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RAIL INFRASTRUCTURE CHARGING IN HELLENIC RAILWAYS

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Abstract

In this paper we consider marginal cost estimation in Greek railways over the period 2000-2004. Marginal cost estimation has been recently an active area of research when disaggregated data by line of operation are available but factor price data are not available. We propose panel data techniques to deal with the problem of statistical efficiency of parameters estimators. Our estimates show that marginal cost in Greek railways is comparable to the estimates in other European countries.

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1. INTRODUCTION

Empirical research and cost estimation in railways has been an active issue of research. Existing research has focused on estimation of scale economies, efficiency, technical change and productivity. This has been facilitated by the prolific research and implementation on flexible functional forms like the translog cost function. However, few studies have been concerned with the problem of pricing and financial sustainability of the railways.

Of the few studies that take up the issue of pricing, all of them focus on estimating marginal costs. The reason is that, despite the fact that marginal cost pricing is not followed by EU railways, the marginal cost still provides guidance to optimal pricing that can be valuable for management. In this paper, we estimate a cost function to derive marginal costs. Marginal cost is simply the derivative of the cost function with respect to output. For a thorough literature review with an emphasis on empirical estimates of marginal costs and the role of utilization rate, the reader is directed to Thomas (2002). The data required to implement this kind of analysis typically differ considerably relative to studies that focus on productivity and efficiency. In the latter case, one often has input prices and outputs in real terms (like passengers and freight) but the data are aggregated and annual. In the former case, one has data disaggregated by line of operation (or similar divisions) on an annual basis but does not have data on input prices and often one does not have data on outputs in real terms. This represents a real challenge in estimating marginal costs but relative to other forms of data permits us to apply econometric techniques developed for panel data. Surprisingly, the existing literature has not used panel data when disaggregated data are available but factor prices are missing. We believe that such techniques will improve the precision of the estimates and therefore will deliver more precise estimates of marginal costs.

One major goal of the European Union (EU) within the ongoing deregulation programme is the liberalization of the European railway sector. This market was dominated by national natural monopolies that were under public control. However, due to a sub-additive cost structure with respect to the track infrastructure, a competitive system in this sector cannot be established easily. Therefore the EU has decided that monopoly in the provision of the track infrastructure will be maintained, under regulatory restrictions securing a high standard of efficiency.

In order to secure use of and non-discriminatory access to the rail infrastructure, the infrastructure businesses must establish an appropriate set of charges for infrastructure use. Commission Directives require that responsibility for access charge regimes be independent of any train operator, that they promote efficient use of infrastructure and they do not discriminate among operators wishing to make comparable us of the infrastructure.

The economic principles behind an appropriate access regime are well established. Access charges should reflect the marginal cost that each user imposes on the infrastructure provider. To these marginal costs should be added the external costs (pollution, accidents, congestion, etc) that each user generates. This is social marginal cost pricing and, if implemented correctly, will result in the most efficient use of the rail infrastructure.

Article 7 of the Directive 2001/14/EC imposes the requirements of marginal cost pricing. Two alternative approaches, used by a number of EU Member States and considered to be best practice in terms of consistency with the provisions of the Directive 2001/14/EC:

- an econometric approach which estimates a total cost function and then takes the first derivative of total cost with respect to gross tone km to derive the marginal cost (seen in Finland, Sweden and Austria); and
- an approach which allocates total variable across all the different vehicles running on the network, using detailed causation engineering relationships (used in Britain).

However, each country appears to treat wear and tear differently and there are different definitions and ways of accounting for operating, maintenance and renewal costs. As a result, each country arrives at very different figures for marginal cost. The differences may partly reflect the overall cost levels in the different countries and the different levels of efficiency with which rail infrastructure is constructed and maintained. It also reflects differences in local circumstances and different objectives concerning the government contribution to infrastructure costs. Differences in the level of charges can also reflect excess costs for some railways when the network is over-dimensioned for current demand. But it is important that in any approach, full account is taken of operating, maintenance and renewal costs if charges are to reflect the total marginal costs of operating a train service.

From January 1st 2006, Hellenic Railways (OSE) has split into two entities (infrastructure and operation), which is an outcome of the harmonization of the Greek legislation with that of the EU Directives. The new group structure will provide a major benefit. It will ensure that infrastructure expenditure will be transparent. Additionally, it will ensure that no indirect subsidization of the rail operations takes place, as it happens with all the other public means of transportation.

Empirical research in railways has concentrated on various aspects like technical efficiency (Perelman and Pestieau, 1988 and Gathon, 1989) and the measurement of productivity growth. Total factor productivity (TFP) measurement is undoubtedly an issue that has received a lot of econometric interest in the past forty years. Typically, the researcher estimates a cost or production function, and derived a TFP index using estimated parameter values. TFP indices are used for productivity comparisons across countries, or across time for the same country. See for instance Baltagi and Griffin (1988), Baltagi, Griffin and Rich (1995), Berndt and Khaled (1979), Caves and Christensen (1988), Caves, Christensen and Tretheway (1980), and Hulten (1992) to name but a few. Studies more specific to the railways include Caves, Christensen and Swanson (1981a, b), Kumbhakar and Bhattacharyya (1996), Gathon and Perelman (1992), Oum and Yu (1994), and Perelman and Pestieau (1989) to name again only few. For a recent survey of empirical research see Oum and Waters II (1997).

In this paper, we use econometric estimation of cost functions estimated separately for traffic and maintenance in OSE (the Greek railways) during 2000-2004. We use Cobb-Douglas and translog cost functions and techniques that combine time series and cross sectional data. To summarize our findings, the Cobb-Douglas functional form seems to be adequate to describe the technology and produces reasonable marginal cost estimates. As expected, marginal costs are slightly less than average costs, implying that there are (slight) economies of scale. The remainder of the paper is organized as follows. The econometric methodology is presented in section 2. The results are discussed in section 3. The final section concludes with some policy recommendations and discussions.

2. ECONOMETRIC METHODOLOGY

It is well known that output can be taken as exogenous in railways so the relevant function to work with, is the cost function. The cost function is defined as

$$C\left(w,Q\right)=\min_{x}:\left\{w'x,\ \text{subject to }\ D(x,Q)=1\right\}$$, where

x is the input vector,

Q is the output vector,

w is the input price vector,

$D\left(x,y\right)$ is a distance function that describes the technology. The distance function is the mathematical representation of the transformation from inputs to outputs.

In most cases we do not have input price data for each line of operation so these variables have to be treated as shift variables in the cost function. Therefore, to estimate marginal cost, we use a cost function of the form

$$C_{it}=f\left(Q_{it},u_{it},z_{it}\right)\exp\left(\varepsilon_{it}\right),$$

where Q_{it} is output in operating line i (for all $i=1,...,n$) and year t (for all $t=1,...,T$), u_{it} is the rate of capacity utilization, z_{it} is a vector of other shift variables entering the cost function, like a linear trend, and a dummy variable for 2002-2004, and ε_{it} is an error term. We do not assume a priori that this error term satisfies all classical econometric assumptions. The presence of linear trend is essential in our context because of (a) technical change, (b) changes in quality as evidenced in Tervonen and Idstrom (2004) and (c) changes in the relative prices of inputs.

The rate of utilization is employed quite often in empirical analyses, see for example Tervonen and Idstrom (2004) and Thomas (2002) and it is very closely related to the efficiency of the underlying production process. In most studies this is unknown and is treated using stochastic frontier analysis. Since we can measure it with fair degree of confidence, direct use of this measure will improve the precision of estimates. See also Caves and Christensen (1988) on closely related issues. Previous estimates of efficiency in Greek railways using data envelopment analysis and stochastic frontier analysis have been provided by Loizides and Giahalis (1995). More recent studies focusing on productivity growth are Loizides and Tsionas (2002, 2004).

In our empirical analysis we use two functional forms. The first is a Cobb-Douglas defined as:

$$\log C_{it} = \beta_0 + \beta_1 \log Q_{it} + \beta_2 u_{it} + \beta_3 t + \beta_4 D_{it} + \varepsilon_{it} \, .$$

The second is a translog cost function of the form:

$$\log C_{it} = \beta_0 + \beta_1 \log Q_{it} + \beta_2 u_{it} + \beta_3 t +$$
$$\tfrac{1}{2}\beta_4 \left(\log Q_{it}\right)^2 + \tfrac{1}{2}\beta_5 u_{it}^2 + \beta_6 t^2 + \beta_7 \log Q_{it} u_{it} + \beta_8 \log Q_{it} t + \beta_9 t u_{it} + \beta_{10} D_{it} + \varepsilon_{it}.$$

The marginal cost is

$$MC_{it} = \beta_1 \cdot \frac{C_{it}}{Q_{it}} \text{, for the Cobb-Douglas}$$

and

$$MC_{it} = \left(\beta_1 + \beta_4 \log Q_{it} + \beta_7 u_{it} + \beta_8 t\right) \cdot \frac{C_{it}}{Q_{it}} \text{, for the translog.}$$

We should note here that in a monopolistic firm, marginal cost pricing is a special case of average cost (AC) pricing. Indeed if we define scale economies as $1-\eta$, where

$$\eta = \frac{\partial \log C}{\partial \log Q},$$

then it is evident that we must have $\eta = \frac{\partial C / \partial Q}{C / Q} = \frac{MC}{AC}$. For a monopolist whose demand elasticity is $\varepsilon = -\frac{\partial \log Q}{\partial \log P} > 0$, the optimal pricing policy is:

$$p\left(1-\varepsilon^{-1}\right) = MC \, ,$$

from which we obtain

$$p = \theta \cdot AC \, ,$$

where $\theta = \eta \cdot \left(1 - \varepsilon^{-1}\right)^{-1}$ is the optimal mark up of the firm. If the demand elasticity is known or it can be estimated with some accuracy, then the optimal pricing policy depends only on the relation between marginal and average costs, so estimating marginal costs is apparently important as we stated in the introductory section of this paper.

It is well known that the translog is a second order approximation to an arbitrary cost function. In that sense it is flexible and therefore on theoretical grounds it is better compared to the Cobb-Douglas. In our application, the number of observations is quite small so estimation of the translog cost function may not yield great statistical accuracy. In the literature, using Cobb-Douglas functional forms is quite common while the translog is used only rarely, see however Tsamboulas and Kopsacheili (2004) and Loizides and Giahalis (1995). In this application we estimate both functional forms and we subject them to the proper econometric tests to decide which one is appropriate.

In addition we use two other econometric approaches. The first is based on the fact that the structural changes that took place during 2002 may have affected marginal costs. Therefore, we use the following alternative Cobb-Douglas cost function:

$$\begin{gathered}\log C_{it} = \beta_0 + \beta_1 \log Q_{it} + \beta_2 u_{it} + \beta_3 t + \beta_4 D_{it} + \\ \left(\beta_5 \log Q_{it} + \beta_6 u_{it} + \beta_7 t\right) D_{it} + \varepsilon_{it}\end{gathered}$$

from which marginal cost is $MC_{it} = \left(\beta_1 + \beta_5 D_{it}\right) \frac{C_{it}}{Q_{it}}$.

The second econometric approach is based on the estimation of Cobb-Douglas and translog cost functions using panel data. Specifically, we use models with fixed and random effects. The methods are based on the estimation of the following models:

$$\log C_{it} = \beta_{0i} + \beta_1 \log Q_{it} + \beta_2 u_{it} + \beta_3 t + \beta_4 D_{it} + \varepsilon_{it}$$

and

$$\log C_{it} = \beta_{0i} + \beta_1 \log Q_{it} + \beta_2 u_{it} + \beta_3 t + \tfrac{1}{2}\beta_4 \left(\log Q_{it}\right)^2 + \tfrac{1}{2}\beta_5 u_{it}^2 + \beta_6 t^2 + \beta_7 \log Q_{it} u_{it} + \beta_8 \log Q_{it} t + \beta_9 t u_{it} + \beta_{10} D_{it} + \varepsilon_{it},$$

where β_{0i} is a fixed or random coefficient for the specific line. It is not necessary to introduce time effects since we have included a time trend in the model. Surprisingly, estimating models appropriate for panel data is not common in the literature.

For **financial sustainability analysis** suppose the profit is $\Pi = p(Q)Q - C(Q) - F$, where $p(Q)$ represents a demand curve, $C(Q)$ is the variable cost function, and F is fixed costs. In the short-run the firm has to cover the variable costs and the financial sustainability condition is $\theta \geq 1$ which implies $\eta \geq 1 - e$, where $e = \varepsilon^{-1}$ is the inverse elasticity of demand. Alternatively we need $\eta + e \geq 1$, provided of course that $e < 1$. For long-run sustainability we need to have $\frac{F}{C} \leq \theta - 1 = \frac{\eta}{1-e} - 1$ or in different form $\eta \geq \lambda(1-e)$, where $\lambda = \frac{F}{C}$ is the ratio of fixed to variable costs (in annual basis). It is not possible to make predictions about what the (steady state) value of λ should be since this depends on the particular country. However, in the short run when economies of scale are close to unity (as we find here, and as all previous empirical studies have demonstrated) the condition for financial sustainability is easily attained. It is also possible to say that when $\lambda \leq 1$ and the system is solid in the short-run, then it should also be solid in the long-run. *Only* when $\lambda > 1$ we can have short-run but *not* long-run sustainability. Therefore, if we have an estimate of economies of scale and a rough estimate of the (inverse) elasticity of demand it is possible to aid policy making by deciding whether the system is solid in the short-run and the long-run. In particular, no other data from financial accounting of the firm are necessary. Most certainly this analysis is static and rough but it *can* nevertheless provide valuable guidance in policy decisions and it has not been suggested before in the literature.

3. EMPIRICAL RESULTS

From the empirical results it turns out that a simple Cobb-Douglas cost function is adequate for the operation but not for maintenance. The Cobb-Douglas cost functions seem to display heteroskedasticity and the values of R^2 are quite low.

In addition, it seems that there is significant technical progress in operation but not in maintenance in which we have cost increases over time. Hausman tests performed in connection with panel data models, show that models with random effects are correctly specified, which means that the explanatory variables are uncorrelated with the error terms. However, the estimated variances of β_{0i} s are quite low compared to the overall equation error so reliable results can be obtained if we restrict attention to least squares results.

From the results it turns out that marginal cost is about 4 euros per train-km (2.5 in operation and 1.5 in maintenance). An important question is how this compares to the European standards. Thompson (2002) in a review of the European empirical analyses reports that marginal cost in maintenance is between 0.13 and 0.55 euros per tone-km. If we take into account that the average weight of a train in Greece in about 400 tones, this implies that the Greek marginal cost in maintenance (which is1.5 euros per train-km) is 0.00375 euros per tone-km. In operation, Greek marginal cost is 2.5 euros per train-km which gives 0.01 euros per tone-km. Had the average weight been 600 tones, marginal cost would fall to about 0.0067 per tone-km. For Sweden, Thompson reports that marginal cost is 0.32 euros per tone-km while for Finland, Tervonen and Istrom (2004) report that marginal costs range from 0.01 to 0.10 for the most expensive line. For Austria, Munduch etc (2002) report similar estimates. Therefore, marginal cost in Greek railways is comparable to what is happening elsewhere in Europe.

CONCLUSIONS

The purpose of this paper was to estimate cost functions for the Greek railway system (OSE) in order to estimate marginal costs. Pricing according to marginal costs is essential in view of recent EU policies aiming at maintaining high standards of efficiency and financial sustainability. The latter is one of the main priorities of the operation company taking into consideration the abolition of state subsidies according to the EU legislation. In any way, OSE’s management is promoting the signing of public service obligations contracts between the Greek State and OSE, through which the state will subsidize itineraries that are unprofitable for the Organisation but at the same time are considered vital from a social point of view. This will ensure a level playing field for all providers of transport services. Moreover, it will benefit passengers as well as increase OSE’s transport work.

We have estimated both Cobb-Douglas and translog functional forms and subjected them to proper econometric testing. In addition we have exploited the panel structure of the data with an aim to improve the statistical precision of estimates. It appears that operation and maintenance have different technological characteristics, the output cost elasticity is slightly above unity, there has technical progress in operation but technical regress in maintenance and marginal costs seem to accord with results from other EU countries.

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TABLE 1. COST FUNCTION IN OPERATION (LEAST SQUARES)

	Cobb-Douglas-1	Cobb-Douglas-2	Translog
const.	1.62829 (.492561)	1.66275 (.795274)	8.06546 (4.34639)
log(Q)	.900717 (.124579)	.859770 (.190463)	-.733829 (2.03897)
u	.548617 (.923921)	.069146 (1.30072)	-22.5503 (13.7393)
t	-.215529 (.107922)	-.059245 (.249075)	-.399114 (.614610)
D	.241700 (.310051)	.027776 (1.13188)	.304466 (.374748)
D*log(Q)		.075460 (.258846)	
D*u		1.22821 (1.93571)	
D*t		-.211766 (.279631)	
log(Q)^2			.320303 (.312702)
u^2			40.4762 (23.6510)
t^2			-.023008 (.115985)
log(Q)*u			2.38097 (3.97172)
log(Q)*t			.067344 (.100085)
u*t			.388731 (.786502)
R^2	0.66	0.67	0.71
LM het	0.98 (0.32)	0.81 (0.37)	0.95 (0.33)
Ramsey	0.103 (0.95)	0.07 (0.97)	0.48 (0.78)

NOTES: Numbers in parentheses denote standard errors. LM het is the Lagrange multiplier test for heteroskedasticity. In parentheses provided is its p-value. Ramsey denotes the Ramsey RESET test for functional form misspecification.

TABLE 2. COST FUNCTIONS IN OPERATION (PANEL DATA / RANDOM EFFECTS)

	Cobb-Douglas	Translog
const.	.917195 (.108318)	-.729675 (2.03751)
log(Q)	.616416 (.791157)	-22.5206 (13.7359)
u	-.159982 (.113548)	-.400103 (.615784)
t	.096859 (.322006)	.320061 (.312452)
D	1.49922 (.467262)	8.05718 (4.34531)
$\log(Q)^2$		40.4281 (23.6452)
u^2		-.022621 (.116251)
t^2		2.37256 (3.96877)
log(Q)*u		.067516 (.100028)
log(Q)*t		.389530 (.785976)
u*t		.302633 (.375590)
R^2	0.650	0.709
LM het	1.24 (0.27)	0.95 (0.33)
Hausman	2.45 (0.65)	6.05 (0.42)

NOTES: Numbers in parentheses denote standard errors. LM het is the Lagrange multiplier test for heteroskedasticity. In parentheses provided is its p-value. Hausman denotes the Hausman test for validity of random effects specification (p-value in parentheses).

TABLE 3. COST FUNCTIONS IN OPERATION
(PANEL DATA / FIXED EFFECTS)

	Cobb-Douglas	Translog
log(Q)	1.01512 (.145067)	-.798962 (2.21767)
u	1.32520 (1.07849)	-26.5625 (15.7354)
t	.246815 (.290682)	-.470175 (1.36135)
const.	-.301144 (.578514)	-.111498 (.636278)
log(Q)^2		.518098 (.355202)
u^2		49.4691 (27.9728)
t^2		.173366 (.246044)
log(Q)*u		2.42610 (4.36116)
log(Q)*t		.056899 (.122225)
u*t		.457219 (.995127)
R^2	.715288	.782840
LM HET	$.841154\text{x}10^{-4}$(.993)	.706349 (.401)

NOTES: Numbers in parentheses denote standard errors. LM het is the Lagrange multiplier test for heteroskedasticity. In parentheses provided is its p-value.

TABLE 4. AVERAGE COST, MARGINAL COST AND TECHNICAL CHANGE IN OPERATION

	AC	MC1	MC2	MC3	TCH
			ΥΚΑ Α′		
2004	2.62000	2.35530	3.83491	2.44555	-0.17825
2003	3.89000	3.50505	5.00227	3.63936	-0.22751
2002	1.37000	1.23516	1.17312	1.28249	-0.29666
2001	2.76000	2.49159	2.80476	2.58707	-0.27118
2000	2.45000	2.21661	2.90875	2.30154	-0.25263
			ΥΚΑ Β′		
2004	4.95000	4.45843	6.03950	4.62927	-0.23006
2003	2.40000	2.15730	2.61252	2.23997	-0.25166
2002	2.44000	2.19749	3.41652	2.28169	-0.15500
2001	3.41000	3.06644	4.24765	3.18394	-0.19941
2000	1.31000	1.17815	1.03089	1.22330	-0.27365
			ΥΚΑ Γ′		
2004	2.33000	2.09383	2.69851	2.17406	-0.21095
2003	3.32000	2.97628	1.91743	3.09033	-0.32183
2002	6.52000	5.88382	5.94881	6.10927	-0.25125
2001	2.29000	2.06575	2.20524	2.14490	-0.23943
2000	4.16000	3.74281	5.52294	3.88622	-0.13281
			ΥΚΑ Δ′		
2004	5.35000	4.80383	6.29512	4.98789	-0.17640
2003	2.20000	1.97626	1.58147	2.05198	-0.25065
2002	4.32000	3.88565	4.45931	4.03454	-0.19828
2001	5.85000	5.24766	2.98838	5.44873	-0.29882
2000	10.02000	9.03301	6.84447	9.37913	-0.25646
			ΥΚΜΘ Α′		
2004	3.09000	2.78170	2.76156	2.88829	-0.21642
2003	4.04000	3.63461	5.11051	3.46938	-0.10882
2002	5.05000	4.53779	6.05093	4.33150	-0.13823
2001	2.11000	1.89645	1.37581	1.81023	-0.22764
2000	4.25000	3.81932	4.09763	3.64569	-0.17527
			ΥΚΜΘ Β′		
2004	5.84000	5.22808	2.58634	4.99040	-0.27582
2003	7.78000	6.99718	3.42655	6.67908	-0.25886
2002	2.80000	2.52346	2.57118	2.40874	-0.17766
2001	4.32000	3.89101	5.23333	3.71412	-0.084338
2000	5.28000	4.74682	5.97475	4.53102	-0.11522
			ΥΚΠ		
2004	2.24000	2.01806	1.31315	1.92632	-0.20463
2003	4.85000	4.36045	4.35217	4.16222	-0.15227
2002	6.43000	5.82561	3.01475	5.56077	-0.24440
2001	6.78000	6.10712	3.88280	5.82948	-0.20074
2000	3.40000	3.06901	2.35497	2.92949	-0.18254

NOTES:

AC	is average cost
MC1	is marginal cost, CD-1
MC2	is marginal cost, TL
MC3	is marginal cost, CD-2
TCH	is technical change index from the translog cost function.

The relevant results are those corresponding to MC-1. ΥΚΑ Α′, ΥΚΑ Β′ etc denote different lines of operation.

TABLE 5. COST FUNCTIONS IN MAINTENANCE (LEAST SQUARES)

	Cobb-Douglas-1	Cobb-Douglas-2	Translog
const.	1.17701 (.374354)	1.32376 (.587134)	2.95602 (1.79456)
log(Q)	.151133 (.100085)	.236551 (.244238)	.982376 (1.35905)
u	.974272 (.788762)	.770949 (1.16782)	-8.72284 (9.52890)
t	.125760 (.094848)	.060915 (.210935)	.144876 (.425823)
D	-.122444 (.273374)	-.293163 (.930597)	.021449 (.308159)
D*log(Q)		-.100239 (.269861)	
D*u		.141533 (1.76263)	
D*t		.080106 (.238854)	
$Log(Q)^2$			.340554 (.198983)
u^2			25.5749 (25.6059)
t^2			.033433 (.092852)
Log(Q)*u			-1.89348 (3.28345)
Log(Q)*t			.045043 (.113287)
u*t			-.419229 (.685232)
R^2	.190423	.195770	.324895
LM het	3.90278 [.048]	4.49793 [.034]	.092657 [.761]

NOTES: Numbers in parentheses denote standard errors. LM het is the Lagrange multiplier test for heteroskedasticity. In parentheses provided is its p-value.

TABLE 6. COST FUNCTIONS IN MAINTENANCE
(PANEL DATA / RANDOM EFFECTS)

	Cobb-Douglas	Translog
log(Q)	.156516 (.088903)	1.07823 (1.12617)
u	1.03367 (.700848)	-9.65209 (7.89983)
t	.127882 (.109287)	.127818 (.412547)
D	-.135870 (.315299)	.333694 (.167036)
const.	1.14409 (.357329)	3.14131 (1.51185)
$\log(Q)^2$		27.8871 (21.2096)
u^2		.034251 (.096873)
t^2		-2.11537 (2.71395)
Log(Q)*u		.045144 (.093978)
Log(Q)*t		-.389259 (.566689)
U*t		.016467 (.325228)
R^2	.190231	.324207
LM het	3.56465 (.059)	.210557 ([.646)
Hausman	0.080640 (.9605)	0.17862 (1.000)

NOTES: Numbers in parentheses denote standard errors. LM het is the Lagrange multiplier test for heteroskedasticity. In parentheses provided is its p-value. Hausman denotes the Hausman test for validity of random effects specification (p-value in parentheses).

TABLE 7. AVERAGE COST, MARGINAL COST AND TCHNICAL CHANGE IN MAINTENANCE

	AC	MC1	MC2	MC3	TCH
ΥΓΑ Α′					
2004	3.11000	0.47003	2.30058	0.42393	0.17420
2003	3.24000	0.49093	0.91943	0.44279	0.095233
2002	3.14000	0.47299	1.57789	0.42661	0.13292
2001	2.40000	0.36314	0.74316	0.32753	0.10208
2000	56.25000	8.53361	1.44105	7.69676	0.067924
ΥΓΑ Β′					
2004	5.08000	0.76796	3.49818	0.69265	0.16067
2003	3.95000	0.59632	2.67038	0.53784	0.17601
2002	6.86000	1.03535	2.43061	0.93382	0.10641
2001	4.96000	0.75016	2.22320	0.67659	0.11029
2000	164.48000	23.45582	-103.15897	21.15562	-0.011549
ΥΓΑ Γ′					
2004	3.78000	0.57159	2.56817	0.51554	0.13701
2003	3.58000	0.54164	0.85298	0.48853	0.061800
2002	2.23000	0.33645	0.75962	0.30346	0.068700
2001	3.63000	0.54945	1.48788	0.49556	0.10977
2000	0.00000	---	---	---	---
ΥΓΑ Δ′					
2004	7.19000	1.08417	5.08312	0.97785	0.14598
2003	2.87000	0.43491	1.78455	0.39226	0.13935
2002	5.03000	0.76057	1.92133	0.68599	0.092633
2001	5.85000	0.88528	2.35980	0.79846	0.076853
2000	8.04000	1.21785	2.08801	1.09842	0.083160
ΥΓΜΘ Α′					
2004	4.26000	0.64474	2.70465	0.58151	0.10358
2003	4.04000	0.61062	0.77962	0.55074	0.028368
2002	2.45000	0.36971	0.82976	0.33346	0.046021
2001	4.01000	0.60877	1.46709	0.54907	0.076338
2000	0.00000	---	---	---	---
ΥΓΜΘ Β′					
2004	3.82000	0.57825	2.65973	0.52154	0.12348
2003	2.45000	0.37060	1.41021	0.33425	0.10592
2002	4.58000	0.69286	1.54378	0.62491	0.059200
2001	4.89000	0.74065	1.75354	0.66802	0.043420
2000	7.53000	1.14053	1.61553	1.02868	0.049727
ΥΓΜΘ Γ′					
2004	2.53000	0.38343	1.47877	0.60014	0.067655
2003	4.45000	0.67350	0.65918	1.05416	-0.0050650
2002	2.66000	0.40156	0.78156	0.62852	0.012588
2001	4.96000	0.75284	1.58992	1.17834	0.042905
2000	0.00000	1.74384	6.74628	2.72944	0.12359
ΥΓΜΘ Α′					
2004	3.07000	0.46288	2.05734	0.72450	0.094598
2003	1.96000	0.29588	0.93560	0.46311	0.057146
2002	3.66000	0.55283	1.11999	0.86528	0.029371
2001	5.23000	0.79170	1.63844	1.23915	0.0099875
2000	7.13000	1.07902	1.20682	1.68887	0.016295

ΥΓΠ Α′/Β′

2004	2.35000	0.35637	1.26822	0.55779	0.034222
2003	4.65000	0.70292	0.47848	1.10020	-0.038498
2002	2.70000	0.40843	0.67321	0.63928	-0.020845
2001	6.01000	0.91067	0.66086	1.42537	-0.017344
2000	0.00000	0.81285	2.76368	1.27226	0.061433

ΥΓΠ Γ′

2004	2.54000	0.38470	1.58838	0.60213	0.060811
2003	2.41000	0.36342	1.28030	0.56882	0.052075
2002	3.57000	0.53816	0.96496	0.84231	-0.0010705
2001	4.80000	0.72664	1.28724	1.13733	-0.023445
2000	6.98000	1.05617	0.86649	1.65311	-0.017138

NOTES:

AC	is average cost
MC1	is marginal cost, CD-1
MC2	is marginal cost, TL
MC3	is marginal cost, CD-2
TCH	is technical change index from the translog cost function.

The relevant results are those corresponding to MC-2. ΥΓΑ Α′, ΥΓΑ Β′ etc denote different locations of maintenance.