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A theory of maintenance and an application

George C. Bitros

76 Patission Str., Athens 104 34, Greece
Tel. (++30) 210-8203911 - Fax: (++30) 210-8203301
www.econ.aueb.gr

A theory of maintenance and an application[*]

By
George C. Bitros
Professor of Economics, Emeritus
Athens University of Economics and Business
76 Patission Street, Athens 104 34, Greece
Tel.: +30 210 8203740 Fax: +30 210 8203301, E-mail: bitros@aueb.gr

ABSTRACT

This paper derives a model of maintenance and repair expenses from an analytical framework based on rational economic behavior in which *maintenance*, *utilization* and *service life* are appropriately integrated and estimates it with the help of data from 433 automobiles imported into Greece from various countries. 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 the GMM estimator in conjunction with country specific dummy variables to allow for shifts in the intercepts; b) as expected, the reported amounts of outlays for maintenance and repair are related positively to the automobile's age, intensity of utilization, and road accidents, and negatively to quality, and c) Japanese made cars may be least demanding in maintenance outlays, followed by cars from Germany, and, lastly, by cars made in all other countries.

JEL classification: D12, E2
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1. Introduction

At the time that Bitros (1976a, 1976b) emphasized the interrelated nature of operating and capital policies,[1] the literature did not offer a unified framework based on rational economic behavior to analyze their interactions. Moreover, even if such a framework did exist, these interactions would be extremely hard to estimate and test because the data on maintenance and repair (henceforth maintenance) expenses were extremely scanty, if at all available. In the decades that have elapsed since then, the literature makes reference only to a few relevant studies. The one by Smith, Cowing (1977) derived a three-equation model in which maintenance expenditures, gross investment and scrappage were interrelated. But it ignored the thorny issues associated with the firm's profit horizon and made no attempt at empirical implementation. The next noteworthy contribution was by Everson (1978, 1982). This gave rise to a four-equations model for a cost-minimizing railway firm and estimated it with the help of data for freight cars of the Class-I railways in the United States. However, on deeper examination it turns out that this model is marred by a grave inconsistency. To highlight it, consider the two-stage constrained cost minimization approach adopted to describe the behavior of the railway firm. In the first stage the firm chooses utilization, maintenance, installations and retirements of freight cars, subject to an arbitrary rate of change in its outstanding freight car capacity. Then, in the second stage, by plowing the optimal values from the first stage back into the cost function, the firm forms its normalized restricted cost function. Finally, upon minimization of the later function, the firm is presumed to obtain the optimal path of the rate of change of its freight car capacity over an infinite horizon, and hence its level. But from Preinreich (1940) and Smith (1961) we know that the optimal lifetime of freight cars should be computed jointly with the economic life of freight cars in the chain of replacements extending as far into the future as the railway's profit horizon. By implication, in the first stage in which the firm solves for the optimal utilization, maintenance, installations and retirements of freight cars it must solve subject not to an arbitrary but to the optimal rate of change of freight car capacity in every future period; because as solved the model may not yield the optimal values of the variables under consideration.

With the exception of the contributions by Hartl (1983) and Choi, Kollintzas (1985), the

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[1] Owners' decisions with respect to their durables may be classified into two categories. The first concerns the decisions that are primarily directed at changing the condition of durables themselves and includes *replacement, scrapping, expansionary investment, overhauling* and *stripping,* whereas the second category comprises the decisions that are associated with the *utilization* and *maintenance* of durables. In this paper I shall refer to the former as *capital policies* and to the latter as *operating policies.*

doctoral dissertation by Smith (1987) and the paper by Kim (1988),[2] the relevant literature remained dormant until the second-half of the 1990s. From then on, and particularly from the publication of the paper by McGrattan, Schmitz (1999), which demonstrated that maintenance and repair expenditures is too big a component of Gross National Product (GNP) to be ignored, research activity intensified and made significant strides in three fronts. In the first front researchers introduced the above-mentioned operating and capital policies into one-sector dynamic general equilibrium models and analyzed their interactions in the steady state. The papers by Perez, Javier, Ruiz-Tamarit (1996), Collard, Kollintzas (2000), Licandro and Puch (2000), Licandro, Puch, Ruiz-Tamarit (2001), Leighter (2001), and Boucekkine, Ruiz-Tamarit (2003), fall in this category. However the planning horizon in the models they adopt is assumed to be infinite and this implies that in the steady state economic agents do not have an independent scrapping policy. In other words, they are prohibited from deciding at any time not to replace worn-out capacity.

Research work in the second front aimed precisely at addressing this limitation. In this the planning horizon is treated as an endogenous variable. By allowing economic agents to decide how many investment cycles, if any, and for how long in each investment cycle would be optimal to replace capacity, the policy of scrapping is brought back into the forefront. But this is made possible at a cost, which implies that the simple one-sector model of the preceding studies, where there is only one representative firm applying continuously a replacement policy, is abandoned in favor of a two-sector dynamic general equilibrium model as follows. Initially, Bitros, Flytzanis (2002) set up a dynamic partial equilibrium model in which the capital using enterprise faces three options: to enter into business, to exit, if it is already in operation, or to replace its capital and continue doing so up to some profit horizon. Then, assuming that the firm plans to exit at the end of the useful life of its current capital stock, Bitros, Flytzanis (2004) analyzed in depth the properties of utilization and maintenance. Lastly, drawing on the analytical results from the above studies, Bitros (2008a) presented a two-sector dynamic general equilibrium model with one representative firm in each sector, the main difference between them being that the firm in the more capital-intensive sector applies replacement, whereas the firm in the less capital-intensive sector applies scrapping.[3]

In the third front researchers have been studying the interactions of operating and capital policies in the presence of embodied technological progress, as well as of various sources of

[2] The analysis in this paper is characterized by the same inconsistency that was pointed out above in regard to the paper by Everson (1982).

[3] Actually, the model that Mullen, Williams (2004, 487) estimated using manufacturing data from Canada derives more consistently from this analytical framework, rather the one they present in Section 2 of their paper.

uncertainty associated with this process of technical change. The papers by Boucekkine, Germain, Licandro and Magnus (1998), Boucekkine and Pommeret (2004), Cruz and Pommeret (2004), Bitros (2008b), Boucekkine, del Rio, Martinez (2009), Boucekkine, Fabbri, Gozzi (2010), and Bitros, Hritonenko, Yatsenko (2010) give a representative sample of the growing literature in this field.[4] But as of the time of this writing I am unaware of any reported attempts to highlight the influence of embodied technological progress on the interactions of operating and capital policies in a general equilibrium model that allows both for replacement and scrapping. As a result, issues such as the degree of substitutability between maintenance and new investment, the trade-offs between utilization and maintenance, the roles of regulatory and operating safety constraints, etc., remain in the promising agenda of future research.

In light of the preceding remarks this paper has three less ambitious objectives. The first is to show how a consistent model of maintenance expenditures for a firm operating under a policy of scrapping can be extracted from Bitros, Flytzanis (2004). The second objective is to substitute into the latter model reasonable analytic forms for the various functions involved so as to highlight the directions in which such expenditures are expected to change in response to changes in the other endogenous and exogenous variables. Thus past and new empirical results will become easier to interpret and more appealing to adopt in the design of maintenance and repair policies. Finally, in order to demonstrate the usefulness of the model, the third objective is to estimate it with the help of data pertaining to a set of 433 passenger cars imported into Greece from various countries. The results that emerge are quite explicit. For example, it is found that: a) the best functional form is obtained when the model is estimated using the GMM estimator in conjunction with country specific dummy variables to allow for shifts in the intercepts and slopes; b) as expected from theory, the reported amounts of outlays for maintenance are related positively to the automobile's age, intensity of utilization, and road accidents, and negatively to quality, and c) Japanese made cars may be least demanding in maintenance outlays, followed by cars from Germany, and, lastly, by cars imported from all other countries.

The paper is organized as follows. Next Section lays out the theoretical model. Starting from this, Section 3 derives the model to be estimated. Section 4 describes the available data, the definitions of the variables, and the conventions that were adopted for their measurement. Section 5 presents and comments on the statistical properties of the estimated model and the experiments performed with it, and, the final Section provides a summary of the main findings and conclusions.

[4] The latest addition is the paper by Albonico, Kalyvitis, Papa (2013).

2. 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 by Bitros, 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:

$$\text{Choose } [T, u(t), m(t)] \text{ so as to maximize}:$$

$$A = \tilde{Q} + \tilde{S} = \int_0^T q(u,m,K)\phi(t)dt + \phi(T)S(K_T,T)$$

$$\text{s.t.} \quad \dot{K} = -s(u,m,K), \text{ with } K(t_0) = K_0, \text{ and} \qquad \textbf{(1)}$$

$$0 \le u \le 1, \; 0 \le m \le 1,$$

where the various symbols are defined as follows:

$\tilde{Q} = \int_0^T q(u,m,K)\phi(t)dt$: 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 break-*

through 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 the 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:

(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 $\mu_0 = pK_0^{1-\varepsilon}$,

and 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:

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

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, 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, 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:

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

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, I 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:

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

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 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 gives ample theoretical support to past results 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 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 the sign of K_0 depends on the balance of two effects, i.e. relating respectively to the quality and the scale of the car. If the effect of quality is larger than that of the scale the sign will be negative, and vice versa.

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 the work by 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 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 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.[5]

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 **Propositions 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 predic-

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[5] 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) shows that maintenance expenditures and scrappage are related negatively.

tions 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.

3. 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, 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 $Dacc_i$ for car accidents.

The model should be expanded also to include two additional dummy variables: one for multiple-ownership of cars, $Down_i$, and another for rating the owner's memory regarding irregular maintenance incidences, $Dmem_i$. 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.

Finally, since the passenger cars in the sample are imported into Greece from various countries, it was deemed pertinent to insert into equation **(6)** a series of dummy variables**,** $D_1, D_2 ... D_n$**,** so as to allow for the possibility of different country effects. The rationale for this specification is twofold. First, that automobiles manufactured in different countries may require different amounts of maintenance services, and second, that spare parts are priced differently by automakers in various countries. In particular, according to the views prevailing in the maintenance and repair shops in Greece, cars imported from Germany and Japan would be expected to be less demanding in maintenance expenditures in comparison to those imported from Italy.

On account of these extensions, the cross-sectional nature of available data, and the grouping of countries from where passenger cars are imported into Greece, the model for maintenance expenses took the form:

$$m_i = [\alpha u_i^{\beta} \cdot \frac{S_{T_i}}{(K_{0i} e^{-\omega T_i})^{\varepsilon}}]^{\gamma} e^{\zeta_1 Dacc_i + \zeta_2 Down_i + \zeta_3 Dmem_i + \xi_1 D_{Fi} + \xi_2 D_{Gi} + \xi_3 D_{Ii} + \xi_4 D_{Ji} + \xi_5 D_{Oi}} \quad . \qquad \textbf{(7)}$$

where *F*=France, *G*=Germany, *I*=Italy, *J*=Japan, and *O*=Other countries. Finally, taking logarithms gave the following estimable form of the model:

$$\begin{aligned} \log m_i = \theta_0 + \underset{(+)}{\theta_1 \log u_i} + \underset{(+)}{\theta_2 \log S_i} + \underset{(+)}{\theta_3 T_i} + \underset{(?)}{\theta_4 \log K_{0i}} + \\ + \underset{(+)}{\zeta_1 Dacc_i} + \underset{(-)}{\zeta_2 Down_i} + \underset{(+)}{\zeta_3 Dmem_i} + \\ + \underset{(?)}{\xi_1 D_{Fi}} + \underset{(-)}{\xi_2 D_{Gi}} + \underset{(+)}{\xi_3 D_{Ii}} + \underset{(+)}{\xi_4 D_{Ji}} + \underset{(?)}{\xi_5 D_{Oi}} + \upsilon_i, \end{aligned} \qquad (8)$$

with υ_i denoting an error term.

So, by way of passing to the next section, it is worth concluding that **(8)** 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.

4. 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 unexpected maintenance events 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.

However, since the questionnaire was addressed to subscribers of a particular motoring association and not to all car owners in Greece, a few qualifications regarding the nature of the sample are in order. Car owners subscribe to motoring associations to minimize the financial cost and the cost of discomfort from an unexpected breakdown of their car, particularly when riding far from home. Hence they are motivated to subscribe by the condition of their car, the reliability of its maintenance, and the mode in which they use it. If the car is of average to old age and is used frequently over long distances, it will pay not only to maintain it meticulously but also to subscribe to the motoring association because of the extra insurance it provides. On the contrary, if the car is relatively new and is used in short trips within the city, subscribing may not be worthwhile. Therefore, my hunch is that the data in the sample come from a population of car owners with above average age cars who maintain them with care and who use them regularly over long distances. For these reasons the magnitudes of effects that will turn up in the statistical analysis should be interpreted with caution as they may not be representative of such effects in the fleet of all passenger cars in Greece.

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.

D_i = Dummy variables indicating the countries from where the automobiles are imported into Greece. The index *i* stands for the following countries: *F*=France, *G*=Germany, *I*=Italy, *J*=Japan, and *O*=Other.

5. Statistical tests, results and interpretations

The variable S_i depends on T_i and K_{0i}. Thus in equation **(8)** three variables are endogenous, whereas the rest are exogenous. The endogenous variables are m_i, u_i, and T_i. In the data section it was indicated that the service life would be measured by the age of cars in the sample. This approximation is necessary because the service life of cars is an unobservable variable. However, age itself is not a decision variable. For this reason in the estimations T_i and S_i have been included in the subset of exogenous variables. Consequently, unless implied otherwise, only m_i and u_i are considered as endogenous.

Table 1 shows the best estimates that were obtained using all 433 observations in the sample. The ones reported in the column (1) resulted by applying Ordinary-Least-Squares (OLS). From them it turns out that all coefficients have the anticipated signs and are statistically significant at comfortable levels of confidence. Also, observe that the explanatory power of the model, while not on the high side, is not unusually low given the cross-sectional nature of the data.[6] Moreover, from the values of various tests at the lower part of the same column we can surmise that, with the exception of the *LM het. test* and *Durbin-Watson* statistics, which indicate

[6] In econometric studies using time series data, the explanatory power of roughly the same model turns out to be consistently higher. For example, see Mullen, Williams (2004, 494) and Bhat (2000, 110).

Table1 Estimates of equation (8)

VARIABLES	Ordinary-Least-Squares[1] (OLS) (1)	First-order Serial Correlation (AR1) (2)	Generalized Method of Moments[2] (GMM) (3)	Two-Stage-Least-Squares[3] (2SLS) (4)
Constant	-1.634	-1.475	-1.634	-1.23
	(-2.68)	(-2.58)	(-2.83)	(-1.66)
$\log u_i$	.681	.621	.681	.521
	(3.83)	(3.53)	(3.97)	(2.09)
T_i	.0087	.0086	.0087	.0084
	(4.42)	(4.63)	(4.48)	(4.20)
$\log K_{0i}$	-.356	-.358	-.356	-.338
	(-2.03)	(-1.91)	(-2.03)	(-1.93)
$Dacc_i$	.221	.240	.221	.229
	(2.27)	(2.58)	(2.16)	(2.35)
$dmem_i$	.187	.187	.187	.191
	(4.01)	(4.67)	(3.97)	(4.15)
D_{Gi}	-.637	-.634	-.637	-.629
	(-2.88)	(-3.40)	(-2.95)	(-2.86)
D_{Ji}	-1.088	-1.102	-1.088	-1.10
	(-4.07)	(-4.67)	(-5.76)	(-4.12)
$\bar{R}^2$	.267	.280	.267	.265
LM het. test	1.27[4]			
Durbin-Watson	2.23[4]	1.99	2.23	2.24
Jarque-Bera	29.64			
Ramsey's Reset	47.45			
F (zero slopes)	23.44			
Log Likelihood	-871.1	-866.4		

Notes

1. $\bar{R}^2$ is the adjusted coefficient of determination. *DF* stands for degrees of freedom. The figures underneath the parameter estimates give the values of the t-statistic. The values of the t-statistic for all estimates are Heteroscedasticity-consistent.
2. The t-statistics are robust to autocorrelation and heteroscedasticity.
3. Aside of the constant and the exogenous variables, the list of instruments included $Down_i$ =multiple car ownership, e_i =engine power, frm_i =frequency of regular maintenance, and fms_i =frequency of models in the sample.
4. The P-values for these tests were respectively .260 and .999. Since they were exceeded the data suffered from both heteroscedasticity and autocorrelation.

that the data suffer from heteroscedasticity and autocorrelation, the estimated model is characterized by absence of skewness and kurtosis in the disturbances, the specification of its functional form is consistent with the data, and the influence exercised by the independent variables on the outlays for maintenance is different than zero. Thus, drawing on these findings, it was natural to try and purge these OLS estimates from the effects of heteroscedasticity and autocorrelation.

The estimates reported in the column (2) of the table were obtained by applying the autoregression procedure with first order serial correlation (AR1) in the disturbances. As it can be seen from the value of the *Durbin-Watson* statistic, the correction was successful. Moreover, while the procedure increased marginally the explanatory power of the model, it left the signs and the statistical significance of the coefficients almost unaffected. But heteroscedasticity continued to remain dormant and had to be confronted simultaneously with autocorrelation. For this reason the model was re-estimated with the Generalized Method of Moments (GMM) and the results are displayed in the third column. Compared to the ones obtained from the AR1 procedure, the latter estimates are not significantly better. But they have the property that they are robust both to autocorrelation and to heteroscedasticity.

Lastly, to find out whether the estimated model could be improved by allowing for the endogeneity of u_i, column (4) in the extreme right of the table reports the estimates obtained from the Two-Stage-Least-Squares (2SLS) estimator. These did not show any improvement over the GMM estimates and besides they could not be purged from autocorrelation. Thus, the GMM estimates were retained as the best representation of the maintenance behavior of car owners who responded to our questionnaire.

At this point it was deemed pertinent to employ the results to highlight the importance of their practical implications. To this effect consider the issue of durability of cars manufactured in various countries. In this respect it is worth making two observations. The first is that the only country dummy variables that enter into the model with statistically significant coefficients are those for Germany and Japan and, secondly, that the latter enter with negative signs. These imply that cars imported from Germany and Japan require less maintenance relative to those imported from all other countries. More specifically, as it can be inferred from the size of the respective coefficients, Japanese made cars are least demanding in maintenance, followed by automobiles from Germany, and lastly by cars imported from all Other Countries.

As for a second example consider the response of such outlays to changes in the independent variables that vary with the country of origin of cars. To proceed I computed the elasticities with respect to age and road accidents at the mean values of the respective variables and the results are reported in **Table 2**. Looking at them, one key feature is the order of elasticities. In this regard notice that cars made in Germany and Japan 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,

TABLE 2 Elasticities of irregular maintenance and repair outlays by the country of origin of cars[1]

	Germany	Japan	All other countries
ε_{mT}	.963	.619	.878
ε_{mDacc}	.232	210	.223

Notes

1. Computed at the following mean values of the respective variables:

$T_G = 110.2,\ T_J = 71.2, T_O = 100.9\ Dacc_G = 1.05, Dacc_J = .905, Dacc_O = 1.01$

renders Japanese made cars a better buy proposition than German cars, which, because they are kept in use longer, are relatively more demanding in maintenance outlays.[7]

6. Conclusions

This paper had three objectives. The first was to derive a model of maintenance expenditures from rational economic behavior. This was accomplished by drawing on the research by Bitros and Flytzanis (2004) who modeled the behavior of a capital using enterprise operating under a policy of scrapping. The second objective was to employ the model to highlight the responses of maintenance expenditures to changes in the other endogenous and exogenous variables. To this effect, the general revenue and wear functions in the model had to be specified further by substituting for them certain reasonable analytic forms. In turn, there resulted an equilibrium maintenance model comprising all the variables that have been identified in the relevant literature and giving sharp sign predictions. Finally, the third objective was to highlight the usefulness of the model by means of an application. For this purpose the model was estimated and tested with the help of data from a questionnaire answered by 433 automobile owners in Greece.

The best functional form was obtained when the model was estimated using the GMM estimator in conjunction with country specific dummy variables to allow for shifts in its intercepts and slopes. As expected from theory, the estimates showed that the outlays for maintenance are related positively to the automobile's age, intensity of utilization, and road acci-

[7] However, from the footnote in **Table 2** it turns out that the average age of Japanese cars in the sample is over 30% lower than that of German cars. Hence, since age is correlated positively to road accidents, if the Japanese segment of the sample includes younger cars because of growing registrations, the differences in these elasticities may be quite smaller.

dents, and negatively to quality. Also the estimates showed that Japanese made cars may be least demanding in maintenance outlays, followed by cars from Germany, and, lastly, by cars imported from all other countries. Finally, from the elasticities of such outlays with respect to age and road accidents, it was found that Japanese cars provide the best value for the money.

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