zero at the 1% level; those marked °° are different from zero at the 5% level.

a non-linear response to excess supply was built in, and variations in capacity and the effect of multiple calls were taken into account. The following statistical specification was obtained:

$$P_{it} = a + b/S_i + (c + dNM_i + eS_i)\,NM_i + fE_t + gE_t^2 + hC_t + kD_i + U_{it}$$

where P_{it} = freight rate in dollars per ton for charter *it*
S_i = deadweight of vessel *i* in thousands of tons
NM_i = voyage length for charter *i* in thousands of nautical miles
E_t = excess supply in period *t* in percent of demand
C_t = capacity supplied in period *t* in million deadweight tons
D_i = 1 for multiple calls; 0 = otherwise
U_{it} = an error term with the usual least-squares assumptions.

The parameters *b*, *c*, *h*, and *k* are expected to be positive; the parameters *d* and *e* are negative if there are scale economies in distance and in costs at sea for large carriers. The results obtained with this specification are given in Table 7. Its explanatory power is superior to that of the log-log equations, as corrected multiple coefficients of determination increase from 0.62 to 0.67 for grain, from 0.75 to 0.78 for iron ore and from 0.70 to 0.88 for coal.

All coefficients have the expected sign, except the coefficient of nautical miles squared in the regression on coal trade.

The influence of size and capacity is highly significant (1% level) in all regressions. As for other variables, the statistical precision of coefficients varies.

The hypothesis that average costs per nautical mile decrease with distance and vessel size is clearly confirmed by the results on iron ore charters, as the estimated coefficients *d* and *e* are statistically significant at the 1% level. The results on grain charters also support this hypothesis, though standard errors of the relevant co-

TABLE 8

Regression Result of Modified Model, Insignificant Variables Dropped

	Grain		*Iron ore*		*Coal*	
Variable	*Estimate*	*Standard Error*	*Estimate*	*Standard Error*	*Estimate*	*Standard Error*
Constant	−123.478	(21.566)°	−24.065	(9.856)°	−65.832	(16.576)°
C	0.715	(0.138)°	0.188	(0.059)°	0.280	(0.102)°
NM	2.168	(0.213)°	1.409	(0.199)°	1.222	(0.089)°
NM^2	—	—	−0.029	(0.013)°°	—	—
$1/S$	172.199	(35.373)°	140.855	(27.516)°	384.704	(41.557)°
E	2.022	(1.118)°°	−0.324	(0.059)°	3.089	(1.005)°
E^2	−0.080	(0.043)°°	—	—	−0.119	(0.035)°
D	4.138	(0.816)°	—	—	0.938	(0.462)°°
$NM \times S$	−0.012	(0.0065)°°	−0.0024	(0.0007)°	—	—
R^2	0.668		0.773		0.875	
Observations	271		87		55	

efficients are higher. The coefficient e is, however, significant at the 5% level. For the coal trade, the estimation results do not confirm the hypothesis, as both d and e are completely insignificant. Moreover, the coefficient of nautical miles has the wrong sign.

Insignificant variables were dropped from the model and the equations were re-estimated. As can be seen from Table 8, most of the coefficients are only slightly different from those reported in Table 7. Moreover, all parameters in this final model have the expected sign and are significant at the 5% level. Hence, these equations are preferred for port investment cost-benefit calculations.

Average elasticities of size for these final regressions are −0.35 for grain, −0.33 for iron ore and −0.53 for coal.[5] These figures are lower than the log-log results except for coal, but are within the range of implicit values of Heaver (1970) and Goss and Jones (1977). The elasticities of distance are 0.50 for grain, 0.57 for iron ore and 0.57 for coal, which is definitely higher than the log-log results but still lower than the values obtained by Heaver, Goss and Jones.

CONCLUSIONS

In previous writings engineering cost functions are available for sea transport in dry bulk carriers. In this paper we adopted the alternative approach to cost functions, that is, statistical estimation on the basis of market data. Whereas the structure of freight rates is determined by the structure of costs of various individual producers, the level of freight rates is governed by the law of demand and supply. Consequently, the statistical models used took into account market forces as well as characteristics of producers. Two versions of the model were estimated.

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[5] Calculated at the mean values of the variables.

In general our results compare well with cost engineering functions, except for a consistently lower relative effect of distance on freight rates.

This finding is important in view of the use of these functions in cost-benefit analysis of port projects. For example, if primary commodities have to be hauled over longer distances in the future, the use of cost engineering functions might lead us to overestimate the benefit of a project intended to serve larger vessels. In addition to the effect of vessel size and distance on freight rates, elasticities of supply for tonnage were estimated. Our results confirm the general theory on supply in shipping, that the tighter the market the more inelastic is the supply function. We found elasticities of supply for tonnage of 0.5% for the iron ore and coal trades and 1% for the grain trade.

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