Second version:8/11/2004

Determinants of Expenditure in Automobile Maintenance: Some Evidence from Greece*

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ABSTRACT

This paper derives a model of maintenance expenditures from an analytical framework in which *maintenance*, *utilization* and *service life* are appropriately integrated and estimates it with the help of automobile data from Greece. On the theoretical plain it is shown that the model allows endogenously for most of the variables that have been identified in the relevant literature as important determinants of maintenance expenditures. Also the model yields sharp sign predictions for the included variables and by doing so it sheds considerable light on several outstanding issues in this area. On the empirical plain it is found that: a) the best functional form is obtained when the model is estimated using Box-Cox power transformed variables in conjunction with the pooled data of the sample and country specific dummy variables to allow for shifts in the intercepts; b) the reported amounts of outlays for automobile maintenance are positively related to the automobile's age, salvage value and intensity of utilization, and c) Italian cars are most demanding in maintenance outlays, followed by cars from France, Germany and Other Countries, which turn out to be roughly equally expensive, and, lastly, by cars made in Japan which appear to be the least expensive to maintain. However, the elasticities of maintenance expenditures with respect to these three variables follow exactly the reverse order, so car buyers face a choice between cars with high levels of maintenance and low elasticities, and vice versa.

JEL classification: D12, E2
Key words: maintenance, utilization, service life, maintenance and car accidents, multiple car ownership.

I. Introduction

Households nowadays are under continuous pressure to spend ever increasing portions of their incomes for the maintenance of the durables they own. The reasons are mainly twofold. First, that their stocks are rising under the changing patterns of consumption, and secondly, that the outlays in question over the life span of many such goods exceed the initial cost for their acquisition. Yet, even though the expenses involved gain in absolute and relative importance in family budgets, the factors that determine them have not been investigated to any significant extent, at least not with respect to consumer durables. The purpose here is to upgrade the attention that this issue receives in the literature and to make a modest contribution towards a better understanding of consumer behavior in this regard.

To attain these goals the paper proceeds in a rather conventional way. Starting from the realization that the relevant literature is meager in comparable endeavors, the first task undertaken is to formulate an appropriate theoretical model. In turn, the model is put through various tests with the help of automobile data that were gathered through a questionnaire addressed to car-owners members of the Hellenic Automobile and Touring Association. One such test tries different specifications of the model in search of that with the greatest explanatory power. Another test investigates whether it would be legitimate to pool the data so as to get sharper and more reliable estimates, and still another test employs covariance and other analyses to allow for possible country-specific differences.

The results that emerge are quite explicit. For example, on the methodological plain, it is found that : a) the best functional form is obtained when the model is estimated using Box-Cox power transformed variables in conjunction with the pooled data of the sample and country specific dummy variables to allow for shifts in the intercepts; b) in line with the existing precepts in theory and practice, the reported amounts of outlays for automobile maintenance and repair are always positively related to the automobile's age, and, c) other important determinants of such outlays are the automobile's salvage value and the intensity of its utilization. As for the more practical aspects, the results reveal Italian cars to be the most demanding in maintenance outlays, followed by cars from France, Germany and Other Countries, which turn out to be roughly equally expensive, and, lastly, by cars made in Japan which appear to be the least expensive.

The paper is organized as follows. Next Section lays out the model. This is done by drawing on a reformulation of the received theory of optimal utilization, maintenance and service life that we proposed recently in Bitros and Flytzanis (2004). Then, Section III describes the nature of the available data, the definitions of the variables, and the conventions that were adopted for their measurement. In Section IV, I present and comment on the statistical properties of the estimated model and the experiments performed with it, and, in the final Section, I provide a summary of the main conclusions.

II. The model

Consider the owner of an automobile. His user's manual informs him how often he is expected to change oils, oil filters, sparkplugs, etc. If he wants to enjoy normal service and avoid the risk of a major damage, he must follow the recommendations of the manufacturer of his car. As a result, these *regular maintenance* requirements 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 his discretion. So 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 recently by Bitros and Flytzanis (2004), the representative car owner would be expected to act in line with the precepts of economic theory. This implies that he would be expected to decide as if he were guided by the rules emanating from the solution to the problem:

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

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*.

$K = K(\mathrm{t})$: Used car measured in efficiency units, reflecting its size and age since first put in operation. New or unused car 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 used car at T. For the scrap value of unused car 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 equipment. 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 car at time T, where:

η : Relative rate of price change. It is the difference between equipment 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: Price of a new car.

With the help of these specifications in Bitros and Flytzanis (2004) we 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:

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

where the logistic value μ stands for the car 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 cars 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 in Bitros and Flytzanis (2004) we 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 car owners in Greece, 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 representative car owner should retain his car up to the time when the extra operating revenue realized from its use is equal to the car'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 representative car owner knows the analytic form of the operating function $r(w)$. But in actuality this is rarely the case, at least with regard to households. 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 model equation, I adopt the following assumptions:

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

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

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

As for the second modification this is recommended by the observation that the services remaining in a car at any time cannot be measured directly. From our analysis in Bitros and Flytzanis (2004) we know that, if the average wear of a vehicle 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 all the merits that eluded my research for many years.

One merit 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 gives ample theoretical support to my earlier work (see Bitros 1976a and 1976b) and at the same time 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. This is a nice result because it highlights the potential of the model for dynamic analyses of the policies under consideration.

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 considerable understanding of past findings in this area. For two cases in point consider first the results obtained, for example, by Griliches (1971), Mertens and Ginsburgh (1985), and Bitros and Panas (1988), according to which the quality of cars is positively related to their size. Clearly if larger cars have more quality, they may tend to break down less frequently than smaller cars, 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.

The second case has to do with the role of salvage value and it has a long story. In the past S_T was introduced into maintenance equations by reference to three arguments. The first of them drew heavily on Eastwood and Anderson (1976), Robin (1983), and other researchers who explored the impact of financial market imperfections. What these authors found is that such proxy variables of credit availability as interest rates, term to maturity, down payment, transactions costs, collateral, and probability of turndown, influence the demand for consumer durables in the same direction. Thus, since the amount one would need to borrow in order to purchase a new car depends negatively on the amount one would expect to collect from selling one’s old car, the proponents of this argument found it natural to conclude that changes in salvage value should be related inversely to maintenance expenditures.

Contrary to the above is the conclusion of those like myself who subscribed to the second argument. To explain it, assume, as it happened in Greece for many decades, that because of credit rationing consumers do not have access to bank loans for buying new cars. In this suppressed financial environment, aside from their transport services, passenger cars are considered good stores of value. As matter of fact in times of rapid inflation the latter function sidered good stores of value. As matter of fact in times of rapid inflation the latter function of cars may be the main reason for owning them. But if so, as salvage value appreciates, car owners would be expected to go out of their way to maintain them in prime condition. On this basis then, salvage value and maintenance expenditures should be related positively.

Lastly, those who adhered to the third argument arrived at the same conclusion but through another train of thoughts. Their conceptualizations derived from the studies, for example, by Armstrong and Odling-Smee (1980), Tishler (1982,1983), and Berkovec (1985) and suggested that, if increases in the prices of new cars raise the prices of older cars, 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 old cars increase, maintenance becomes a better substitute for a new car, so the owners of older cars, who otherwise might have scrapped them, are induced to maintain them. Consequently, they argued, since all evidence from the movement of prices in second hand markets shows that increases in new car prices do raise the prices of older cars, a shift in S_T would be expected to increase maintenance expenditures.[2]

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 in the past 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.

Next let me 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: the decision to restrict attention in this paper 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, the operating policies move from softer (less utilization and more maintenance) to harder (more utilization and less maintenance), and vice versa, when the relative magnitudes of the two discount rates σ / ε and $\sigma - \eta$ differ, 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 I am going to report below will stir enough interest for more applications using data from different durables, time periods, and countries.

A. From the theoretical to the estimating model

As it was stressed above equation **(6)** includes the main variables that economic theory considers important determinants of maintenance expenditures. However, given that my focus is on the explanation of expenditures for *irregular maintenance*, the model derived from theory may be too narrow to account for several other factors, which may influence the decision to scrap or to maintain. 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 maintenance expenditures, irrespective of whether their identification originates in the theoretical or empirical literature.

Thinking along these lines, it seems reasonable to assume that maintenance expenditures may be related positively to the number and the severity of car accidents. Of course, since both the salvage value S_T and the intensity of utilization u_t may act as proxies for past and contemporaneous car accidents, one may be tempted to surmise that allowing separately for such occurrences is superfluous and liable to introducing specification errors. Yet the impact of accidents that is transmitted to maintenance through these two channels is obscured, if at all discernible, because it operates together with other influences working in the same or different directions. Therefore, the decision to account separately for accidents is justified, at least on an experimental basis. For this reason I shall introduce the dummy variable *dacc* for car accidents.

Finally, equation **(6)** was expanded to include two additional dummy variables: one for multiple-ownership of cars, *down*, and another for rating the owner's memory regarding irregular maintenance incidences, *dmem*. Referring to the former, its influence on maintenance expenditures was expected to be negative on the presumption that owning more than one car may afford owners the freedom to be lax about their maintenance. As for the latter, this was entered with a positive sign because, when car owners reflected and reported on their relevant historical records, it was natural for them to remember more accurately the more recent maintenance bills that they had paid.

On account of these extensions, the cross-sectional nature of available data, and a linear approximation of (6), the equation for maintenance expenditures that was adopted for the estimations took the form:

$$m_i = \alpha_0 + \overset{(+)}{\alpha_1 u_i} + \overset{(+)}{\alpha_3 T_i} + \overset{(+)}{\alpha_4 S_{Ti}} + \overset{(+)}{\alpha_5 K_{0i}} + \overset{(+)}{\alpha_6 dacc_i} + \overset{(-)}{\alpha_7 down_i} + \overset{(+)}{\alpha_8 dmem_i} + \upsilon_i, \qquad \textbf{(7)}$$

where υ_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 statistical model that could be formulated on purely ad hoc grounds.

III. Data and measurement of variables

Data were obtained in collaboration with ELPA, the Greek Automobile and Touring Association, through a questionnaire, which was sent to the Association's magazine subscribers. The questionnaires were returned anonymously and 433 responses were received from various places in Greece. Those who responded answered a series of questions regarding the type and features of their car, the timing and extent of normal and abnormal maintenance they had undertaken in recent years, the resale price of their car, etc.

In particular, to obtain information about the type and features of the automobiles, the respondents were asked to indicate: the model of their car, its manufacturer and country of origin, the year of its first circulation, its engine capacity, and the number of kilometers the car was run on the average per year. To gauge normal maintenance experience, the questions referred to the frequency with which engine oil, oil filter, air filter, petrol filter, points, spark plugs, brake pads and windscreen wipers were replaced. On the other hand, in order to obtain information about irregular or unexpected maintenance and repair the questions required the respondents to report: the years and the amounts they had spent for repairs of such major car components as engine, cooling system, electric circuits, brakes, suspension, steering system and exhaust pipe. Finally, additional information that was considered necessary in the research was obtained from questions referring to the record of accidents, the resale price of the car, the number of cars owned, etc.

The variables which enter the statistical analysis are based on information extracted from the questionnaire and are defined and measured as follows:

m_i = Expenditure for irregular maintenance and repair, calculated as an average of such outlays in the last three years and deflated by the Consumer Price Index (CPI).

u_i = Average number of kilometers run by the car per annum.

T_i = Age of the car measured in months from the date of its first circulation.

S_{Ti} = Resale price of the car as reported by its owner.

$K_{0i} = e_i$ = Capacity of engine. This variable takes on integral values of which the smallest, (7), corresponds to cars with engine capacity between 600-700cc and the highest, (26), depicts cars with capacity above 2500cc.

$dacc_i$ = Record of accidents. This variable takes the values 0 for no accidents, 1 for no serious accidents, 2 for accidents of average seriousness and 3 for serious accidents.

$down_i$ = Multiple car ownership taking the value of 0 if the owner does not own other passenger cars and the value of 1 if he does.

$dmem_i$ = Owner's memory with respect to the expenditure for his automobile's maintenance and repair. This takes values equal to the number of intervening years from the earliest for which some irregular maintenance was reported to the most recent.

IV. Statistical tests, results and interpretations

Equation **(7)** includes three endogenous variables and two exogenous. The endogenous variables are m_i, u_i and T_i, whereas the exogenous are S_{Ti} and K_{0i}. In the data section I indicated that service life would be measured by the age of cars in the sample. This approximation is necessary because the optimal service life of cars is an unobservable variable. However, age itself is not a decision variable in the model. For this reason in the estimations T was included in the subset of exogenous variables. Consequently, in the estimating equation **(7)** all variables are exogenous with the exception of m_i and u_i, which are endogenous.

Preliminary tests using the Two-Stage-Least-Squares estimator (2SLS) showed that the data, as grouped by the country of origin of cars, suffered from heteroscedasticity. For this reason, it was decided to obtain several heteroscedasticity-consistent estimates and report those that were judged to be best on the basis of conventional statistical criteria. After extensive experimentation it was determined that, the estimates shown in **Table 1** below constituted a representative sample of such results.

<u>Table1</u> Two-Stage-least-Squares Estimates[1] of equation (4)

VARIABLES[2]	COUNTRY OF ORIGIN				
	France[3]	Germany[3]	Italy[4]	Japan[3]	Other[3]
Constant	-17.4	0.212	-34.3	-0.83	0.686
	(-2.9)	(0.09)	(-2.6)	(-0.5)	(0.56)
u_i	0.159	0.228	0.856	0.118	0.118
	(2.23)	(5.33)	(2.26	(1.59)	(2.27)
T_i	0.099	0.047	0.213	0.02	0.041
	(2.56)	(2.17)	(3.57)	(1.79)	(3.84)
S_{Ti}	0.008	…..	0.014	…..	…..
	(2.42)		(2.25)		
$dacc_i$	3.655	…..	…..	…..	1.611
	(2.69)				(2.16)
$dmem_i$	1.230	…..	…..	…..	…..
	(2.18)				
$\bar{R}^2$	0.216	0.125	0.080	0.055	0.255
SSR	9135	20176	19578	786	5642
DF	74	118	59	60	102

Notes

1. Aside of the constant and the exogenous variables appearing in the table, the list of instruments included $down_i$ =multiple car ownership, e_i =engine power, frm=frequency of regular maintenance, and fms=frequency of models in the sample.
2. $\bar{R}^2$ is the adjusted coefficient of determination, SSR and DF stand for the sum of squared residuals and the degrees of freedom, respectively, and the figures underneath the parameter estimates give the values of the t-statistic.
3. The values of the t-statistic for all estimates are Heteroscedasticity-consistent.
4. The values of these estimates have been corrected for autocorrelation

Clearly, with the exception perhaps of the cars originating in France and Other Countries, the results leave much to be desired. For one, it is easy to observe that the explanatory power of the model is very weak. Of course, from research it is known that in cross-section studies the R^2s tend to be lower than those from time series. But R^2s as low as those shown in the table for Germany, Japan, and Italy are disappointedly small. Moreover, despite the significance at high levels of confidence of S_{Ti} for cars from France and Italy, this variable, the size of the car, e_i, and the severity of accidents, *dacc*, are absent from most of the countries.

However, two findings are encouraging and their importance should not be missed. The first of them is the presence of age, T_i, and the intensity of utilization, u_i, across all countries. This confirms the widely held view according to which older durables and durables that are most intensively utilized require increasing amounts of maintenance expenditures. As for the second finding, this springs from the larger coefficient for u_i whenever the variable of accidents, $dacc_i$, does not appear in the equation. Such cases are those of German and Italian cars and their occurrence suggests that at times, and not unexpectedly, u_i may stand as a good proxy for $dacc_i$.

In the light of the rather unsatisfactory results from the linear model, my efforts turned to non-linear specifications. To this effect, and following the methodology first suggested by Box and Cox (1964), equation **(7)** was specified as the generalized functional form

$$m_i^{\nu} = \alpha_0 + \alpha_1 u_i^{\mu} + \ldots\ldots + \alpha_7 dmem_i^{\mu} \tag{8}$$

where the variables have the meaning assigned to them above and the power transformations are defined so as to conform to the scheme:

$$y_i^{\varphi} = \begin{cases} \dfrac{y_i^{\varphi} - 1}{\varphi}, & \text{if } \varphi \neq 0, y_i > 0 \\ \log y_i, & \text{if } \varphi = 0. \end{cases} \tag{9}$$

Upon substitution of **(9)** into **(8)** we get the expression:

$$\frac{m_i^{\nu} - 1}{\nu} = \alpha_0 + \alpha_1 \frac{u_i^{\mu} - 1}{\mu} + \ldots\ldots\ldots\ldots + \alpha_7 \frac{dmem_i^{\mu} - 1}{\mu}\ . \tag{10}$$

From this it is obvious that, if $\nu = \mu = 1$, there results **(7)**. Therefore, in order to determine the appropriate functional form of the maintenance equation, what had to be done was to find the values of the parameters ν and μ for which equation (5) would best fit the sample of available data. At the same time, given that some of the right-hand variables in (5) might not exert a statistically discernible influence on maintenance expenditure, for the best specification of the model, one must find the subset of variables with the best explanatory power. Here both objectives were pursued by means of a two-step estimating strategy. More specifically, in the first step, a search was conducted for the values of ν and μ where the adjusted $\bar{R}^2$ was maximized in the context of applying the Non-linear Two-Stage-Least-Squares (NL2SLS) estimator with all variables included in the model. The interval of search was (-1,2) and the best values for these parameters are shown in the third row of **Table 2**. Then, in the second step, the estimator was applied to various subsets of variables and the estimates for every country, which gave the best fit by conventional statistical criteria, are the ones, which are reported, in the same table.

Table 2 Non-linear Two-Stage-least-Squares Estimates[1] of Equation (10)

VARIABLES	**COUNTRY OF ORIGIN**				
	France	**Germany**	**Italy**	**Japan**	**Other**
	$\nu=0.25$ $\mu=0.35$	$\nu=0.65$ $\mu=1.00$	$\nu=-0.7$ $\mu=0.25$	$\nu=0.28$ $\mu=1.00$	$\nu=0.28$ $\mu=1.00$
Constant	-2.421	-5.717	8.135	-5.759	-4.874
	(-2.3)	(-1.8)	(2.83)	(-1.7)	(-1.73)
u_i	0.009	0.949	-0.435	1.106	1.242
	(2.42)	(7.0)	(-2.3)	(1.82)	(3.08)
T_i	0.272	0.258	-1.070	0.531	1.043
	(3.65)	(2.4)	(-3.7)	(1.97)	(4.51)
S_{Ti}	0.123	…	-0.898	…	…
	(2.64)		(-2.7)		
$dacc_i$	0.106	…	…	…	0.859
	(2.46)				(2.10)
$dmem_i$	0.172	…	…	…	…
	(1.97)				
$\bar{R}^2$	0.216	0.125	0.080	0.055	0.255
D-W	1.914	1.741	2.120	2.317	2.213
SSR	9135	20176	19578	786	5642
DF	72	116	57	58	100

Notes

1. For questions pertaining to the instruments that were employed in the estimations, look at the notes at the bottom of Table 1.

Now, if these estimates are compared with the ones exhibited in **Table 1**, it emerges that the non-linear specification of the model gives better results on two counts. The first of them is that the explanatory power of the model is enhanced. In this regard, notice that, with the exception of German and Other cars, where the adjusted $\bar{R}^2$s increase only by small percentages, in all other cases the explanatory power of the model improves significantly. As for the second count, this is reflected in the gains in statistical significance observed in the case of Japanese cars. However, despite their importance at the margin of research efforts, these improvements were not sufficiently large to warrant the selection of equation **(10)** as the best specification of the model. For this reason, at this point, the inquiry addressed the question whether better results could be achieved if the data in the sample were used more efficiently through pooling[3].

To proceed with this approach in a statistically legitimate way it was necessary to find out whether the automobiles from different countries of origin for which we had information represented a sample selected from the same universe. In turn, resolving this matter required testing the stability of estimated intercepts and to do so we adopted Dhrymes's (1971) tests

$$\frac{Q_T - \sum_{i=1}^{s} Q_i}{\sum_{i=1}^{s} Q_i} \, \frac{s(T-m-1)}{m(s-1)} \sim \mathrm{F}_{\mathrm{m(s\text{-}1)},\ \sum_{i=1}^{s} T_i - s(m+1)} \qquad \textbf{(11)}$$

$$\frac{(y - X\widehat{\beta})'(y - X\widehat{\beta})}{\sigma^2} \sim \mathrm{X}^2_{\sum_{i=1}^{s} T_i - s(m+1)} \qquad \textbf{(12)}$$

where Q_T and Q_i are respectively the sums of squared residuals from the regression on the pooled data and the regression using only the ith sub-sample, s indexes the number of the sub-samples, m is the number of estimated coefficients from each sub-sample, not including the constant, and F and X^2 indicate the probability distribution of the test with the corresponding degrees of freedom. Carrying out these tests for both the linear and the non-linear specifications of the model needed some further estimations using the pooled data of the sample.

In particular, to implement **(11)**, I assumed that the coefficients of the variables in the model are equal across countries and expanded equations **(7)** and **(10)** to:

$$m_i = \alpha_0 + \alpha_1 u_i + ... + \alpha_7 dmem_i + \alpha_8 d_{1i} + \alpha_9 d_{2i} + \alpha_{10} d_{3i} + \alpha_{11} d_{4i} \qquad \textbf{(13)}$$

$$\frac{m_i^v - 1}{v} = \alpha_0 + \alpha_1 \frac{u_i^\mu - 1}{\mu} + ... + \alpha_7 \frac{dmem_i^\mu - 1}{\mu} + \alpha_8 d_1 + \alpha_9 d_{2i} + \alpha_{10} d_{3i} + \alpha_{11} d_{4i} \qquad \textbf{(14)}$$

i.e. by adding to them the country-specific dummy variables, d_{ji}, for the purpose of allowing for differences in the intercept terms of the model at the country level. These were then estimated using all the data in the sample and the best results are reported under COVM in **Table 3**. Finally, with the help of pertinent information from the last rows of **Tables 1**, **2** and **3**, I

Table 3 2SLS Estimates of equations (13) and (14) using all data in the sample[1]

VARIABLES	EQUATION (13) ROBUST 2LSL[2]			EQUATION (14) ROBUST NL2SLS		
	COVM	LSDV	WTDV	COVM[3]	LSDV	WTDV
Constant	-4.634	…..	-4.268	-32.60	…..	-35.69
	(2.06)		(-2.1)	(-4.1)		(-4.4)
u_i	0.215	0.222	0.220	0.164	3.943	4.031
	(6.70)	(7.24)	(6.41)	(8.60)	(6.28)	(6.58)
T_i	0.062	-0.057	0.069	2.73	0.068	3.087
	(4.61)	(7.72)	(5.03)	(5.65)	(7.90)	(6.15)
S_{Ti}	0.002	…..	0.002	0.573	0.003	0.597
	(1.68)		(1.54)	(1.68)	(1.78)	(1.71)
$dacc_i$	1.185	…..	1.150	…..	…..	…..
	(1.95)		(1.85)			
d_{1i}	2.871	…..		…..	…..	
	(2.03)					
d_{3i}	6.139	4.977		4.863	1.430	
	(2.49)	(2.13)		(2.12)	(3.45)	
d_{4i}	-3.332	-4.713		-4.434	-1.739	
	(-3.8)	(7.12)		(-5.4)	(-2.5)	
$\bar{R}^2$	0.172	0.179	0.143	0.217	0.193	0.191
D-W	2.063	2.042	1.957	2.029	2.038	1.037
SSR	57982	58032	61042	55098	57032	57650
DF	425	429	430	427	428	429

Notes

1. The set of instruments used in all estimations reported here was expanded to include also the country-specific dummy variables.
2. The term ROBUST implies heteroscedasticity-consistent estimates, whereas the notations COVM, LSDV and WTDV stand respectively for the types of models from which the estimates have been derived. More specifically, COVM=Covariance Model, LSDV=Least Squares with Dummy Variables, and WTDV=Least Squares Without Dummy Variables.
3. For the estimates under COVM and LSDV the values of the parameters v and μ were (v =0.28 μ =1), whereas for those under WTDV they were (v =0.65 μ =0.70).

calculated the values of the statistic in **(11)** for the two specifications of the model. These values turned out to be 0.969, for the linear, and 3.494, for the non-linear model. At the 1% level of significance these indicated that the null hypothesis, i.e. the hypothesis that the intercepts did not vary across countries, ought to be accepted for the former model and rejected for the latter.

Turning next to the application of the second test, the first step was to re-estimate **(13)** and **(14)** without the intercepts at both the country and the pooled-sample levels. The best results that I was able to get with the pooled data for the two specifications of the model are displayed in **Table 3** under LSDV, whereas the corresponding estimates at the country level are not shown separately in order to save space. With relevant information from these results, i then calculated the values of the statistic in **(12)**. These were 0.637 for the linear model and 1.208 for the non-linear one and both fell well within the region of acceptance of the null hypothesis. This evidence suggested that the slope coefficients did not shift significantly from one country of the sample to the other.

In summary, the tests which were conducted showed that : a) pooling the data was statistically legitimate because they could be conceived as coming from the same regression process; b) if the non-linear (linear) were chosen as the better specification of the model, it would (not) be necessary to introduce dummy variables to allow for variation in the intercepts, and c) pooling the data improved the explanatory power of the model as well as the sharpness of the estimates. So, the last issue, which had to be resolved, was that of choosing between the two alternative specifications of the model.

From **Table 3** it is apparent that in terms of their explanatory power the non-linear functional form of the model performs better than the linear form. In particular, looking at the coefficients of determination, we see that the non-linear model explains over 25% more of the variation in maintenance expenditure than the linear model. Hence, following Dhrymes's (1971) informal criterion, which is based "... on the interpretation of the coefficient of determination of multiple regression as a correlation coefficient between observed and predicted values of the dependent variable", I decided that the available statistical evidence discriminated in favor of the non-linear specification. On these grounds then, and the provisions that were mentioned under (b) in the preceding paragraph, I selected the non-linear model under COVM to be the best approximation to the true model.

TABLE 4 Predicted annual expenditure for irregular maintenance of automobiles imported from various countries[1]

	All other countries[2]	Italy	Japan
,000 of 1980 Drs.	7.2	12.1	2.8

Notes

1. The pooled-sample means of the variables T, S_T and u where the calculations took place were respectively 99.2, 1098.9 and 16.6.
2. Included in this group are cars imported from France, Germany and Other Countries for which the country specific dummy variables did not enter into the model with coefficients significantly different than zero.

In turn, having brought the statistical analysis to its conclusion, it was natural to use it in order to draw certain implications of practical importance. For this purpose, the selected model was first used to calculate the levels of expected maintenance expenditures by owners of cars from various countries at the means values of T, S_T and u in the pooled-sample of the data. The results of these calculations are exhibited in **Table 4** and suggest that, depending on the country of their origin, automobiles may come with low, medium or high inherent requirements for irregular maintenance and repair. For as it is seen, Japanese made cars are least expensive in terms of built-in maintenance outlays, followed by the automobiles from France, Germany and the group of Other Countries, and, lastly, the Italian cars which are the dearest.

TABLE 5 Elasticities of maintenance expenditure by Country of origin of cars[1]

	All other countries	Italy	Japan
$\bar{T}$	1.37	0.82	3.55
$\bar{S}_T$	0.56	0.33	1.46
$\bar{u}$	0.05	0.03	0.13

Notes

1. The elasticities were evaluated at the pooled-sample means of the variables and at the expected average levels of maintenance expenditure, which were presented in the preceding **Table 4**.

The next question of particular interest concerned the response of maintenance expenditure to changes in the independent variables. To highlight it I computed the elasticities, which are implied by the model, and the results are reported in **Table 5**. Looking at them, one of the first features to draw attention to is the order of elasticities by country of origin. In this regard notice that Japanese and Italian cars have respectively the highest and the lowest elasticities, whereas those of automobiles from all other countries fall in between. This observation, in conjunction with the inference derived in the preceding paragraph, implies that between the levels and the elasticities of outlays for irregular automobile maintenance and repair there exists an inverse relationship like the one, which is depicted in **Figure 1** below. This implies that, when buying cars from various countries, Greek consumers may have a range of choices between automobiles, which are characterized by high and inelastic maintenance outlays, and automobiles with low but mostly elastic maintenance requirements.

Another noteworthy feature springs from the magnitudes of the elasticities across variables. More specifically, whereas the elasticities with respect to T are for most countries of the sample greater than one, those with respect to S_T and u are predominantly lower than one. Therefore maintenance and repair costs may be subject to economies with regard to the variables of salvage value and intensity of utilization and diseconomies with regard to age.

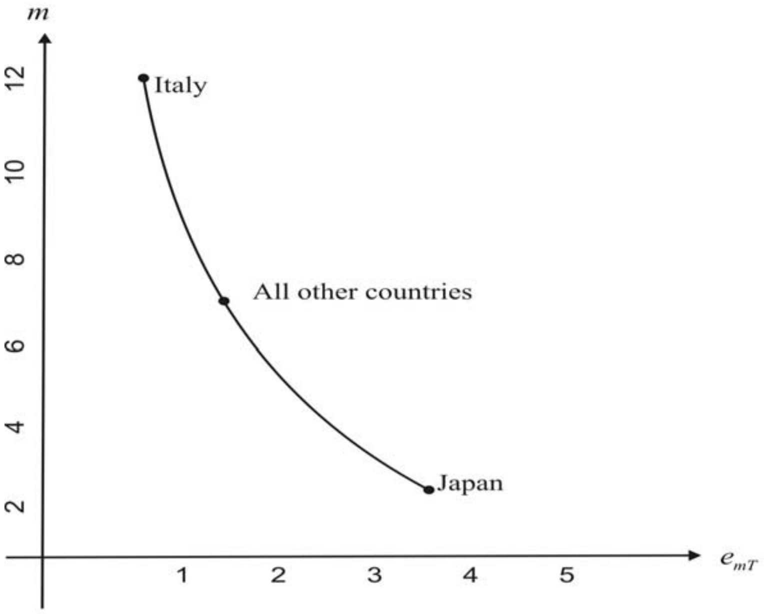

Figure 1

Finally, observe that the elasticities with respect to the intensity of utilization, u , are all close to zero. This finding suggests that the outlays for irregular maintenance and repair are almost insensitive to the utilization of automobiles and corroborates the prevailing view in the trade, which associates utilization mainly to the regular upkeep of cars.

VIII Conclusions

The present paper had two objectives. First, to draw attention to a neglected area of research in Consumer Economics, and, secondly, to make a modest contribution to it mainly from an empirical point of view. For this purpose a model of maintenance expenditure was derived by drawing information from the related literature on producer durables and tested by using the responses to a questionnaire from 433 automobile owners in Greece. On the methodological plain, in addition to extracting from the data all relevant information, the statistical tests sought to determine the best specification of the model in terms of included explanatory variables and functional form. To this effect the model was estimated at the country and pooled-sample levels using consistent linear and non-linear estimating techniques and the results were quite conclusive. They indicated as best the non-linear form of the model whose set of determinants included age, salvage value, intensity of utilization and certain country-specific dummy variables.

This model was then employed to carry out a few calculations relating to questions of practical importance. One such calculation showed that the order of cars from the least to the most expensive with regard to irregular maintenance and repair started with those made in

Japan, reached a plateau with those made in France, Germany and Other Counties, and was topped by Italian cars. Another calculation showed that the elasticity of maintenance and repair outlays with respect to age may be greater than one and thus corroborated the established view that maintenance increases more than in proportion with age. And last, but not least, other calculations showed irregular maintenance outlays to be highly inelastic with respect to the intensity of car utilization.

Endnotes

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[*] This paper has a long story. The first draft was completed in1990 and after some iteration it was submitted for publication to *The Review of Economics and Statistics*. The editor of the journal at the time liked the empirical part of the paper but asked me to work further on the theory so as to come up with a formal model, which might be consistent with the results. His challenge led me into a protracted research program, which has culminated in the paper by Bitros and Flytzanis (2004). The relationship between *utilization*, *maintenance*, and *service life* established in this paper is the one that eluded me for many years. So with this version of the present paper I revisit my older efforts. The Center of Economic Research of the Athens University of Economics and Business offered me a small research grant, the Hellenic Automobile and Touring Association helped me gather the data, and many colleagues two numerous to mention individually provided assistance and encouragement. To all of them I express my warmest thanks and sincere appreciation.

[2]. 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

[3]. Such a presumption may be supported by the fact that the model from pooled data is estimated with the use of more data, and hence, more information, thus leading to more reliable parameter estimates.

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