A cross sectional analysis of ship maintenance expenses

By

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Abstract

This paper introduces an econometric model to explain the determinants of expenditure in ship maintenance and repair. The data refer to 112 vessels of different types that operated in 1999 and were collected from ten Greek ship owning and management companies. On the methodological plain the best functional form is obtained when estimating a semi log-linear model. As expected from theory, the empirical results show that maintenance expenditure is positively related to utilization, age, and size. In addition the effect of age is found to be stronger on vessels younger than 20 years. This may be due to the fact that vessels less than 20 years old can be sold more easily in the second-hand market, whereas older vessels have a shorter lifetime and are also constrained by safety regulations. Therefore, ship owners are more reluctant to spend more once the vessel passes its 4th and especially its 5th special survey. To trace the effect of company policies we included in the model company dummy variables. We found that such effects are present particularly when stores expenses are estimated separately. In turn, this suggested that company policies have still some control on maintenance expenses. Another result is that the elasticities of maintenance expenses with respect to utilization, age, and size at least in 1999 were uniformly less than one, thus revealing the existence of significant economies of scale. And still another result is that the type of ship, the flag, the classification and even the yard where maintenance takes place are significant determinants of the respective outlays.

JEL Classification:
Keywords: ship maintenance expenses, utilization,

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1. Introduction

Ship owning and management companies are facing new pressures and challenges in procuring an effective and cost efficient maintenance schedule. During the 90's a new stream of regulations and the increasing activity of State Port Authorities in ensuring that visiting vessels satisfy their seaworthiness certificates changed the perception on how ship maintenance should be dealt. Indeed, the new policy trend towards eliminating substandard ships aims at improving seaworthiness and at raising the quality and quantity as well as the frequency of maintenance. Overhauling, in terms of major surveys, is no longer perceived to be the only means of maintenance but rather regular maintenance is required to be preventive in nature and allow for upgrading the equipment and condition of the vessel. Thus, understanding which factors contribute in what way and by how much towards maintenance effectiveness may assist managers optimise the allocation of respective resources in their efforts to determine the useful lives of their vessels, and thus, to an extent, their policies regarding fleet composition.

The literature to which we could turn for helpful leads in our research focuses mainly on the theory of scrapping and replacement and much less on utilisation, maintenance and the other decisions pertaining to ships in particular and to equipment in general. Recently Jin and Kite-Powel (1999) studied the issue of fleet renewal and found that ship replacement and ship operating decisions are taken jointly so as to permit maximum fleet utilisation. But they did not pay attention to maintenance. A decade earlier Evans (1989) analysed the problem of ship replacement under technological obsolescence and ship modifications, but without considering the issues that are associated with ship utilisation and maintenance. At about the same time Ye (1990) investigated equipment replacement with emphasis on the stochastic nature of maintenance and operating costs, but without allowing explicitly for the intricate interrelatedness of policies regarding utilization, maintenance and scrapping. In short, by concentrating on a few of the relevant decisions and ignoring the rest, all specialised and general purpose literature has adopted a partial equilibrium approach to study a problem, which is essentially general equilibrium in nature. For this reason the model that came closer to serving our research objectives is the one that has evolved from the contributions by Bitros (1976a, 1976b, 2004) and Bitros and Flytzanis (2002, 2003, 2004).

On the theoretical plain, the estimated model took a semi log-linear form and fitted well the observations. No matter how the data were segmented the estimates highlighted three key factors that explained total ship maintenance expenses in 1999. These were the age, the size and the utilisation of ships. In addition we estimated the effect on maintenance for vessels under 20 years old and for each type of vessel in the sample. The results confirm Frankel's (1991) findings that total maintenance expenses increase for vessel over 20 years, though this increase is not as dramatic as it is presumed. Last, but not least, we estimated separate models for stores, spares and repairs/surveys and found that the issue of upgrading is still a company policy matter.

Turning to the practical plain, our results may have quite useful implications. With regard to maintenance decision-making we found that the yard where major repairs take place is of importance. Given our sample, we point out a number of yards that raise total ship maintenance expenditure. When separate models for stores, spares and repairs expenses are estimated, it turns out that ships, which are not painted with epoxy coating on cargo and ballast tanks at construction, exhibit increased spares maintenance expenses. Vessels that are built with high tensile steel result also in higher repair expenses because of the need to replace the old thin steel with new one. Interestingly, in the estimated model for stores the effect of company dummy is the most apparent one than anywhere else. Hence it is here where most likely company policy could have more control on maintenance expenses given the new regulations, even though it may be the case that it could reduce the quality and standard of maintenance.

The following Section lays down the formulation of the model and the considerations that were introduced to adapt it to the characteristics and operating conditions of ships. Section III describes the sources of the data, the definitions of the variables that enter into the various specifications of the model, and the compromises that we adopted for their measurement. In Section IV we present the estimated models and interpret the significance of the results from both the theoretical and the practical point of view. And lastly, in Section V, we summarise our conclusions and suggest certain aspect of our research, which warrant further research efforts.

2. The model

Consider a ship of any kind. The manufacturers of its various systems and components prescribe what type of maintenance is due at any given time. So to secure normal service and avoid the risks of major damages, the manager of the ship must follow the recommendations contained in the owners' manuals. As a result these *regular maintenance* procedures may be considered mandatory. However, the same is not true with respect to the cases of *preventive maintenance and repair*, or just *maintenance*, because these are under the manager's discretion. Consequently the problem that he faces is to decide when and how much to spend in the undertaking of such activities.

According to the model presented by Bitros and Flytzanis (2004), the manager of the ship is expected to act in line with the precepts of economic theory. This implies that he is expected to decide as if he were guided by the rules emanating from the solution to the problem:

$$
\begin{aligned}
&\text{Choose } [T, u(t), m(t)] \text{ so as to maximize:}\\
&A = \tilde{Q} + \tilde{S} = \int_0^T q(u,m,K)\varphi(t)dt + \varphi(T)S(K_T,T)\\
&\text{s.t.} \quad \dot{K} = -s(u,m,K), \text{ with } K(t_0) = K_0, \text{ and}\\
&\qquad 0 \le u \le 1,\ 0 \le m \le 1,
\end{aligned} \tag{1}
$$

where the various symbols are defined as follows:

$\tilde{Q} = \int_0^T q(u,m,K)\varphi(t)dt$: Expected net operating revenue for operating horizon *T*.

$K = K(\mathrm{t})$: Existing ship measured in efficiency units, reflecting its size and age since first put in operation. New or old ship will be denoted by $K_0 = K(0)$.

$u = u(t)$: Utilization intensity relative to some extremal values, with $0 \le u \le 1$.

$m = m(t)$: Maintenance intensity expressed as expense relative to some extremal values, with $0 \le m \le 1$.

(u,m): Operating policy factors.

$q(u,m,K)$: Flow of net operating revenue.

$s(u,m,K)$: Flow of net capital wear.

(q,s): Operating policy flows.

$S = S(K_T,T)$: Scrap value of existing ship at T. For the scrap value of new ship we set $S_0 = S(K_0,0)$.

$\varphi(t) = e^{-\sigma t}$: Effective discount factor. Let $F(t)$ denote the probability of a *technological breakthrough* by time t, with $F(0) = 0$ and $F(t) < 1$ for all t. Assuming a constant discount rate ρ, the discount factor would be $e^{-\rho t}$. To account for technological uncertainty this is multiplied by $[1 - F(t)]$. In keeping with the specification of time invariance, attention is limited to the usual exponential case: $F(t) = 1 - e^{-\theta t}$. Then, since $\varphi(t) = e^{-(\theta+\rho)t}$, the effect of uncertainty is equivalent to introducing a revised *effective discount rate*, expressed by $\sigma = \theta + \rho$.

Expression **(1)** describes the general setting of an optimal control problem. Instead the analysis focuses on a more specific model by assuming q and s of the following type:

$q = rK^{\varepsilon}$: Where $r = r(u,m)$ is the operating net revenue rate. Usually positive, but it can also be negative. Increasing in *u,* decreasing in *m,* concave in *(u, m)*.

$s = wK$: Where $w = w(u,m)$ is the capital wear rate. Increasing in *u,* decreasing in *m,* convex in (u,m). It expresses the effect on car of *maintenance* and *utilization*, including *aging*. Usually positive but it can also be negative, if aging causes upgrading or if investment type of maintenance overbalances the wear of equipment, allowing K to even rise above the original K_0.

(w,r) *: Operating policy rates*

These rate functions characterize the operating features of the ship. They have been taken to be time invariant. However, prices are allowed to vary by setting:

$S = p_K e^{\eta T} K$: Scrap value of ship at time T , where:

η : Relative rate of price change. It is the difference between ship price change and operating revenue price change, because any common part can be subtracted from the discount rate σ. It can have either sign, or be zero.

p_K : Construction cost of a new ship.

With the help of these specifications Bitros and Flytzanis (2004) investigated the dependence on the parameters $\{\varepsilon,\sigma,\eta,p_K,K_0\}$ of: a) the *operating policies,* defined by the optimal rates of *utilization* and *maintenance* as functions of time*:* $\{u = u(t), m = m(t)\}$, and b) the *scrapping policy,* defined by the optimal duration or service life T^*.

From that investigation it turned out that the solution to **(1)** yields several conditions that the optimal operating and scrapping policies must obey. In particular, the ones for *utilization*, *maintenance* and *service life* are given by:

(i). For operating policies: $\{r = r(w), r'(w) = \mu\} \Rightarrow \{w = w(\mu), r = r(\mu)\}$
(ii). For capital stock: $\dot{K} = w(\mu)K$, with initial condition $K(0) = K_0$
(iii). For logistic value: $\dot{\mu} = \varepsilon\mu[\sigma/\varepsilon - i(\mu)]$, with final condition*:* $\mu_T = pe^{\eta T} K_T^{1-\varepsilon}$ **(2)**
(iv). For service life, the terminal scrapping condition: $i(\mu_T) = \sigma - \eta$,
(v). For profitability*:* $\sigma - \eta < i(\mu_0)$ where $\mu_0 = pK_0^{1-\varepsilon}$,

where the logistic value μ stands for the ship owner's shadow cost per unit of operating capital. Looking at **(2)** we observe that **2(iii)** is autonomous. Moreover, since μ is continuous it will move in time monotonously. The sign of the derivative $\dot{\mu}$ determines the direction of monotonicity at any time, in particular at the terminal time T, given that ships are scrappable. Substituting from **2(iv)** into **2(ii)** we find:

$$\dot{\mu}_T = \varepsilon[\sigma/\varepsilon - (\sigma-\eta)]\mu_T \text{, where } \mu_T = pe^{\eta T}K_T^{1-\varepsilon} > 0 \,. \qquad \textbf{(3)}$$

Observe that the monotonicity property depends on the relative magnitude of the discount rate σ/ε, for operating capital K^{ε}, and the discount rate $\sigma-\eta$, for scrapping capital K. Drawing on this finding Bitros and Flytzanis (2004) established:

Proposition 1: Time shift of operating policies
If the equipment is scrappable, then we distinguish three cases:

1. If $\sigma/\varepsilon > \sigma-\eta \Rightarrow \eta > (1-1/\varepsilon)\sigma$, i.e. if the operating discount is higher than the scrapping discount, then $\mu(t)$ increases in time from harder (more utilization and less maintenance) to softer (less utilization and more maintenance) policies.

2. If $\sigma/\varepsilon < \sigma-\eta \Rightarrow \eta < (1-1/\varepsilon)\sigma$, i.e. if the operating discount is lower than the scrapping discount, then $\mu(t)$ decreases in time from softer (less utilization and more maintenance) to harder (more utilization and less maintenance) policies.

3. If $\sigma/\varepsilon = \sigma-\eta \Rightarrow \eta = (1-1/\varepsilon)\sigma$, i.e. if the operating discount and the scrapping discount are equal, then $\mu(t)$ stays fixed in time at the equilibrium policy.

Hence, since the focus in this paper is on the equilibrium operating policies applied by ship owning and management companies, the analysis will be limited to **Proposition 1(3)**.

Under this stipulation, the value of $\mu(t)$ stays fixed up to scrapping time *T*. By implication it must hold that:

$$r'(w_t) = p_K e^{\eta T} K_T^{1-\varepsilon} \,. \qquad \textbf{(4)}$$

This suggests that the ship manager should retain the ship up to the time when the extra operating revenue realized from its utilization is equal to the ship's scrap value per unit of operating capital. Consequently **(4)** provides a rule of optimal conduct on his part, as well as a model to gauge his behavior. But before it can be adopted for empirical analysis, two modifications are in order.

The first of them is required because **(4)** has been derived on the hypothesis that the ship manager knows the analytic form of the operating function $r(w)$. But in actuality this is rarely the case. Hence, in order to obtain an estimable model, it is necessary to assign to this function an analytic form and at the same time to express it in terms of variables that can be observed. To this end, and in order to allow for the most general specification of the estimating equation, we adopted the following assumptions:

$$\begin{aligned} &\textbf{(i)} \quad r_t = a_0 w_t^{\alpha_1} - \alpha_2, \text{ for } \alpha_0, \alpha_2 > 0 \text{ and } 0 < \alpha_1 < 1, \\ &\textbf{(ii)} \quad w_t = \beta_0 u_t^{\beta_1} m_t^{\beta_2}, \quad \text{for } \beta_0, \beta_1 > 0 \text{ and } \beta_2 < 0. \end{aligned} \qquad \textbf{(4)}$$

Thus, substituting **4(ii)** into the derivative $r'(w)$ from **4(i)**, introducing the result into **(3),** and rearranging, yields:

$$m_t = [\alpha u_t^{\beta} \cdot \frac{p_K e^{\eta T} K_T}{K_T^{\varepsilon}}]^{\gamma},$$
$$\alpha = \frac{\beta_0^{1-\alpha_1}}{\alpha_0 \alpha_1} > 0,\ \beta = \beta_1(1-\alpha_1) > 0,\ \gamma = \frac{1}{\beta_2(\alpha_1 - 1)} > 0. \qquad \textbf{(5)}$$

As for the second modification this is recommended by the observation that the services remaining in a ship at any time cannot be measured directly. From the analysis in Bitros and Flytzanis (2004) we know that, if the average wear of a ship is given by: $\omega = \frac{1}{T}\int_0^T w(t)dt$, the amount of services left in it at T is: $K_T = K_0 e^{-\omega T}$. Thus substituting the latter expression into **(5)** and recalling that $S_T = p_K e^{\eta T} K_T$ gives rise to:

$$m_t = [\alpha u_t^{\beta} \cdot \frac{S_T}{(K_0 e^{-\omega T})^{\varepsilon}}]^{\gamma}. \qquad \textbf{(6)}$$

This maintenance equation has several merits. One is that it constitutes an equilibrium relationship derived from an analytical framework based on rational economic behavior in which operating and capital policies are properly integrated. As such it provides a model of choice for related empirical applications at various levels of aggregation and for all kinds of consumer and producer durables. Moreover, since from **Propositions 1(1)** and **1(2)** we know how the operating policies depend on the relative magnitude of the two discount rates, we are able to trace their time paths as well as all their possible shifts.

Another merit is that it features endogenously most of the variables that have been considered in the relevant literature to be important determinants of maintenance expenditures. What this implies is that we gain significant understanding of past findings in this area. For two cases in point consider the roles of size and salvage value. With respect to the former, the available empirical evidence indicates that the quality of durables is positively related to their size. But if larger durables in the same class have more quality, they may tend to break down less frequently than smaller ones, so that on the average they may cost less to maintain. To capture this effect, in previous endeavors researchers included a proxy variable for size without any guidance regarding the sign of its coefficient. By contrast, the prediction from **(6)** is that K_0 should be negatively related to maintenance expenditures.

Lastly, regarding the salvage value S_T, in the past this was introduced into maintenance equations by reference to three arguments. The first asserted that, since the amount one would need to borrow in order to purchase a new durable depends negatively on the amount one would expect to collect from selling one's old durable, in the presence of significant financial market imperfections, salvage value should be related inversely to maintenance expenditures. The second argument claimed that, in suppressed financial environment and particularly under inflationary conditions, durables become good stores of value. So, as salvage value appreciates, owners of durables may be expected to maintain them in good condition, and hence, salvage value and maintenance expenditures should be related positively. Lastly, those who adhered to the third argument suggested that, if increases in the prices of new durables raise the prices of older durables, S_T should enter into the maintenance equation with a positive sign, because the cost of maintenance becomes relatively cheaper than before. In other words, as the prices of older ships increase, maintenance becomes a better substitute for a new ship, so managers of older ships, who otherwise might have scrapped them, are induced to maintain them. Consequently, since all evidence from the movement of prices in second hand markets for ships shows that increases in new ship prices do raise the prices of older ships, a shift in S_T would be expected to increase maintenance expenditures.[1]

In light of the preceding remarks it is clear that the appearance in **(6)** of K_0 and S_T from theory resolves two issues that have been clouded in uncertainty for many years. But these are not its only novel features. In addition it includes two key variables, i.e. utilization u_t and service life T. Turning first to the latter, from **(6)** we observe that as service life increases maintenance expenditures are predicted to increase. So what we have here is solid theoretical evidence in support of the ad hoc arguments that were occasionally adopted to rationalize the introduction of service life into partial and general equilibrium analyses of capital. However, whether maintenance expenditures increase faster with increasing service life, as hypothesized, say, by Brems (1968), or not is a question that can be resolved only on empirical grounds. For this reason the importance of empirical research in this respect can hardly be overstressed.

Now let us return to the utilization rate. From **(6)** it emerges that an increase (decrease) in the intensity of utilization u_t would be expected to increase (decrease) maintenance expenditures. What this implies is that the operating policies move from the region of less intensive policies, i.e. less utilization and less maintenance, to the region of more intensive policies, i.e. more utilization and more maintenance, and vice versa. The reason for this result is found in two choices, i.e. the decision to restrict attention solely to the equilibrium solution of the model, and the specification of the operating function in **4(i)**. For, as **Proposi-**

tions 1(1) and **1(2)** succinctly state, when the relative magnitudes of the two discount rates σ / ε and $\sigma - \eta$ differ, the operating policies move from softer (less utilization and more maintenance) to harder (more utilization and less maintenance), and vice versa, whereas if **4(i)** were specified as linear no determinate equilibrium policies would exist.

To summarize the discussion so far, the model that was just presented yields sharp sign predictions for most of the main variables that determine maintenance expenditures. As a result it sheds considerable light on several long-standing issues in the relevant literature and opens the road for fruitful theoretical and empirical research in both partial and general equilibrium setups. Hopefully, the case on which we report below will stir strong interest for more applications using data from different durables, time periods, and countries.

2.1 A brief note on ship maintenance policies and regulations

In the period before the introduction of the International Safety Management Code (ISMC), ship owners opted usually for a "breakdown" policy. In other words, all equipment would be lubricated and operated with care, yet no maintenance would take place until equipment would break down and it would require repairs or complete change of spares. This policy led to substandard vessels and coincided with a number of prominent shipping accidents (e.g. Exxon Valdez). As a result policy makers changed attitudes on how shipping maintenance should be done.

The imposition of the ISMC and the increasing number of Port State Controls have changed the disposition of shipping companies with respect the maintenance of ships. Nowadays any ISMC certified shipping company is obliged to carry a planned maintenance policy. Although some may be more organized than other shipping companies, the preventive nature of the new regulations imposes higher maintenance cost for all companies. In addition, the fact that planned maintenance work requires stricter control and existence of records has led to more frequent maintenance rather than postponing it until the next intermediate and special survey. ICS/ISF[2] suggest that preventive maintenance policies be established for the non-exhaustive list of ship components shown in the **Table 2.1**. Actually the ISMC does not recommend an infrequent maintenance policy, but it imposes a continuous assessment of the vessel's condition and requires immediate action by the shipping company to remedy any system fault or malfunctioning.

Lastly, the increasing number of Port State Controls and Detentions of vessels has obliged ship owners to be very careful on keeping good track maintenance records and to detect possible maintenance work before the ship entering a strict port on safety issues. Therefore, whenever it is practically feasible, ship companies increase maintenance work during a ship voy-

Table 2.1: Ship components for preventive maintenance as suggested by ICS/ISF

- Hull and superstructure steel work
- Safety, fire and anti-pollution equipment
- Navigational equipment
- Steering gear
- Anchoring and mooring equipment
- Main engine and auxiliary machinery
- Pipelines and valves
- Cargo loading discharging equipment
- Inerting systems
- Fire, gas and heat detection systems
- Bilge and ballast pumping and separator systems
- Waste disposal and sewage systems
- Communication equipment

age, in particular when the vessel is on ballast, to avoid potential detentions in ports. The potential risk of a vessel being detained has huge commercial as well as legal and insurance implications since these are reported and may affect the vessel's cash flows in terms of income and insurance premia, which will have to pay for a substandard vessel.

2.2. From the theoretical to the estimating model

Equation (6) includes the main variables that economic theory considers important determinants of maintenance expenditures. However, given that our focus is on the determinants of expenditures that are associated with the maintenance of ships, the model derived from theory may be too narrow. By implication equation (6) ought to be expanded to allow for additional factors that have been shown or are suspected to exert significant influences on the maintenance expenditures of ships, irrespective of whether their identification originates in the theoretical literature, the empirical literature, or the regulations from national and international authorities. Hence, it is reasonable to consider the addition of the following quantitative and qualitative variables:

2.2.1 Number of crew and crew composition

Having extra crew on board to undertake maintenance work may increase directly maintenance expenditure. However, if the maintenance is postponed, it may result in higher future maintenance outlays (higher dry-docking bills) and foregone earnings. Hence the relationship of crew on board and maintenance expenditure is not straightforward. In addition, the composition of the in terms of different nationalities does not impose any a priori expectation, since all crew carry internationally equivalent certificates. To be sure there are wage differences among different crew nationalities and possibly different productivity levels. But a more productive crew may pay more attention to maintenance, thus raising current maintenance outlays but potentially reducing the risk of unexpected higher maintenance bills in the future.

2.2.2 Type of vessel

Vessel type is expected to be a significant factor because different vessel types imply that operational procedures may have an impact on the vessel’s wear and tear and result in a wide spectrum of maintenance expenses among all types of vessels. Usually, containerships, gas carriers like Liquefied Petroleum Gas (LPG), Liquefied Natural Gas (LNG), and Ro-Ro vessels are committed in haul trades that require them to operate at high speeds so as to meet their time schedule targets. Moreover, the high number of ports visited per year and the higher frequency of charging and discharging, leads to higher levels of physical stress of the vessel. Tramp ships on the other hand, are more flexible in terms of adjusting their speed, since the latter depends on the conditions prevailing in the freight market, ship managers of tramp vessels may consider more carefully whether to accept a shipment. Factors such as where to charge/discharge are considered carefully since the benefit from the freight may not always compensate the risk of damaging the vessel in a substandard terminal, especially when cargoes like iron ore can damage significantly the vessel’s cargo hulls. In sum, it is expected that LPGs that use sophisticated technology for the safe transportation of gas products to exhibit higher maintenance expenses than simpler types of vessels.

2.2.3 Flag

Choosing a Flag may enable a ship owner to avoid expenses since countries with the respective flags set regulations on maintenance, nationality of crew, and safety conditions. Li and Wonham (1999) undertook a study on the safety records in terms of accidental total loss rates of thirty-six world principal fleets using twenty years of data. Their study confirmed that open registered ships tend towards substandard ships. In addition the study showed that the developing country fleets performed better than those of developed countries, although some of the former flags had performed much worse than the average. Therefore, choosing a flag may affect maintenance policy, and condition a vessel’s seaworthiness record. For example, Panama was recorded in the above-mentioned study as one of the worst flags in terms of safety grounds. The Drewry report (1999) shows a summary of the Australian Maritime Safety Authority port state control inspection in Australia and 29% of the ships inspected were registered with Panama. It may be that port authorities get more suspicious with flags that have a worse reputation relative to than others. Interestingly, however, while Singapore was rated better than Panama in the above study, the highest percentage of ships detained were not those with Panama flags but those with Singaporean flags, since 10% of the latter were detained as opposed to 6% of the former.

Eventually the ship maintenance rules imposed ISMC scheme, as well as the increasing number of port state controls, may vitiate the influence of flag on the respective expenditures. This is likely to happen because, although there are still some flags from developing countries for which the ISMC rules are relatively laxed, shipping companies are obliged to pay increasing attention to safety issues, irrespective of their vessels' flag. But in 1999 the flag factor was present and should be included in the set of explanatory variables.

2.2.4 The ship's construction

Factors such as the ship's original construction may affect subsequent maintenance requirements. If epoxy coating was applied on cargo and ballast tanks when the vessel was built it may bring long lasting benefits because it protects the vessel from the early corrosion on its surface. In addition, a series of vessels built with high tensile steel technology resulted in higher maintenance demands. High tensile steel is thinner and resulted in higher future steel replacements as a result of extensive corrosion on vessels' hull superstructure. It is expected that vessels built with high tensile steel require higher maintenance expenditures. In particular, one should test if the specific repairs and survey expenses are positively related to this factor.

2.2.5 Class

Classification Societies play a role in assessing the vessel's seaworthiness. According to Stopford (1999) the main job of classification societies is to enhance the safety of life and property at sea by securing high technical standards of design, manufacture, construction, and maintenance of mercantile and non-mercantile shipping. It is the classification societies that have imposed the obligatory intermediate and special surveys. These class requirements set the general regulation for classing existing vessel. Each society, nevertheless, can extend its requirements and set even stricter rules. For example, Lloyds Register[3] imposes a hull and machinery special survey-every five years-, dry-docking-every 2 and a half years- annual hull and machinery surveys, tail shaft inspection – every five years-, and boiler survey-every two and a half years. Clearly, there are implications related to the ship's insurance cover, because a classed vessel faces reduced insurance premiums. However, there has always been controversy in cases where classed ships were detained by the Port Authorities or had a serious accident because of faulty maintenance. For these reasons it is difficult to form an a priori expectation for the relationship between class and maintenance expenditures.

2.2.6 Location and yard for maintenance work

Another characteristic in a vessel's trading pattern is that it may condition the location of yard for the intermediate or special survey. Containerships are very limited in choosing the cheapest yards because they are committed in fixed routes and on tight schedules. As they provide a continuous service, container companies are very careful in planning the next surveys of their fleet. Any time delay may hamper the reputation of the company and fierce competition may take over its services. It is not uncommon for most containers to dry-dock in a yard where they offer services, in order to avoid travelling from one point of the world to another and cancel its scheduled trips. The selection of where to do the special survey or intermediate survey becomes equally important to all shipping companies since these can considerably affect maintenance cost. It is true that tramp shipping is favoured in this aspect since bulk carriers and tankers have a greater choice among yards. Since all companies must undertake the special survey and intermediate survey every 5 and 2 ½ years, the choice of yard makes a great difference in costs. The most competitive yards are in Far East Asia, such Singapore, and China. However, it is not the purpose of this dissertation to list the factors that affect the decision where to dry-dock, but one point that should be mentioned is the following. The shipping market is truly an international market. Even though different sectors such as the shipbuilding and repair yards, follow a similar trend under the same economic conditions, there are still local conditions that predetermine the relative cost of labour and resources, let alone that the regional economic situation may favour some yards to be more competitive than others. In sum, a vessel that has to be repaired in a yard will experience higher maintenance expenses. Nevertheless, the choice of yard will determine the extent of the increase in maintenance expenses. It may also be possible that some yards are cheaper than others are and ship owners may save costs in more competitive yards.

On account of these extensions, the cross-sectional nature of available data and the realization that the addition of dummy variables prohibits logarithmic linearization of **(6)**, the equation for maintenance expenditures that was adopted for the estimations took the form:

$$x_{0i} = A \cdot \prod_{h=1}^{n} x_{hi}^{\alpha_i} \cdot e^{\sum_{j=1}^{m} \beta_j Y_{ji}} \cdot e^{\sum_{k=1}^{q} \gamma_k Z_{ki}} \cdot e^{\varepsilon_i} \qquad \textbf{(7)}$$

where $x_{0i} = log\, m_i$, x_{hi} =Variables expressed in logarithms, Y_{ji} =Variables expressed in levels, Z_{ki} =Dummies for qualitative variables, and ε_i is an error term. So, by way of passing to the next section, it is worth concluding that **(7)** constitutes a compromise between a narrow maintenance model derived from rational economic behavior and a model that could be formulated on purely statistical grounds.

3. Data and definition and measurement of variables

Our data come from the records of 112 vessels that operated in 1999. Their collection took place in Piraeus and London during August and September 2000 by contacting directly 10 ship-operating companies. The officers in charge were asked to fill a questionnaire regarding maintenance expenses and provide additional information on an extensive list of other characteristics pertaining to each and every ship under management. **Figure 3.1** summarizes some of the main features of the data by reference to the averages that characterized the fleet of each company with respect to maintenance outlays and ship sizes and ages. From this we observe that, with the exception of the first company, which exhibited abnormally high maintenance expenditures per ship, and the seventh company, which managed ships of large average size in terms of Dead-Weight Tones (DWT), the ships in the sample were distributed fairly close to the averages of all four criteria of the classification. Perhaps what explains the aberrations in the two exceptions is that company CO1 managed only LPGs, whereas the fleet of company CO7 comprised only Bulk Carriers.

Figure 3-1: Distribution of vessels in the sample by company and the averages of maintenance outlays, size, and age

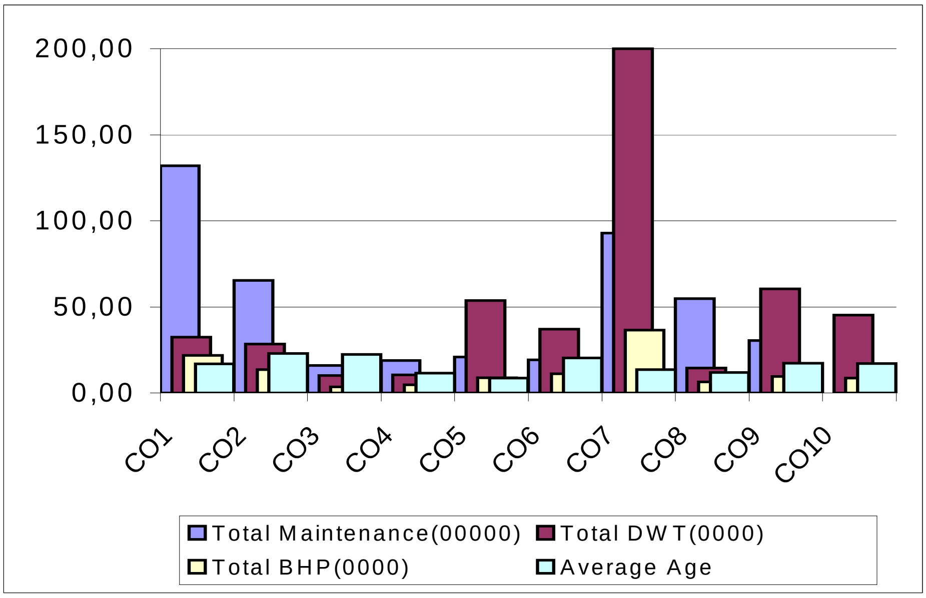
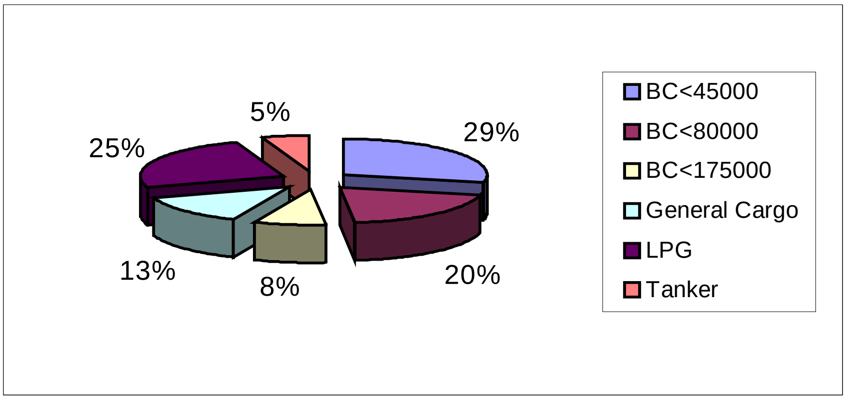


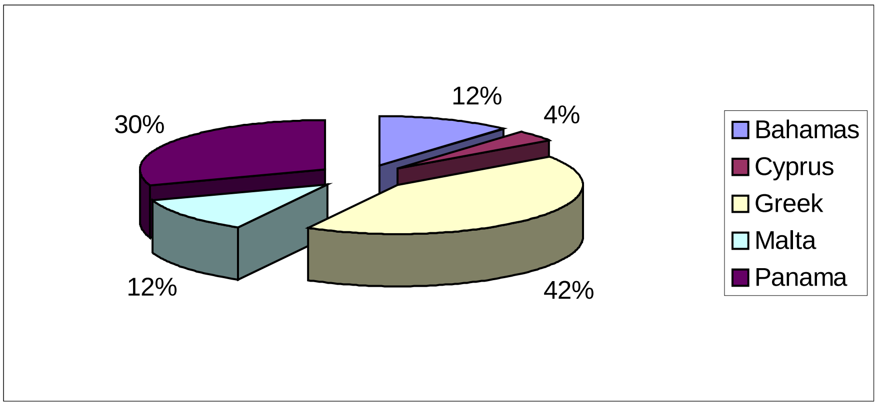
Figure 3.2 presents the distribution of the vessels in the sample by type. From this it can be seen that our sample is composed of four types of ship, namely, Bulk Carriers (BC), General Cargo, LPGs, and Tankers. Note also that we have divided Bulk Carriers into three categories according to their DWT size. This distribution is very close to the distribution of ships by type in the population, and hence, our sample is quite representative in this respect.

Figure 3-2: Distribution of vessels in the sample by type



The distribution of vessels in the sample according to flag is shown in **Figure 3-3**. From this it turns out that the predominant flag is the Greek with frequency of 42%, followed by that of Panama with a frequency of 30%. So to a large extent the analysis with respect to this factor is expected to reveal the effects on maintenance expenditures exercised by these two flags. Finally, concerning the ship's class in the sample, out of 9 classes, Lloyds Register of Shipping (LRS) dominates in the sample with 33%, followed by American Bureau of Shipping (ABS) with 21% and Det Notske Veritas (DNV) with 15%. The rest of the classes attracted the remaining 31% where individually none took up more than 7%.

Figure 3-3: Distribution of vessels in the sample by flag



Having characterised the nature of our data sample, we turn now to the definition and measurement of the variables that will be used to estimate **(7)**. We begin with the variables that can be quantified in one way or another.

$x_{0i} = log\, m_i$ = Maintenance expenditures. Maintenance outlays were obtained from each vessel's profit and loss (P&L) account. The most common problems we faced were twofold. The first was that the 1999 accounts included some of the surveys expenses that took place in previous years, and the second was that, if the vessel had a special survey during 1999, the respective expense was allocated over the next 5 years, so only a part of the total cost was included in 1999. Our efforts aimed at an accurate measurement of *realised maintenance expenditure for every vessel during 1999* and for this purpose we asked the companies managers to carry out the adjustments to the best of their knowledge and experience.

Table 3-1 shows the three major categories of maintenance expenditures reported in the P&L account for every ship in the sample. Total maintenance expenditures can be distinguished into three major categories: Stores, Spares and Repairs and Special Surveys. Stores expenses refer to the amount spent for consumable supplies. Necessary equipment replacement is allocated to spare expenses, while repairs and surveys expenses reflect the cost of maintenance work either carried out in a yard or on board. Hence, by defining in logarithms x_{0i}^{1} = stores, x_{0i}^{2} = spares, and x_{0i}^{3} = repairs and surveys, we set $x_{0i} = x_{0i}^{1} + x_{0i}^{2} + x_{0i}^{3}$. The most common subgroups under each of these three categories of maintenance expenditures are shown in **Table 3-1**. All in all, it was very important to adopt a precise definition and measurement of maintenance outlays and for this reason we followed also the advice of shipping experts so as to include all expenses related to maintenance work.

Table 3-1: Typical P&L account of ship maintenance expenses

➢ STORES	➢ SPARES	➢ REPAIRS/SPECIAL SURVEYS
• Deck stores • Engine stores • Engine chemicals • Forwarding expenses for stores	• Paints • Safety equipment • Slopes • Spare parts for repairs	

$x_{1i} = log\, u_i$ = Utilization. Utilization in ships is a truly multifaceted activity. There are a lot of parameters that must be taken into account. For example, apart from the fact that they are rarely recorded by shipping companies, miles traveled alone cannot capture the intensity by which a ship is utilized. Therefore, understanding a vessel's trading pattern may provide a wider array of information regarding utilization.

To explain how trading patterns play such an important role, we used the example from the Drewry Report (1999). A small product tanker operating in coastal/short sea trade will probably make thirty or more voyages in a year. In that case there are certainly more chances for higher maintenance cost compared to a capesize bulk carrier that makes four or five long voyages in a year. The smaller size vessel will probably undergo greater stress since she charges and discharges more frequently than the larger vessel. In addition, there is a higher risk of accident, since the small product tanker will use a higher number of ports that not only differ in organization and technology, but also will be busier than others, increasing the chances of accidents. Yet, secondary issues should not be neglected. For example a capesize bulk carrier travels longer transoceanic voyages and as a result she may fall prey to wide changing climatic conditions that prevail around the world. It is the case that the vessel may risk movement of cargo during the voyage, which can damage the hull superstructure as well as reduce safety in general. In this context, Talley (1996) shows that containerships suffer greater damage cost in transoceanic rather than inland voyages, because the climatic conditions can change much more abruptly and affect the vessel and its cargo. Hence, in order to capture the intensity of utilization of ships, the companies were asked to provide information for 1999 regarding the routes that ships traveled (costal, inland, oceanic), the days they were Off-Hire, the miles they traveled, their average speed, which had dry dock, special surveys or other major repairs, etc. Unfortunately the companies in our sample were unable to give us the number of miles traveled. So, even though in the estimations we employed several measures of utilization, the one that performed best is the following:

$$u_i = (365 - X_{1i}) \cdot X_{2i} \cdot 24 \cdot Z_{1i},$$

where for each ship in 1999, $X_{1i} =$ total port time, $X_{2i} =$ average speed, and $Z_{1i} =$ 0 if the vessel had dry dock, special survey or other major repairs in a yard during 1999, otherwise 1.

$x_{2i} = log\, T_i =$ Service life. This variable is approximated by the age of the ship and it is measured in the logarithms of years from the date of construction.

$x_{3i} = log\, K_{0i} =$ Size. This is measured in Dead-Weight Tones (DWT) and in Break Horse Power (BHP).

$x_{4i} = log\, S_i =$ Salvage value. Unfortunately we forgot to include in the questionnaire a question relating to the resale value of ships. So, in the estimations we found it necessary to rely on proxy variables. One such variable is size. Consequently, the sign of x_{3i} may turn out positive, negative or zero depending on the relative strength of opposite influences of size and salvage value on maintenance expenditures.

Y_{1i} = Number of crew.

Y_{2i} = Days Off-Hire.

Z_{ki} = Dummy variables for type of vessel with $k = 1,\ldots,7$. They take the value of 1 for:

Bulk Carrier from 0 to 45000 DWT, Bulk Carrier from 45000 to 80000 DWT,
Bulk Carrier from 80000 to 175000 DWT, General cargo, LPG, Tanker,
Oil and Asphalt, and 0 otherwise.

Z_{ki} = Dummy variables for flag with $k = 8,\ldots,12$. They take the value of 1 for: Bahamas, Cyprus, Greek, Malta, Panama, and 0 otherwise.

Z_{ki} = Dummy variables for ship's construction with $k = 13,14$. They take the value of 1 for: High tensile steel, Epoxy coating, and otherwise 0.

Z_{ki} = Dummy variables for class with $k = 15,\ldots,24.$ They take the value of 1 for:

ABS: American Bureau of Shipping, BV: Bureau Veritas, CCS: China Class Society, DNV: Det Notske Veritas, GL: Germanischer Lloyd, KRS: Korean Register of Shipping, LRS: Lloyd's Register of Shipping, NKK: Nippon Kaiji Kyokei, RINA: Registro Italiano Navalo, RMRS: Russian Maritime Register of Shipping, and otherwise 0.

Z_{ki} = Dummy variables for yards with $k = 25,26.$ They take the value of 1 for each of the two groups of yards: high cost (Greece, Holland, Italy, Japan, Turkey) and low cost (China, Korea, Curacao, Romania, Singapore). Otherwise 0.

Z_{ki} = Dummy variables for ship owning and management companies with $k = 27,\ldots,36.$ They take the value of 1 if a ship belongs to a company and 0 otherwise.

In the light of the above specifications, our estimating equation took the following semi log-linear form:

$$x_{1i} = \alpha_0 + \alpha_h \sum_{h=1}^{3} x_{hi} + \beta_j \sum_{j=1}^{2} Y_{ji} + \gamma_k \sum_{k=1}^{36} Z_{ki} + \varepsilon_i\,. \qquad \textbf{(8)}$$

This equation was fitted to the data at the level of total maintenance expenditure and also separately for stores, spares, and repairs/special surveys as shown in **Table 3.1** above.

4. Results and interpretations

Table 4-1 shows the Ordinary Least Squares (OLS) estimates obtained from equation **(8)** using total maintenance expenses. Looking first at the lower section of the table, we observe that the estimates are characterized by several desirable properties. In particular, the test for functional form ascertains that the model is well specified. As presumed by the estimating method, the tests in the last two rows indicate that the errors are distributed normally and their distribution is free from heteroscedasticity. The value of the F-statistic suggests that the data reject decisively the hypothesis that there is no relation between total maintenance expenditures and the independent variables; and lastly from the value of $\bar{R}^2$ it turns out that the model explains 68.9% of the variation in maintenance expenditures.

Table 4-1: OLS estimates from equation (8) using total maintenance expenses (x_0)

Regressor	**Coefficient**	**Standard Error**	**T-Ratio**	**[Probabil-**
Constant	9.509	0.552	17.217	[.000]
x_1 (Utilization)	0.190	0.046	4.108	[.000]
x_2 (Age)	0.329	0.056	5.826	[.000]
x_3 (Size)	0.032	0.008	4.087	[.000]
Y_2 (Days-Off Hire)	-0.005	0.001	-3.670	[.000]
Z_8 (Flag: Bahamas)	0.552	0.147	3.761	[.000]
Z_{12} (Flag: Panama)	0.485	0.108	4.499	[.000]
Z_{23} (Class: RINA)	0.567	0.150	3.793	[.000]
Z_{24} (Class: RMRS)	-0.813	0.216	-3.756	[.000]
Z_{25} (Yard: High-cost)	0.221	0.101	2.181	[.032]
Z_{27} (Company: CO1)	0.399	0.137	2.909	[.004]
Z_{36} (Company: CO10)	0.592	0.177	3.344	[.001]
Number of observations		112		
R^2		0.720		
$\bar{R}^2$		0.689		
S.E. of Regression		0.359		
F-statistic: F (12,99)		23.451(0.00)		
Functional Form CHSQ (1)		1.968(0.161)		
Normality CHSQ (2)		1.646(0.439)		
Heteroscedasticity CHSQ (1)		0.952(0.329)		

However, aside from the above properties, the reliability of parameter estimates depends also on two additional criteria. These are, first, the consistency of coefficient signs with those anticipated from economic theory, and, second, the statistical significance of the estimated coefficients. So if we turn to the upper section of **Table 4.1** it is easy to see that both criteria are met with remarkable success. On the one hand the overwhelming majority of coefficients are statistically significant at the 1% level of confidence and on the other their signs are in line with the predictions of the model. More specifically, as anticipated the variables of utilization (x_1), age (x_2) and size (x_3) enter with a positive sign, the coefficient of Days Off-Hire (Y_2) is negative, and the same consistency holds for the dummy variables. Hence, from a statistical point of view, the results are even better that we might have expected.

Furthermore to test their robustness we carried out several experiments. In one we estimated the model separately for each type of vessel. In another we restricted the estimation only to hose vessels in the sample that were less than 20 years old. And in still another experiment we introduced additional variables in the form of cross products of the independent variables to check on the stability of the slope coefficients. Unfortunately in all these experiments the small number of observations rendered the results somewhat unreliable. For this reason we re-estimated the equation in **Table 4.1** with the addition of: a) one dummy, which took the value of 1 for vessels under twenty years of age, b) four dummies, which took the value of 1 for each of the following categories: bulk carriers, LPGs, general cargo and tankers, and c) several interaction terms in the form of cross products between independent and dummy variables. From this experiment it turned out that all estimates remained very close to those in **Table 4.1,** while the explanatory power of the model increased to 76,1% and the effect of age on maintenance expenses increased to 0.429 for ships under 20 years old.

With these remarks in mind, let us turn now to the economic meaning and implications of our results. Since ship utilization, age and size are measured in logarithms, their coefficients give the elasticities of total maintenance expenditures with respect to the corresponding variables. From these we surmise that all three activities are characterized by economies of scale. This implies that, if each of utilization, age and size increases by 10%, ceteris paribus, total maintenance expenditures will increase respectively by 1.9%, 3.29%, and 0.032%. So what our findings show is that ship owning and management companies could reap substantial benefits by streamlining their operations to exploit these economies. Moreover, it is interesting to observe that percentage wise total maintenance expenditures increase modestly with respect to age and almost nil with respect to size. The former of these findings contrasts sharply with the traditional view according to which maintenance outlays increase more than in proportion with age, whereas the latter indicates that the positive effect of salvage value and the negative effect of size on maintenance expenses nearly cancel out. Lastly, notice that not least significant are the effects of class, flag, yard, and company.

Tables 4.2 displays the estimates of equation **(8)** for maintenance outlays directed to stores. On inspection it is seen that the results are in line with those obtained earlier regarding the determinants of total maintenance expenditures. Hence, if there are some noteworthy differences, these are the following. First notice that the company factor plays a major role in determining maintenance expenses for stores. Especially in the case of the company CO1 the coefficient takes the value of 1.648, which is by far the highest. Since this company owns and manages a fleet of LPGs, it is no wonder that the evidence corroborates the view that these ships have the most complicated structure. Second, observe that the coefficients of the remaining companies in **Table 4-2** are also relatively high, strongly indicating that the amount spent on stores depends mostly on company policies. The factors of utilisation, age, and size present a similar pattern with the analysis on total maintenance expenses. In addition it can be seen that some other factors such as the flag of Cyprus, the Italian classification society, the middle-sized bulk-carriers and the Greek yards affect stores positively.

Table 4-2: OLS estimates from equation (8) for stores (x_0^1) only

Regressor	**Coefficient**	**Standard Error**	**T-Ratio**	**[Probabil-**
Constant	8.286	0.709	11.688	[.000]
x_1 (Utilization)	0.174	0.061	2.844	[.005]
x_2 (Age)	0.218	0.070	3.104	[.002]
x_3 (Size)	0.015	0.009	1.654	[.101]
Y_2 (Days-Off Hire)	-0.005	0.002	-3.012	[.003]
Z_2 (Bulk carrier)	0.263	0.126	2.091	[.039]
Z_8 (Flag: Cyprus)	0.461	0.247	1.869	[.065]
Z_{23} (Class: RINA)	-0.505	0.183	-2.765	[.007]
Z_{252} (Yard: Greece)	0.274	0.140	1.964	[.052]
Z_{27} (Company: CO1)	1.648	0.151	10.911	[.000]
Z_{28} (Company: CO2)	0.911	0.167	5.467	[.000]
Z_{34} (Company: CO8)	-0.505	0.183	-2.765	[.007]
Z_{26} (Company: CO10)	0.600	0.225	2.665	[.009]
Number of observations		112		
R^2		0.761		
$\bar{R}^2$		0.732		
S.E. of Regression		0.458		
F-statistic: F (12,99)		26.331(0.00)		
Functional Form CHSQ (1)		1.944(0.163)		
Normality CHSQ (2)		1.466(0.480)		
Heteroscedasticity CHSQ (1)		2.031(0.154)		

Table 4-3: OLS estimates from equation (8) for spares (x_0^2) only

Regressor	**Coefficient**	**Standard Er-**	**T-Ratio**	**[Probability]**
Constant	10.287	0.203	50.752	[.000]
x_2 (Age)	0.416	0.090	4.614	[.000]
x_3 (Size)	0.039	0.009	4.364	[.000]
Z_1 (Type: Bulk carrier)	-0.470	0.143	-3.291	[.001]
Z_8 (Flag: Panama)	0.541	0.140	3.868	[.000]
Z_{14} (Epoxy coating)	0.522	0.311	1.676	[.097]
Z_{18} (Class: GL)	-0.437	0.231	-1.892	[.061]
Z_{20} (Class: LRS)	-1.888	0.313	-6.033	[.000]
Number of observations		112		
R^2		0.659		
$\bar{R}^2$		0.636		
S.E. of Regression		0.514		
F-statistic: F (12,99)		28.760(0.00)		
unctional Form CHSQ (1) (1)		1.390(0.238)		
Normality CHSQ (2)		0.214(0.898)		
Heteroscedasticity CHSQ (1)		1.431(0.231)		

Table 4-4: OLS estimates from equation (8) for repairs and surveys (x_0^3) only

Regressor	**Coefficient**	**Standard Error**	**T-Ratio**	**[Probability]**
Constant	8.038	0.874	9.191	[.000]
x_1 (Utilization)	0.246	0.072	3.395	[.001]
x_2 (Age)	0.338	0.098	3.458	[.001]
x_3 (Size)	0.068	0.012	5.527	[.000]
Y_2 (Days-Off Hire)	-0.005	0.002	-2.226	[.028]
Z_{14} (High tensile steel)	0.488	0.129	3.785	[.000]
Z_{18} (Class: GL)	-0.541	0.297	-1.823	[.071]
Z_{20} (Class: GLS)	-0.365	0.139	-2.634	[.010]
Z_{22} (Class: RINA)	0.785	0.243	3.226	[.002]
Z_{23} (Class: RMRS)	-0.633	0.343	-1.848	[.068]
Z_{251} (Yard: China)	-0.513	0.177	-2.892	[.005]
Z_{253} (Yard: Holland)	-0.605	0.318	-1.905	[.060]
Z_{34}(Company: CO8)	1.016	0.226	4.489	[.000]
Number of observations		112		
R^2		0.556		
$\bar{R}^2$		0.568		
S.E. of Regression		0.503		
F-statistic: F (12,99)		10.366(0.00)		
Functional Form CHSQ (1)		0.253(0.987)		
Normality CHSQ (2)		1.502(0.472)		
Heteroscedasticity CHSQ (1)		0.018(0.893)		

Regarding spares, the results in **Table 4-3** are fairly comparable to the preceding ones with two exceptions. First, that the size variable does not appear to affect such outlays, and second, that the factor of epoxy coating influences them significantly. Specifically, vessels that had not been applied with epoxy coating when built require relatively higher spares expenses. Since paints are included in this category, it can be concluded that higher spares expenses result later on from the additional painting applied on the surface of the cargo and ballast tanks..

Lastly, as far as the expenses for repairs and surveys are concerned, the results in **Table-4.4** indicate that the factor of high tensile steel has a significant positive effect. This means that the vessels built with high tensile steel have relatively higher repairs and surveys costs, since the amount of steel replaced later on in order to meet the restrictions imposed by the classification societies is greater. This evidence is also reinforced by the finding that the impact on repairs and surveys costs of classification societies is significant. In particular, observe that *"Germanischer Lloyd"* (Z_{18}), *"Lloyds Register of Shipping"* (Z_{20}) and *"Russian Maritime Register of Shipping"* (Z_{23}) have a negative effect, whereas *"Registro Italiano Navale"* (Z_{22}) has a positive effect. On the other hand, whereas the variables of utilisation, age and size turn out with coefficients roughly similar to the ones identified above, the yards that matter are only those of China (Z_{251}) and Holland (Z_{253}), with coefficient values –0.513 and –0.605 respectively.

V. Conclusions

In this paper we pursued two objectives. The first was to introduce a model with strong theoretical foundations to explain the determinants of ship maintenance expenses. To accomplish it we adopted the framework of analysis presented recently by Bitros and Flytzanis (2004) in which the operating policies of utilization and maintenance are consistently integrated with the capital policy of optimal service life. Limiting ourselves to the equilibrium solution of their model, we were able to extract an estimable equation relating maintenance expenditure to most of the main variables that have been identified in the theoretical and empirical literature as important determinants of these expenses. However, since this equation is meant to apply generally to all durables, we had to adjust it to the particular conditions under which ships are operated. Thus we expanded the equation to include such variables as the type of ship, the flag, the classification, the yard where surveys and maintenance work take place, etc. Through this procedure we obtained an adequately general yet ship specific model.

Our second objective was to employ this ship specific model to shed light on several important questions. For one we wished to find out the nature of maintenance economies that are associated with the processes of utilization, age, and size of ships. Given that the traditional view has been that maintenance expenditure increases more than in proportion with age, it is clear that some evidence from ships would be particularly useful. Also, since the introduction of ISM and the increasing activity of Port State Authorities have made ship managers to be more conscious about maintenance, we were very much interested to trace the effects of these regulatory institutions on company policies. And last but not least this research was intended as a test case to demonstrate its usefulness for further research and applications at company and higher levels of aggregation.

The estimated model took a semi log-linear form and passed all standard statistical tests for functional form, normality and heteroscedasticity. Also, in all experiments that were performed, the model fitted well the data and the overwhelming majority of coefficients had the right sign and were significant at 1% level of significance. All elasticities of maintenance expenditure with respect to utilization, age, and vessel size were found to be significantly less than 1, thus indicating that at least in 1999 there existed large economies of scale in these activities. In particular, the elasticity of maintenance expenses with respect to age was 0.339 for the whole sample and 0.428 for vessels that are less than 20 years old. Also we found that: a) vessels not painted with epoxy coating on cargo and ballast tanks at construction exhibited increased spares maintenance expenses, b) vessels built with high tensile steel resulted in higher repairs and surveys expenses, and c) certain flags, classifications and yards exercise significant effects on maintenance expenses, so they should be chosen by ship owning and management companies with care.

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Endnotes

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[1] Since at the same time the change in salvage value would influence scrappage in the opposite direction, this implication is fully corroborated by the empirical evidence, which, as in Bitros (1976a, 1976b) and Bitros and Kelejian (1974), shows that maintenance expenditures and scrappage are related negatively

[2] See International Chamber of Shipping and International Shipping Federation, ***Guidelines on the application of the IMO International Safety Management (ISM) Code*** (3rd ed., 1996), available from 12 Carthusian Street, London.

[3] Stopford (1997, pp. 425).