SESO UNIVERSITAIRE FACULTEITEN ST.-IGNATIUS TE ANTWERPEN

STUDIECENTRUM VOOR ECONOMISCH EN SOCIAAL ONDERZOEK

STATISTICAL COST FUNCTIONS FOR DRY BULK CARRIERS

DE BORGER B. en NONNEMAN W.

Rapport 80/101
Juni 1980

This study was financed by the Ghent Port Authority.
We thank Mrs. Y. Buts for research assistance.

Universitaire Faculteiten St.-Ignatius
Prinsstraat 13 - 2000 Antwerpen
D/1980/1169/11

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 R.O. GOSS, (1970)). Cost functions may also be of interest to shipowners, shipbuilders and shippers as they provide information on the relative importance of economies of size, the effects of route length, and the consequences of the general market situation on freight rates.

The classic approach to quantify sea transportation costs consists of calculating 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 R.O. GOSS & C.D. JONES (1977), T.D. HEAVER, (1968)). 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, crew and other operating costs. This 'engineering' method to derive cost functions can be used to simulate the effects of size, route length etc. on costs.

In this paper direct statistical estimates of the major determinants of sea transportation costs viz. vessel size and route lengths are presented for dry bulk carriers operating in grain, iron ore and coal trades.

Theory and method

It is clear that in order to single out the effects on costs of different vessel sizes and route lengths with data on spot market freight rates one must control for variations in market conditions.

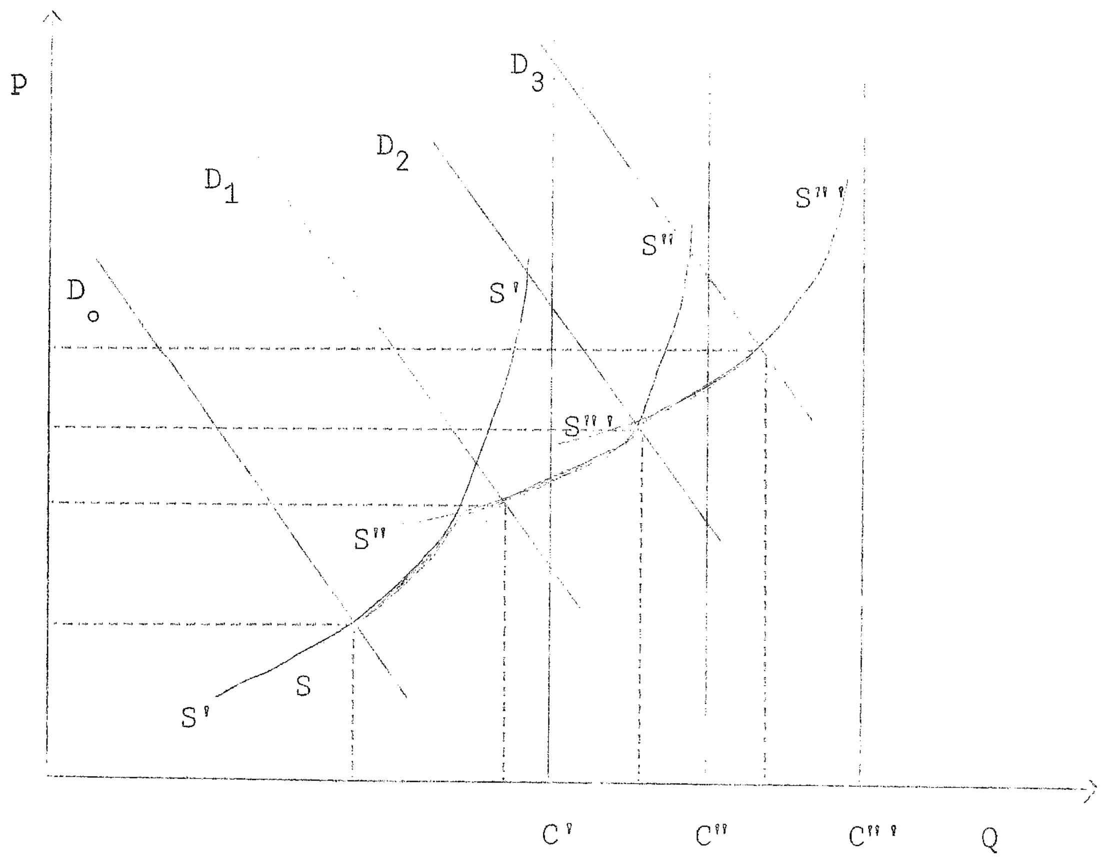
Especially in the spot market for voyage charters, freight rates will respond volatile to demand shifts as the short-run supply of tonnage for a particular trade is fairly inelastic (See C. O'LOUGHLIN, (1967)). Short-term adjustments to an expanding demand are limited to e.g. switches from economic to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

In the shipping market short-term variations of freight rates are more due to shifts in the demand curve than to shifts in the supply curve. E.g. during 1979 the coefficient of variation of monthly supplied capacity for dry bulk was 2.4 %, the coefficient of variation of monthly capacity demanded was twice as high viz. 5.1 % (°).

By estimating a single equation regression on the level of freight rates versus observed sailings (or a proxy variable such as excess supply) the supply curve is identified as can be seen from Figure 1.. Curve SS is the long-run supply curve. Short-run supply curves (e.g. S'S' S"S") depend upon existing capacity (e.g. C' C", etc.)

(°) Data from Lloyd's Shipping economist and clearly are less elastic than long-run supply.

Figure 1.



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

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 supplied at time of chartering

Data

The data for this study were derived from fixtures for voyage charters published monthly by Fairplay during 1979. For most fixtures details are mentionned 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 on size (S in deadweight tons), price per ton cargo (P in $), voyage length (NM in 1 000 nautical miles) and a dummy variable (1 if multiple calls; 0 otherwise) for 271 fixtures in grain trade, 87 in iron ore and 55 coal trade was elaborated. (°)

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

Table 1. Vessel size distribution parameters

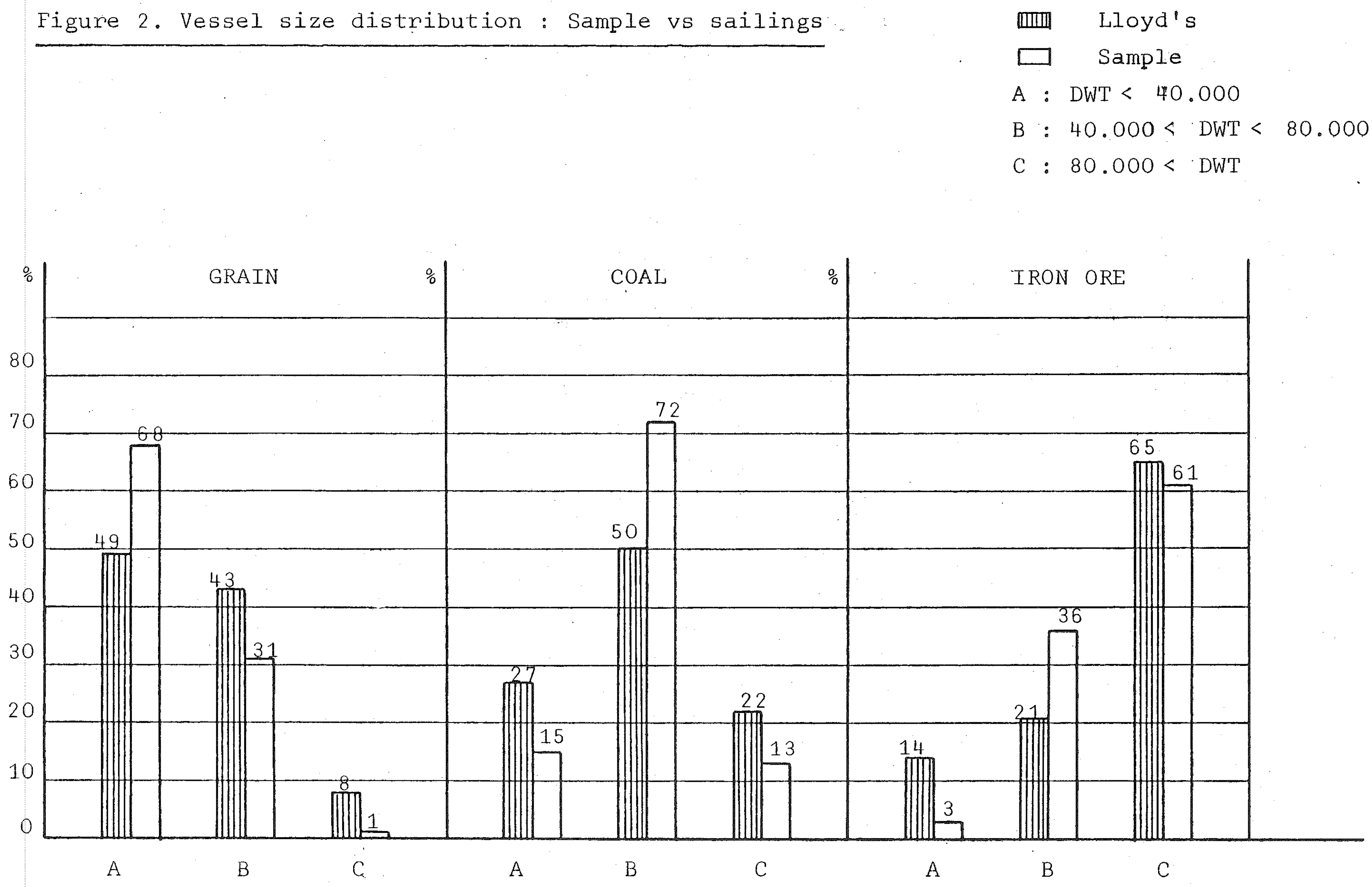
	Average size (in 1 000 tdw)	Standard deviation (in 1 000 tdw)	Number of vessels
Grain trade	33.9	15.7	271
Iron ore trade	91.3	37.0	87
Coal trade	56.1	21.2	55

In Fig. 2 the vessel size distribution in this sample is compared with the profile of sailings from the important exporting regions during 79 as estimated by Lloyd's Shipping Economist (°°).

(°)Data are available on request

(°°) Lloyd's Shipping Economist, May 1980

Figure 2. Vessel size distribution : Sample vs sailings



The general shape of the sample distribution corresponds with the estimated distribution of sailings. However smaller vessel sizes for grain trades are overrepresented in this sample, while for coal and iron ore they are underrepresented.

In table 2 averages and standard deviations are listed for sailing distances and dollar prices, as well as the number of voyage charters where more than two ports had to be called. Especially in grain trade, multiple calls are quite frequent and add to the variation in freight rates.

Table 2. (°) Average and standard deviation

	NM	SIZE	PRICE	MULTIPLE CALLS
Heavy grain	A = 6242.2 SD = 2974.3	A = 33.9 SD = 15.7	A = 21.9 SD = 9.2	168
Iron ore	A = 5331.1 SD = 2824.6	A = 91.3 SD = 37.0	A = 8.3 SD = 3.7	14
Coal	A = 6203.0 SD = 3159.8	A = 55.0 SD = 21.2	A = 13.3 SD = 5.2	21

Single correlation coefficient between freight rate, vessel size and nautical miles 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 confirming the shallow dip in theoretically derived relations between optimum ship size and voyage length (See P.M.H. KENDALL, (1972)).

(°) A = average SD = standard deviation

Table 3. Correlation coefficients

		P	NM	S
GRAIN	P NM S	o	0.445 o	-0.456 0.107 o

		P	NM	S
ORE	P NM S	o	0.592 o	-0.197 0.341 o

		P	NM	S
COAL	P NM S	o	0.659 o	-0.264 0.204 o

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

Figure 3.a : Excess supply

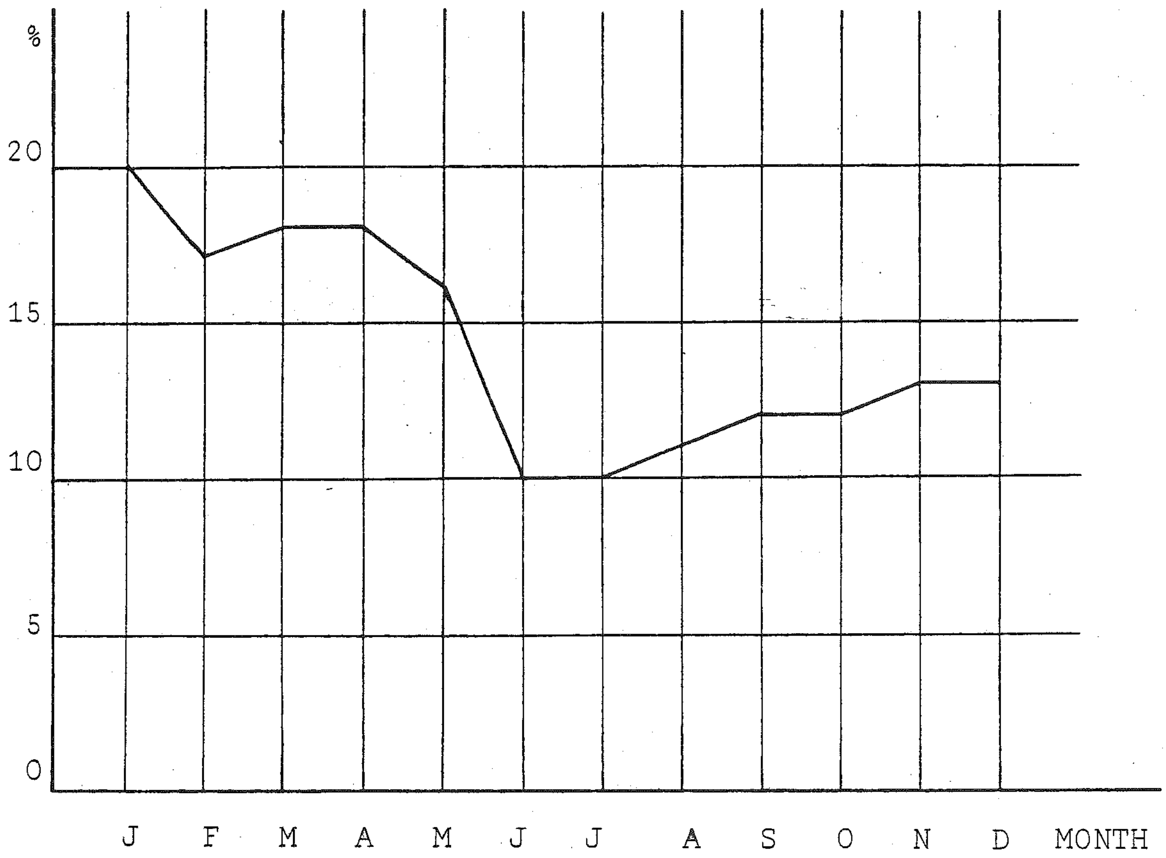
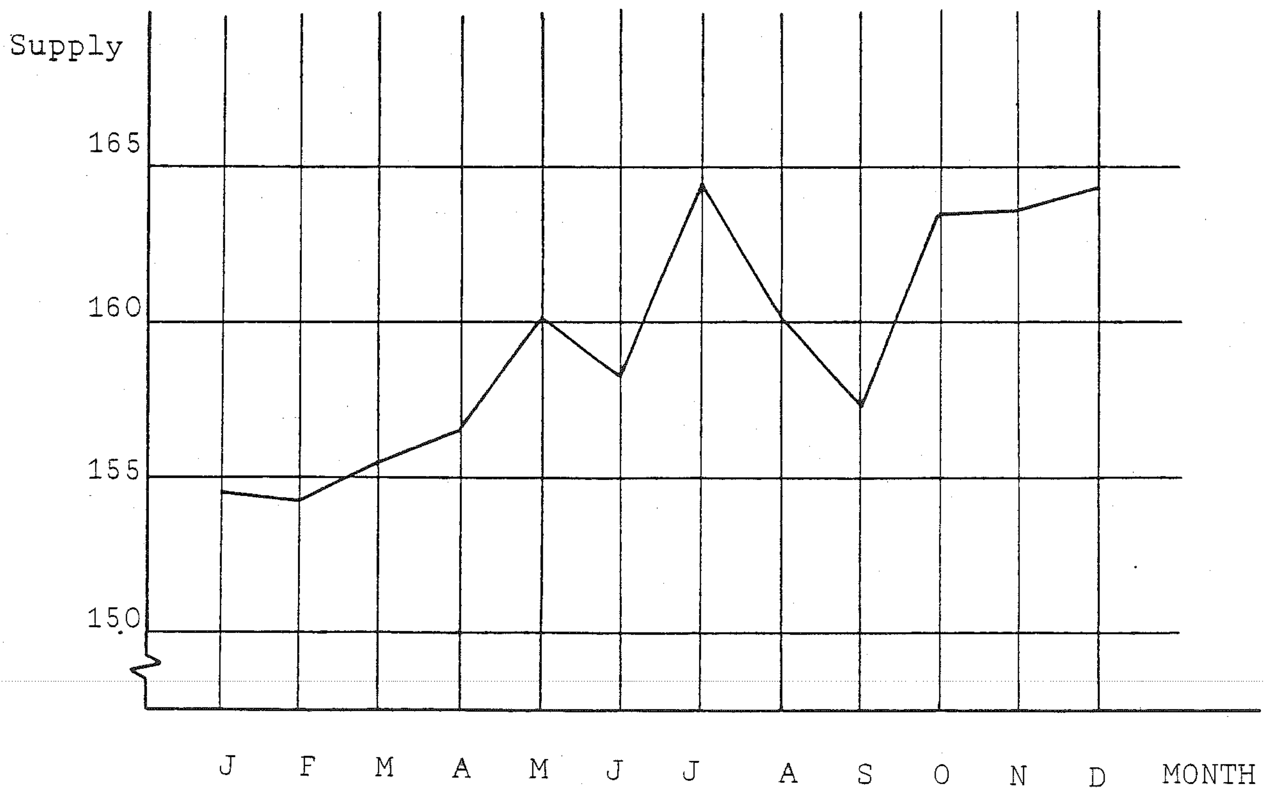


Figure 3.b :



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 following results : (°)

for grain :

$$\ln P = \underset{(5.015)^{\circ}}{-28.437} + \underset{(.953)^{\circ}}{6.434} \ln C + \underset{(.026)^{\circ}}{.317} \ln NM \underset{(.044)^{\circ}}{-.423} \ln S$$

$$\underset{(.096)}{-.143} \ln E + \underset{(.040)^{\circ}}{.173} D \qquad R^2 = .619$$

for iron ore :

$$\ln P : \underset{(6.184)^{\circ}}{-19.320} + \underset{(1.192)^{\circ}}{4.705} \ln C + \underset{(.037)^{\circ}}{.420} \ln NM \underset{(.058)^{\circ}}{-.406} \ln S$$

$$\underset{(.108)^{\circ}}{-.512} \ln E + \underset{(.064)}{.087} D \qquad R^2 = .746$$

for coal :

$$\ln P = \underset{(9.364)^{\circ\circ}}{-20.847} + \underset{(1.792)^{\circ}}{5.043} \ln C + \underset{(.053)^{\circ}}{.414} \ln NM \underset{(.102)^{\circ}}{-.511} \ln S$$

$$\underset{(.184)^{\circ\circ}}{-.353} \ln E + \underset{(.067)}{.101} D \qquad R^2 = .700$$

(°) Figures between brackets are standard errors. 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.

With P the US dollar price per ton, NM the distance in nautical miles, S the vessel size in 1 000 deadweight, E the percentage excess supply and D = 1 for multiple calls and zero , else ,and ln natural logarithms.

The statistical quality of the above regressions is fairly good. On average two third of the variation in prices is explained by the above 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.

The average elasticity of voyage length is about .38 meaning that a one percent increase in voyage length raises freight rates by slightly less than four tenths of a percent. These values are smaller than those obtained with 'engineering cost functions'. The elasticities implicit in the analysis of T.D. Heaver and Goss and Jones range between .6 and 1.

According to the above equations a one percent increase in vessel size results in a decrease of freight rates of about .45 percent. These elasticities are comparable with those found by T.D. Heaver and Goss and Jones. Their absolute values of implicit elasticities range between .3 and .7.

Market conditions have an important effect on the level of freight rates. In 1979 the average percentage of excess supply was 14.2 percent. Extreme values of excess supply were noted in june/july at 10 percent and in january at 20 percent. The net effect of a drop in excess supply from 20 to 10 percent is an increase in freight levels between 10 (grain) to over 40 (iron ore) percent. 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 depending upon the excess supply level. Consequently, periods of high excess supply tend to coincide with periods of low capacity (See figure 3). High-cost vessels will be expelled of trade 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 reenter as a tight market tends to coincide with high supply capacity. This reentering of marginal vessels will further increase freight rate levels.

The total effect of a change from a slack market with low capacity (january '79) to a tight market with high capacity (july '79) is an increase in prices of about 60 to 80 percent. This is illustrated in table 4.

Table 4. 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 %

Also, 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 :

$$E_S = \frac{1}{(\alpha)} \cdot \frac{E}{100 + E} + \frac{1}{(\beta)} \, (°)$$

(°) The first part of the expression was obtained by calculating the supply elasticity $\frac{\partial Q}{\partial p} \frac{p}{Q}$ (Q = observed quantity supplied), using the definition $E = 100 \left(\frac{C^o - Q}{Q}\right)$ and considering capacity C^o as fixed. The second part of the expression relates to the price elasticity of capacity $\frac{\partial C}{\partial p} \frac{p}{C}$

Relevant values for this sample are given in table 5.

Table 5. Supply elasticity

	E = 10 %	average excess supply (E = 14.1 %)	E = 20 %
Grain	0.79	1.02	1.32
Iron ore	0.39	.46	0.54
Coal	0.46	.55	0.67

As can be expected, the elasticity of supply of tonnage in grain trade in 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 maximize explanatory power and explicitly take into account a few important inferences of Goss-Jones-Heaver engineering cost functions.

From the GJH results it follows that required revenue per ton decreases with vessel size but at a decreasing rate and bounded below. Second, their analysis indicate that average costs per nautical mile decrease with distance and with vessel size. Finally, a non-linear response to excess supply was built in, and capacity variations as well as the effect of multiple calls were controlled for. This results in the following statistical specification.

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

where P_{it} = freight rate in dollars per ton for charter it
S_i = deadweight of vessel i in 1 000 tons
NM_i = voyage length for charter i in 1 000 nautical miles
E_t = excess supply in period t in percent of demand
C_t = capacity supplied in period t in Million ton deadweight
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 following results were obtained with this specification (°)

Grain :

$$P = \underset{(21.660)^\circ}{-125.718} + \underset{(.138)^\circ}{.715}\ C + \underset{(.635)^\circ}{2.812}\ NM - \underset{(.043)}{0.046}\ NM^2 + \underset{(35.396)^\circ}{173.800}\ 1/S$$

$$+ \underset{(1.219)}{2.073}\ E - \underset{(0.043)}{0.081}\ E^2 + \underset{(.823)^\circ}{4.255}\ D - \underset{.0065)}{0.0122}\ (NMxS) \qquad R^2 = .670$$

Iron ore :

$$P = \underset{(10.080)^\circ}{-23.020} + \underset{(.072)^{\circ\circ}}{.159}\ C + \underset{(.203)^\circ}{1.454}\ NM - \underset{(.013)^\circ}{0.035}\ NM^2 + \underset{(28.496)^\circ}{132.495}\ 1/S$$

$$+ \underset{(.673)}{.202}\ E - \underset{(.024)}{.019}\ E^2 + \underset{(.536)}{.559}\ D - \underset{(.0007)^\circ}{.0025}\ (NMxS) \qquad R^2 = .778$$

(°) Coefficients marked by ° significantly different from zero at the 1 % level, those indicated by °° different from zero at 5 % level.

coal :

$$P = -64.907 + .274\ C + .982\ NM + .029\ NM^2 + 350.576\ 1/S + 3.314\ E - .126\ E^2$$
$$(16.717)^{\circ}\ (.103)^{\circ}\quad (.527)^{\circ\circ}\quad (.039)\qquad (60.815)^{\circ}\qquad (1.032)^{\circ}\quad (.036)^{\circ}$$

$$+ 1.087\ D - .0022\ (NM \times S) \qquad R^2 = .879$$
$$(.586)^{\circ\circ}\quad (.0024)$$

Explanatory power of this specification is superior to that of the log-log equations as multiple coefficients of determination increase from .62 to .67 for grain, from .75 to .78 for iron ore and from .70 to .88 for coal. Hence, these equations are preferred for port investment cost-benefit purposes.

All coefficients have the expected sign, except for 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 miles 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. Also, the results on grain charters support this hypothesis although standard errors of the relevant coefficients are much higher. Concerning results on coal trade, estimation results do not contradict the hypothesis.

Although the estimated coefficient of nautical miles squared has the wrong sign, in view of the large standard error the true coefficient may be negative.

Average elasticities of size of these regressions are -.35 for grain, -.32 for iron ore and -.54 for coal (°). These figures are lower than the log-log results except for coal but are within the range of T.D Heaver's and Goss-Jones implicit values. The elasticities of distance are .52 for grain, .55 for iron ore and .57 for coal which is definetly higher than the log-log results but still lower than the values obtained by Heaver, Goss and Jones.

(°) Calculated at the mean values of the variables.

Conclusions

In the literature engineering cost functions for sea transportation in dry bulk carriers are available. In this paper we adopted the alternative approach to cost functions viz. 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 the producers' characteristics. Two versions of the model were estimated.
In general our results compare well with cost engineering functions, except for a systematically lower relative effect of distance on freight rates.

This finding is important in view of the use of such functions in cost-benefit analysis of port projects. E.g. if primary commodities have to be hauled over longer distances in the future one might overestimate the benefit of a project intended to serve larger vessels by using cost engineering functions.
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 supply function is more inelastic the tigher the market. Values ranging from .5 for iron ore and coal trade to 1 for grain trade were found.

References

(1) GOSS, R.O. : "Toward an economic appraisal of port investments", Journal of Transport Economics and Policy, Vol I, no. 3, september 1967, pp 249-72.

(2) GOSS R.O. and JONES, C.D. : "The economies of size in dry bulk carriers", Advances in maritime economics, (edited by R.O. GOSS), Cambridge, Cambridge University Press, 1977, pp 90-137.

(3) HEAVER, T.D. : "The cost of large vessels - An examination of the sensitivity of total vessel costs to certain operating conditions", National Ports Council, Research and Technical Bulletin, no. 7, 1970 pp 342-56.

(4) O'LOUGHLIN, C. : The economics of sea transport, Pergamon Press 1967.

(5) KENDALL, P.M.H. : A theory of optimum ship size" Journal of Transport Economics and Policy, Vol VI, no. 2 may 1972, pp 128-46.

(6) Lloyd's Shipping Economist, Vol I and II, 1979-1980.

(7) Fairplay, International Shipping Weekly, 1979.