STUDIECENTRUM VOOR ECONOMISCH EN SOCIAAL ONDERZOEK

Basic Cost-Size Relations in General Cargo Ships

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Rapport 86/185
Februari 1986

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D/1986/1169/02

Abstract

This paper discusses a basic cost relationship applied to the purchase costs of general cargo ships, sold in Yen in the period 1975-1984, and delivered by Japanese wharfs. The use of the Fairplays sample allows to amend classical double log-relationships,for gear, of which only derricks and cranes are considered. As far as the basic cost-size relationship is concerned, a power factor of 0.7 has been estimated. This exactly averages the 0.6-0.8 range, which follows from traditional geometrical properties of mechanical engineering. The specific introduction of number of gear by type (derricks, cranes or both) allows to identify a single cost function for all classes with separately estimated cost components for gear equipment. The latter prove cranes to be more expensive both in terms of their net installation costs as with respect to their influence on the over-all pruchase cost, i.e. hull and machinery.

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Introduction

This note addresses the cost-size relationship of general cargo ships, delivered between 1976 and sold in Yen. The main aim is to check the parameters of a double-logaritmic cost-size relationship, which is the basic formula for this kind of industrial applications (a), especially to the shipping industry (b). The main parameter of 0.7 found for this cost-elasticity is a well known average for applications of mechanical engineering, against lower values down to 0.4 for process-productions (as e.g. chemicals etc.).(c).

A further contribution consists in amending the basic cost function for additional cost components. For the present sample this is gear equipment, especially derricks and cranes (d). Because of the basic double log form of the main cost function gear is introduced by a semi-log specification, which introduces the assumption of negative scale effects for equipment.

In spite of a satisfying goodness-of-fit over the sample as a whole, some indications warn for applying the general results to smaller sub-samples (e.g. only-derrick or only-crane equipped vessels, gearless or combined ships), since some of those cover too few observations.

The general cost relation is stable enough to include further specifications such as inflation and corrections for price-cyclicality, currency-influences including dumping, or similar promotional devices between wharfs and shipping companies. Finally, the empiry provides vital empiry on the basic scale-factor of capital costs, which comes up for comparison with operating costs (with even higher scale effects) or voyage cost, and can also be compared between types of vessels.

1. The main four classes

The sample consists of 448 ships which are constructed between January 1976 and March 1984, i.e. 98 months later. They can be subdivided into four groups, according to the gear they carry:

a/ 148 vessels, equipped with derricks which are produced over the whole sample period (first launching in the 3th month and last in the 98th),

b/ 112 vessels, equipped with cranes, also scattered over over the whole period (from the sixth to the 97th month) The crane equipped ships are at the average of a more recent date since their construction centers around the 38/39th month (i.e. March 1979) against the 28/29th month (May-June 1978) for the derrick geared vessels.

c/ 70 vessels equipped both with derricks and cranes. Their construction scatters between the first and the 69th period (october 1981); thus the last three years none of those combined-gear units has been delivered. Their average age centers around the 28/29th month, i.e. about the same age as the derrick geared vessels (class a).

d/ 18 gearless vessels which are produced between the 10th and the 70th month (october 1981) averaging 32 months or somewhat more recent than most others.

Those figures about average age and construction span are repeated in Table 1 (third variable = month) which also provides the information on the other variables, discussed hereafter.

Table 1 : Key statistics on the main variables

		no gear	derricks	cranes	both
observations/ *month cons.*		18/*32*	148/*28.5*	112/*38*	70/*29*
1/ PRICE	average	1976	2688	5773	10758
	minimum	*600*	*720*	*800*	*1100*
in million YEN	*maximum*	*7000*	*93000*	*346600*	*256000*
	st.dev.	*1802*	*7563*	*32528*	*42382*
	variation	0.91	2.81	5.63	3.94
	assymetry	1.67	11.62	10.41	5.65
2/ DEADWEIGHT	average	7271	10687	13109	18165
	minimum	*2250*	*2895*	*3482*	*6208*
in tons	*maximum*	*18748*	*23382*	*39943*	*31555*
	st.dev.	*6036*	*4743*	*6559*	*5486*
	variation	0.83	0.44	0.50	0.30
	assymetry	0.88	0.61	0.62	-2.25
3/ MONTH	of const.aver.	31.9	28.5	38.6	28.7
	minimum	*10.*	*3.*	*6.*	*1.*
	maximum	*70.*	*98.*	*97.*	*69.*
4/ DERRICKS	(number)	0.00	6.48	0.00	5.03
	minimum		*1.0*		*1.0*
	maximum		*16.0*		*12.0*
	st.dev.		*3.50*		*2.73*
5/ CRANES	(number)	0.00	0.00	3.75	2.77
	minimum			*1.0*	*1.0*
	maximum			*7.0*	*8.0*
	st.dev.			*1.31*	*1.77*
7/ DERRICKS	(load)	0.00	108.9	0.00	158.4
	minimum		*10.0*		*20.0*
in tons	*maximum*		*555.0*		*710.0*
	st.dev.		*78.2*		*138.0*
8/ CRANES	(load)	0.00	0.00	67.6	54.3
in tons	*minimum*			*6.0*	*3.0*
	maximum			*190.0*	*150.0*
10/ DERRICKS aver.load			16.8		31.5
11/ CRANES average load				18.0	19.0

2/ Deadweight distribution by class

The class of gearless vessels averages the lowest deadweight (with 7271 dwt) as well as the lowest minimum (2250 dwt) and maximum (18748 dwt). They are followed by derrick-equipped vessels (averaging 10,687 dwt.) and crane-equipped vessels (13109 dwt.) . Combined gear vessels average 18,165 dwt. They show the highest minimum and average deadweight, but the biggest unit of this class is smaller compared to crane-geared ships.

The above parameters already provide crude evidence on the size distribution which can be completed by the "variation" (standard deviation divided by the mean) and the asymetry.

Those additional statistics show the exceptional position of combined gear vessels, as being probably the most compact class. Their high average deadweight combines with a fairly low variation and a negative assymetry. Thus this class consists of relatively heavy units with some smaller outlayers.

The first three classes display opposite features. The positive assymetry points at smaller sizes with some bigger outlayers. Generally these classes span wider deadweight ranges, especially the gearless ships with the highest variation of "0.83", and the highest asymetry of 0.88. This supports intuitive evidence that gearless units provide dominantly shortsea feeder services (partly containerized) between modern ports which are sufficiently equipped by handling equipment. Those feeders traditionally resorts to small-scale operations, but may also require exceptionally large size units.

3/ Gear distribution by class

At the average derricks are most frequently used. This not only follows from the larger size of the sample (148 units) of ship only equipped with derricks, but also from the average equipment by ship. Indeed, on specialized vessels (i.e. those either equipped by derricks OR cranes) derricks average 6.5 units per ship with a peak of 16 units on one single ships, whereas cranes average 3.75 units with a peak of 7. On ships, both equipped with derricks AND cranes, the maximum number of derricks is 12 and 8 for cranes, with their averages respectively being 5 and 2.72.

The average loads vary too. In the present sample the average crane-load scatters around 18/19 tons for the two concerned samples. However, derricks are clearly smaller on the only derrick equipped vessels (with 16.75 tons) compared with the combined crane-derrick units, where derricks average 31.6 tons average load.

4/ Correlation Analysis

Further supporting evidence is provided by inspecting the correlation matrices of the complete sample (Table 2) and those of the four previously identified subsamples (Tables 3 through 6). In this analysis our attention will be concentrated on:

- the basic cost size correlation (between variables nrs. "2" (dwt) and "1" (price),
- a potential source of collinearity between size "2", and various gear ("4" derricks and "5" cranes), and also between the above variables and the total loads (variables "7" for derrick loads and "8" for crane loads).

Those correlations are framed in Tables 2 through 6.

The basic cost relationship evidently shows the highest correlation in case of the subsample of gearless vessels, (Table 6) since there is no errative influence from gear upon price. The second best correlation between cost and size is that of derrick-equipped vessels (Table 4) where 0.32 indicates that gear is relatively distributed over the various size classes, something which is completely absent in the case of crane vessels.

A comparison of the second and first column accross all tables further learns that gear (both in number "4" & "5" as in load "7" & "8") better correlates to size than to price with coefficients often above the 0.5. This correlation is higher for cranes than for derricks which introduces clear warnings regarding the estimation of a combined size/gear cost relationship.

Table 2 : Correlation matrix for complete sample (348 ships)

var.	1	2	3	4	5	7	8	10
2.	0.08	1.00						
3.	0.04	-0.20	1.00					
4.	0.04	0.11	-0.23	1.00				
5.	0.08	0.49	0.04	-0.47	1.00			
7.	0.02	0.38	-0.25	0.60	-0.23	1.00		
8.	0.08	0.52	0.07	-0.42	0.87	-0.16	1.00	
10.	-0.01	0.39	-0.02	-0.27	0.26	0.60	0.28	1.00
11.	-0.01	0.25	0.04	-0.04	-0.03	-0.07	0.52	0.19

Table 3 : Correlation matrix for subsample of 70 ships equipped both with derricks and cranes

var.	1	2	3	4	5	7	8	10
2.	-0.05	1.00						
3.	0.26	-0.27	1.00					
4.	0.26	0.15	-0.02	1.00				
5.	-0.09	0.37	-0.18	0.06	1.00			
7.	-0.01	0.52	-0.16	0.26	0.08	1.00		
8.	-0.13	0.58	-0.17	-0.19	0.75	0.11	1.00	
10.	-0.08	0.27	-0.11	-0.31	0.04	0.62	0.35	1.00
11.	-0.15	0.47	0.03	-0.31	0.20	0.16	0.70	0.20

meaning	price in mill.yen	dwt ton	month 1975+	number of gear derricks	cranes	load capacity derrick	crane	average load of

Table 4 : Correlation matrix for subsample of 148 ships only equipped with derricks.

var.	1	2	3	4	7	10
1	1.00					
2	0.32	1.00				
3	0.13	-o.38	1.00			
4	0.02	0.41	-o.22	1.00		
7	0.06	0.65	-o.34	0.45	1.00	
10	0.05	0.39	0.05	-o.23	0.51	1.00

Table 5 : Correlation matrix for subsample of 112 ships only equipped with cranes.

var.	1	2	3	5	8	11
1	1.00					
2	0.09	1.00				
3	-o.10	-o.22	1.00			
5	0.09	0.67	-o.22	1.00		
8	0.13	0.64	-o.10	0.73	1.00	
11	0.04	0.24	0.03	-o.05	0.48	1.00

Table 6 : Correlation matrix for subsample of 18 ships without any gear

var.	1	2	3
1	1.00		
2	0.86	1.00	
3	0.73	0.80	1.00

A curious and informative side-product of the correlation matrices is the relation between the number of elapsed months (variable "3") and the various other variables, of which the coefficients are given along the third row or column. There only the correlation between price and time is positive (except for crane-equipped vessels) and most others are negative. This tends to indicate that over the last eight years, ships tend to become smaller (at least for general cargo ships generally spoken) and are progressively less equipped with various gear. The latter ascertion only applies to the number of gear since some evidence shows that the average load might increase. If this evidence might be pursued in the future then general cargo ships tend to loose their bigger units to the container market and remain with a fewer combination of predominantly feeder vessels.

5/ Regression analysis

The general form of best regression fit is:

$$\log PRICE = a + b \log DWT + c\ GEAR + f\ TIME$$

or $$PRICE = DWT^{b} . \exp(a + c.GEAR + f.TIME)$$

This specification assumes a multiplicative relation between cost and size (i.e. the scale factor), which is corrected by:

- an annual inflation factor ($e^{12.f}$) wherein "f" gives the compound monthly increase of construction costs.
- a progressively upbuilding cost component for the number of gear units installed. This semi-log specification does not allow for scale factors and even postulates a slight diseconomy of scale for the larger batteries of deck gear.

The regression results involving all 350 ships, are:

log YEN =	0.74 +	0.71 log DWT +	0.04 DER +	0.08 CRN +	0.003 MTH
t-stat.	1.15	9.95	3.75	3.74	2.01

R: 0.66

or after re-transformation:

$$YEN = 2.09 . DWT^{0.71} . e^{0.04\ DER + 0.08\ CRN + 0.003\ MTH}$$

with: YEN : construction cost in millions of yen,
DWT : deadweight tonnage,
DER : number of derricks installed,
CRN : number of cranes installed,
MTH : months elapsed from january 1975 onwards.

A more articulated approach consists in amending the standard equation (1) for scale factors which typically correspond to each of the subsamples. n this case, the derrick vessels are taken for most neutral base-case, and significant deviations are checked for the scale factors of crane-equipped and combined gear vessels. The results of this estimation are (e):

$$\log PRICE = \underset{(0.90)}{0.680} + \underset{(8.37)}{0.698} \log DWT + \underset{(4.45)}{0.056} DER + \underset{(2.15)}{0.064} CRN + \underset{(1.79)}{0.003} MTH$$

$$+ \underset{(1.68)}{0.020} \log DWT.DCG \text{ (for combined gear vessels)}$$

$$+ \underset{(1.55)}{0.024} \log DWT.DCR \text{ (for crane-equipped vessels)}$$

R = 0.65

with : DCG a dummy taking "1" for vessels carrying both cranes and derricks and being zero otherwise,
DCR a dummy taking "1" for vessels only equipped with cranes and being zero otherwise,

The estimates of those small amendments to the basic dwt-coefficient of 0.698 are acceptable in view of their very small value and in spite of a quite low t-statistic. Moreover, the over-all picture now portrays the need for a stronger (i.e. more expensive) hull composition for geared vessels which is especially marked for cranes, to which is added an additional cost per crane being also higher than the cost per additional derrick. In the first equation (1) both effects have been joined in the coeffcients of "DER" and "CRN" whereas here the cost increase of the number of gear gear is separated from the cost increase due to the strenghtening of the hull.

In spite of some less attractive characteristics (especially the due ommission of gearless ships° the latter equation is more informative on the basic cost relationship and as such is best suited for simulation work.

6/ Evaluation (f)

The satisfying results of the general regressions should not dismiss the ennoying evidence of some collinearity , which is observed between dwt-size and gear. This stands for the fact that at the average bigger ships may carry more gear; it is consequently not always possible to allocate exactly the higher purchase cost at the margin to either the bigger size (i.e. hull and machinery) or to a different lay-out of derricks and cranes. This collinearity is acceptable over the whole population but may obtain prohibitive levels for some subsamples, especially for the group of ships which are equipped with cranes or with both gear.

The scale factor of 0.7 is close to the so-called "two-thirds" power rule applicable for mechanical engineering (hull) as well as for installed power (machinery). This number is generally higher than the operating costs but lower than the direct voyage costs, especially fuel. It also sticks to most observations in the past, which reveal higher scale factors only for some specific bulk carriers.

The initial restriction to Japan built ships sold in Yen has allowed to concentrate on the basic cost relation. since the other half of the sample is scattered over at least ten nationalities and/or currencies. Further research on this basic model may include currency conversions over time, but will have to make corrections as well for different inflation rates, dumping or similar devices favouring one customer more than another. All those amendeents might require a fully integrated cost model over all ship classes, for which the present exercise was a constructive introduction.

Notes and References

(a) The basic reference for multiplicative cost-size functions is given by traditional textbook approaches of a firm's production function as being:

- either constituted by successive sections of increasing and decreasing returns in the production function and the associated cost-function,
- or by the simultaneous action of several cost-components featuring either more-than-proportional or less-than-proportional cost increases fueled byseparate causes at the same moment of time

The former point has been initiated by Chamberlin pointing at "indivisibilities", the proportions of factors employed as well as their aggregate amount for generating scale effects, whereas the "greater complexity of the unit as it grows in size" suggests adverse scale effects; see E.H. CHAMBERLIN, Proportionality, Divisibility and economics of scale, Quaterly Journal of Economics, Vol.62,nr.2.,pp.229-61, with two comments by A.N. Mc Leod and F.H.HAHN plus authors' reply in op.cit., Vol.63,nr.1, pp.128-43; or W.W. COOPER and A. CHARNES, Silhouette Junctions and short run cost behavior, Quaterly Journal of Economics, Vol.68,nr.1, pp.131-50

The latter point is connected to the size of production and intensity of production given respectively positive and negative scale factors; see e.g. ALCHIAN, Cost and Outputs in M. Abramovitz et al., The allocation of Economic Resources Stanford University Press, 1959 with further contributions by J. HIRSHLEIFER, the firm's cost function, a successful reconstruction, The Journal of Business, Vol.35,nr.3,pp.235-55.

(b) For empirical research on the shipping business we refer to recent publications by JANSSON J.O. and SHNEERSON D., Economies of Scale of General Cargo Ships, in The Review of Economics and Statistics, Vol.60/2 ; pp.287-93, where a 0.66 scale factor is mentioned for size influence upon newbuilding capital costs. These author additionally provide a most instructuve overview of size elasticities of capital costs , ranging from 0.7 for bulk carriers, over 0.67 for tramps, down to 0.6 for liners and tankers. All those capital-cost figures are higher than operating-cost elasticities which follow a .4 to .6 power. Lower cost elasticities are also found by R.O. GOSS and M.C. MANN in The Cost of ship's time in R. O. GOSS (editor) Advance in Maritime Economics,Oxford University Press, 1977, pp.150-1, where General Cargo Ships feature a 0.5 cost-elasticity for all costs associated to sgip's time. Since time costs include capital and operating costs (including the "hotel load" fuel spent in ports) the 0.5 figure seems a fair average between the higher elasticity of capital costs and the lower one of operating costs.

(c) initially the basic a-priori assumptions governing this "two thirds" power rule refer to the fact that for sferical bodies the ratio of surface to capacity is about two thirds, and so do costs to capacity. For cylinders that factor would only be 0.5 such that 0.6 seems to be a reasonable average. see CHILTON C.H.; "The six thenths factor applied to complete plant costs" and R. WILLIAMS jr. "'Six-Tenths Factor' Aids in Approximating Costs" as referred to among others by F.T.MOORE Economies of Scale; some statistical evidence, Quaterly Journal of Economics, Vol.73,2, May 1959, pp. 232-245, with further comments by S.C. SHUMAN and S.B.ALPERT and reply in op. cit. Vol.74,3,pp.493-9. A similar 2/3 power rule was identified by JANSSON and SHNEERSON (see op.cit.) for the relation between shaft horsepower and size, whereas it follows a cubic relation against speed. Thus both "Hull and Machinery" bear a similar parameter of a-priori assumptions, some of which are based on 25 years old, but probably not outdated, thumb rules.

(d) The presently used data follow the regularly updated Fairplays listing of newly delivered ships published on computer prints of which the April 1984 edition has been used. Those files provide excellent information the ship's gear. For the present research only those ships have been taken for observation, which are delivered in Yen, with known gear or which are certainly known to be gearless. Additionally, two units with "twin cranes" were omitted for being too small a "subsample" for this kind of speci lized equipment. The others form four subsamples with 18 gearless units, 148 only equipped with derricks and 112 only with cranes, whereas 70 are equipped both with derricks and cranes. The regression thus totals 348 observations.

(e) this regression only refers to the 380 bservations of geared vessels, in which the 18 gearless units were omitted.

(f) with thanks to W. Nonneman, M. Willems, M. Cliquet, C. Van Mechelen, R.Schelfaut, A. Verbruggen, L.Baudez sJ R.Vleugels and W.Pauwels for the constructive sharing of their engineering proficiency or vital knowledge of the shipping business; also my sincere appreciation for informative talks with Mr.Coppieters (Ahlers Shipping) and Mr.P. Verstuyft (Boel shipyard).

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