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Energy demand and energy-related CO_2 emissions in Greek manufacturing: Assessing the impact of a carbon tax

Nikolaos Floros[a], Andriana Vlachou[b,*]

[a]Cooperative Bank of Chania, 19-21 Augoustou, 71202, Iraklion, Greece
[b]Department of Economics, Athens University of Economics and Business, 76 Patission Street, Athens 104 34, Greece

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Abstract

The purpose of this paper is to study the demand for energy in two-digit manufacturing sectors of Greece and to evaluate the impact of a carbon tax on energy-related CO_2 emissions. The theoretical model utilized in the analysis is the two-stage translog cost function. The model is estimated using time series data over the period 1982–1998. The results indicate substitutability between electricity and liquid fuels (diesel and mazout), and substitutability between capital, energy and labor. A carbon tax of \$50 per tone of carbon results in a considerable reduction in direct and indirect CO_2 emissions from their 1998 level. This implies that a carbon tax on Greek manufacturing is an environmentally effective policy for mitigating global warming, although a costly one.

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1. Introduction

In recent years, the growing concern about the negative environmental impacts of energy production and consumption has revived the interest in studying the energy

* Corresponding author. Tel.: +30 210 8203130; fax: +30 210 8203301.
E-mail address: vlachou@aueb.gr (A. Vlachou).

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structure of different sectors of the economy. In particular, the combustion of fossil fuels is heavily implied for the rising concentrations of greenhouse gases in the earth's atmosphere which are expected to lead to significant changes in climate with serious economic and social effects (IPCC, 1996). Carbon dioxide (CO_2) emissions are believed to be responsible for approximately half of the man-made contributions to the greenhouse effect. Accordingly, most of the efforts to mitigate global warming have concentrated on reducing CO_2 emissions.

CO_2 emissions account for the majority of the total greenhouse gases emissions in Greece since they were responsible for approximately 80.8% of the total emissions in 1998, while methane and nitrous oxide accounted for 8.6% and 7.5%, respectively. The combustion of fossil fuels accounted for 91% of total CO_2 emissions in the same year. CO_2 emissions increased by 18% between 1990 and 1998. The contribution of the industrial sector as an end-user to the total CO_2 emissions from fossil fuels (26% in 1998) was only second to the contribution of the domestic and tertiary sector (Ministry for the Environment and National Observatory of Athens, 2000). As a result, the study of interfuel and interfactor substitution possibilities in Greek manufacturing can significantly help in designing effective policies to reduce CO_2 emissions.

A number of studies have investigated the demand of energy in Greek manufacturing (Caramanis, 1979; Samouilidis and Mitropoulos, 1982; Vlachou and Samouilidis, 1986; Donatos and Mergos, 1989; Kintis and Panas, 1989; Calogirou et al., 1997; Christopoulos, 2000; Christopoulos and Tsionas, 2002). However, most of these studies cover the period before 1990 and are conducted at a very aggregate level. Moreover, to the best of our knowledge, none of these studies was really concerned with the environmental implications of the energy demand in manufacturing.

Greece, however, as a signatory of the UN Framework Convention on Climate Change in Kyoto, has certain obligations to fulfill jointly with the other member-states of the EU. In particular, under the Kyoto Protocol, the EU is committed to a reduction of 8% of greenhouse gases from their 1990 level in the period 2008–2012. The burden sharing arrangement for all member states, finalized in June 1998, allows Greece to increase its greenhouse emissions by 25% compared to 1990 levels. This target might not seem so restrictive at first sight. However, according to the Ministry for the Environment and the National Observatory of Athens (2000), total greenhouse gas emissions have already increased by 18% during the period 1990–1998. This implies that great efforts are needed in order to limit the increase to 25% by the year 2012.

The objective of this paper is to formulate and estimate a two-stage translog model using recent data in order to analyse intrerfuel and interfactor substitution in Greek manufacturing. The analysis is conducted at the two-digit level in order to avoid the shortcomings of aggregation. The estimated elasticities are then used to investigate the impact of a carbon tax on the energy-related CO_2 emissions from two-digit manufacturing sectors. Given the advantages of a carbon tax over alternative instruments (Pearce, 1991; Vassos and Vlachou, 1997a), the analysis provides an assessment of the possibilities for reducing CO_2 emissions from manufacturing to mitigate global warming in the case of Greece.

The paper is organized as follows. The second section presents in brief the theoretical model and discusses the data and the estimation technique. The third section reports and analyses the empirical results. The final section is devoted to basic conclusions.

2. The model and data

The econometric approach adapted in this study is a generalized translog production frontier, originally developed by Christennsen et al. (1973) and extensively applied in studies investigating the energy demand of industry (see, for example, Berndt and Wood, 1975; Griffin, 1977; Griffin and Gregory, 1976; Fuss, 1977; Pindyck, 1979; Vlachou and Samouilidis, 1986; Calogirou et al., 1997). In the context of this methodological approach, we assume that there exists a twice differentiable aggregate production function for each two-digit manufacturing sector which relates the flow of gross output (Y) to the services of three inputs: capital (K), labor (L) and energy (E).[1] We further assume that the production function is weakly separable in the major categories of capital, labor and energy.[2] The assumption permits us to construct an energy price index that aggregates the prices of three fuels: electricity (EL), diesel (D) and mazout (M). Under these assumptions, the production function can be written as follows:

$$Y = f[K,L,E[\mathrm{EL},D,M),T] \tag{1}$$

where T is an index of technological change.

If the factor prices and output level are exogenously determined, this production structure can alternatively be determined by a cost function of the form

$$C = G[P_K,P_L,P_E(P_{\mathrm{EL}},P_D,P_M),Y,T] \tag{2}$$

where C is total cost, and P_K, P_L and P_E are the input prices of K, L and E, respectively, while P_{EL}, P_D, and P_M are the prices of electricity, diesel and mazout, respectively. Notice that P_E is the aggregate price index of energy which is homothetic in its arguments.

We represent the cost function (2) by a non-homothetic translog cost function.[3] By imposing symmetry on the second-order partial derivatives and assuming exogenously given input prices (as in the case of perfect competition), the translog cost function is specified as follows:

$$\begin{aligned}\ln C = {} & \alpha_o + \gamma_y \ln Y + 0.5\gamma_{yy}(\ln Y)^2 + \sum_{i=1}^{n} \beta_i \ln P_i + 0.5 \sum_{i=1}^{n}\sum_{j=1}^{n} \gamma_{ij} \ln P_i \ln P_j \\ & + \sum_{i=1}^{n} \gamma_{yi} \ln Y \ln P_i + \sum_{i=1}^{n} \gamma_{i\tau} T \ln P_i + \gamma_\tau T + 0.5\gamma_{\tau\tau} T^2 + \gamma_{y\tau} T \ln Y \end{aligned} \tag{3}$$

where i, j=K, L, E.

Shephard's lemma (Shephard, 1953) implies $\partial C/\partial P_i$=X_i, the cost-minimizing quantity of the ith input. Then

$$\partial \ln C/\partial \ln P_i = P_i X_i/C = S_i,$$

[1] We assume that capital, labor and energy inputs are as a group weakly separable from materials. This assumption was necessary since we had no data from which to construct price indices of materials.

[2] See Fuss (1977), Griffin and Gregory (1976), Pindyck (1979), Vlachou and Samouilidis (1986), Andrikopoulos et al. (1989).

[3] The translog production function and cost function were introduced by Christensen et al. (1973).

and the input demand functions, in terms of cost shares S_i, take the form

$$S_i = \beta_i + \sum_{j=1}^{n} \gamma_{ij} \ln P_j + \gamma_{yi} \ln Y + \gamma_{i\tau} T \tag{4}$$

where i, j=K, L, E.

The cost function must be homogeneous of degree 1 in prices, and satisfy the properties of a well-behaved cost function. In addition, the system of Eq. (4) must satisfy the adding up condition ($\sum_i^n S_i$=1). This implies the following parameter restrictions:[4]

$$\begin{aligned} &\sum_{i=1}^{n} \beta_i = 1; \gamma_{ij} = \gamma_{ij}; \sum_{i=1}^{n} \gamma_{ij} = 0 \\ &\sum_{i=1}^{n} \gamma_{iy} = 0, \sum_{i}^{n} \gamma_{i\tau} = 0 \end{aligned} \tag{5}$$

Two sets of elasticities can be calculated from the system of Eq. (4): (i) the Allen partial elasticities of substitution σ_{ij}; and (ii) the factor price elasticities of demand ε_{ij}. The Allen elasticities are summarized as follows:

$$\begin{aligned} &\sigma_{ii} = \left(\gamma_{ii} + S_i^2 - S_i\right) / S_i^2 \\ &\sigma_{ij} = \left(\gamma_{ij} + S_i S_j\right) / S_i S_j, i \neq j \end{aligned} \tag{6}$$

The price elasticities of demand are calculated as

$$\begin{aligned} &\varepsilon_{ii} = \sigma_{ii} S_i \\ &\varepsilon_{ij} = \sigma_{ij} S_j, i \neq j \end{aligned} \tag{7}$$

We turn now to the derivation of the energy sub-model, which permits us to study interfuel substitution in two-digit manufacturing sectors and to construct the aggregate price index of energy to be used in Eqs. (3) and (4). Since P_E is the price per unit of energy, it is also the cost per unit to the optimizing agent. This cost is represented by a homothetic translog function with constant returns to scale, which takes the form

$$\ln P_E = \alpha_0 + \sum_{i=1}^{n} \beta_i \ln P_{Ei} + 0.5 \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} \ln P_{Ei} \ln P_{Ej} \tag{8}$$

Cost-minimizing behavior implies that the demand functions for individual energy types, in terms of the cost shares in the cost of aggregate energy, take the form

$$S_{Ei} = \beta_i + \sum_{j=1}^{n} \gamma_{ij} \ln P_{Ei}, \quad i,j = \mathrm{EL}, D, M \tag{9}$$

where S_{Ei} is the cost shares of the i fuel in the cost of aggregate energy, $\sum_i^n S_{Ei}$=1.

[4] Note that $\sum_i^n \gamma_{iy}$=0 does not impose hometheticity on the underlying production structure unless each γ_{iy}=0 (see Fuss, 1977). Also note that $\sum_{i=I}^n \gamma_{i\tau}$=0 implies a Hicks-neutral technical change.

The adding up criterion and the properties of neoclassical production theory require the following restrictions:

$$\sum_i \beta_i = 1; \gamma_{ij} = \gamma_{ji}; \sum_i \gamma_{ij} = 0 \tag{10}$$

The Allen–Uzawa partial elasticities of substitution (σ_{ij}) and the price elasticities of demand for each energy type can be calculated by using Eqs. (6) and (7), respectively. However, these elasticities are calculated on the assumption that the total quantity of energy consumed remains constant. Dropping this assumption and following Pindyck (1979), we can estimate the *total* price elasticities for each energy type as follows:

$$\varepsilon_{ii}^* = \varepsilon_{ii} + \varepsilon_{\mathrm{EE}} S_{Ei}$$

$$\varepsilon_{ij}^* = \varepsilon_{ij} + \varepsilon_{\mathrm{EE}} S_{Ej}, i \neq j \tag{11}$$

where $\varepsilon_{\mathrm{EE}}$ is the own price elasticity of aggregate energy (E), calculated from Eqs. (3) and (4).

Estimation of the complete model is accomplished in two stages. In the first stage, we estimate the system (9) subject to the constrains (10). This provides an estimate of the interfuel substitution patterns. By substituting the parameter estimates into Eq. (9), we obtain an estimate $\hat{P}_E$ of the aggregate price index (up to arbitrary scaling factor α_0). This estimate serves in the second stage. In particular, in the second stage, we estimate the system (4) subject to the constraints (5), replacing P_E by its estimate $\hat{P}_E$.

2.1. Data and their sources

The model described above was estimated for 22 two-digit manufacturing sectors of Greece employing more than 10 employees, for the years 1982–1998. The main source of our data was the Annual Industrial Surveys (AIS) of the National Statistical Service of Greece (NSSG, 1981–1998). Since the NSSG changed the industrial classification of several sectors in 1993, it was necessary to adjust the 1982–1992 data to the new classification to achieve continuity and compatibility for the time series.

The AIS provides data on total labor compensation and the number of workers employed. The AIS also provides data on energy. In particular, the expenditures and quantities of electricity, diesel and mazout consumed by the two-digit manufacturing sectors are available from this source, while the price for each energy type is calculated as the ratio of these two measures.[5] The quantity of each type of energy was converted into tons of oil equivalent (TOE).

In order to estimate the capital stock, we used the perpetual inventory method. Data on (gross) investment and depreciation at the two-digit level come from NSSG. The capital stock for the benchmark year (1982) of our study was obtained from the studies made by

[5] Natural gas appears to be used in manufacturing since 1997 so that we had to exclude it from our energy time series. In addition, we left coal out from our analysis since the data on it was missing for several years.

Table 1
The energy structure of Greek manufacturing in 1998 (selected sectors)

Code	Sectors	Sector's share in the energy consumption of manufacturing (%)	Fuel share in total energy consumption of the sector (%)			
			Electricity	Diesel	Mazout	Other
15	Food products and beverages	19.87	55.19	6.13	32.25	6.43
17	Textiles	6.94	77.70	2.17	14.62	5.51
21	Pulp and paper	5.77	66.18	2.63	30.94	0.25
23	Coke and refined	6.42	38.10	0.00	61.90	0.00
24	Petroleum products Chemicals	5.97	68.63	1.85	13.23	16.29
26	Non-metallic mineral products	15.78	53.09	6.82	10.23	29.89
27	Basic metal industries	30.27	82.64	1.75	14.30	1.31
	Total	91.02	–	–	–	–

"Other" includes lignite, coal and natural gas.

Skountzos and Mattheou (1991) and Georganta et al. (1994).[6] The capital stock was estimated in constant 1982 prices by deflating gross investment and depreciation by the deflator of investment in fixed capital in manufacturing, provided by the NSSG. The return on capital was calculated from value added by subtracting from it total labor compensation. The price of capital was calculated by dividing the return on capital by the estimated net fixed capital.

Data on gross output come from the AIS of the NSSG. Factor expenditures and prices, and gross production are deflated using the deflator of final manufacturing products for internal consumption, provided by the NSSG.

On the basis of the data collected for the study, we observe that in the majority of sectors, the energy share in total cost has been decreasing over the period 1982–1998. This seems to reveal a tendency of energy conservation and of substitution away from costly fuels by manufacturing firms, as Patsouratis and Souflias (1995) have also noticed. In particular, the energy share in the total cost of the sector in 1998 was 19.7% for sector 27, 15.4% for 26, 9.4% for 21 and 8.2% for 17. The most energy intensive sectors are the basic metal industries (27), the non-metallic mineral products (26), the pulp and paper (21), and the textiles sector (17).

Seven sectors (15, 17, 21, 23, 24, 26, 27) accounted for 91% of the energy consumption in manufacturing, as Table 1 shows. Almost all manufacturing sectors were electricity-intensive in 1998. This seems to be in part explained by the absence of natural gas from the energy balance of Greece prior to 1996. It might also indicate a substitutability between electricity and liquid fuels over the period. However, since a high percentage

[6] Calogirou et al. (1997) also used in their study, covering the 1980–1991 period, the capital stock provided by Georganta et al. at the two-digit level. In our study, we constructed our own series of capital stock for the period 1982–1998, taking only as a benchmark estimate the capital stock estimate of 1982 provided by Georganta et al. (1994), and based on the previous study made by Skountzos and Mattheou (1991).

(65% in 1998) of electricity is generated by lignite-fired stations, a high electricity consumption by manufacturing tends to increase the CO_2 emissions produced in the country.

2.2. Estimation technique

For the estimation of the interfuel sub-model and the total cost (interfactor) model, the iterative Zellner method (or the seemingly unrelated regression estimation) was used. This method, which is equivalent to maximum likelihood estimation, gives consistent and asymptotically efficient estimates.

3. Empirical results

3.1. Interfuel sub-model

Parameter estimates for the energy sub-model are presented in Table 2.[7] Most of the parameter estimates are statistically significant. In particular, 73.7% of estimated coefficients are statistically significant at 5% level of statistical significance, while 90% are statistically significant at 10%. The R^2s for the share equations are fairly high when compared with similar studies.[8]

Table 3 presents own and cross-price elasticities for the three energy types, estimated at the mean values of cost shares. The majority of the own price elasticities (with the exception of nine, of which six refer to mazout) are negative. Moreover, 76.5% of the own price elasticities are statistically significant at 5% level of statistical significance. Overall, the results suggest that the demand for electricity is inelastic to its own price changes in all sectors since the majority of own price elasticities are less than one. The demand for diesel is greater than one in eight sectors (17, 23, 25, 27, 28, 29, 35 and 36), while the demand for mazout is elastic in only three sectors (18, 28 and 36). In short, the demand for diesel exhibits the highest price responsiveness among the three energy types.

The cross-price elasticities suggest that electricity and diesel are substitutes in 16 manufacturing sectors : 15, 16,17, 19, 20, 21, 23, 24, 25, 26, 27, 28, 29, 34, 35 and 36. Only in three of these sectors (16,23,29) is this substitutability statistically insignificant at a level of 5%. Electricity and mazout are substitutes in 11 manufacturing sectors (15, 16, 17, 18, 21, 23, 24, 27, 28, 31 and 36) and this relation is not statistically significant at a 5% level only in three of them (15, 16, 31). Between diesel and mazout, complementarily prevails since the cross-price elasticity is negative in 12 sectors (15, 17, 19, 20, 21, 24, 25, 26, 28, 31, 34, 36); however, in four sectors (21, 25, 28 and 31), this complementary relation is insignificant at a 5% level. Overall, there is evidence that electricity and diesel

[7] Since sectors 30 and 32 use only electricity, an interfuel model is not estimated for these sectors. Moreover, results from the interfuel model are not reported for sectors 22 and 23. Due to the high share of electricity in these sectors, interfuel estimates are quite disturbing.

[8] See, for example, Vlachou and Samouilidis (1986) and Christopoulos (2000).

Table 2
Parameter estimates of the interfuel submodel, 1982–1998

Code	Sectors	β_{EL}	β_D	β_M	γ_{ELEL}	γ_{DD}	γ_{MM}	γ_{ELD}	γ_{ELM}	γ_{DM}	R^2 S_{EL}	DW S_{EL}	R^2 S_M	DW S_M
15	Food products and beverages	0.248	−0.075	0.827	0.111	0.010	0.278	0.078	−0.190	−0.089	0.660	0.940	0.750	0.990
		(0.088)	(0.019)	(0.086)	(0.052)	(0.005)	(0.050)	(0.012)	(0.049)	(0.010)				
16	Tobacco	0.483	0.037	0.480	0.074	0.001	0.094	0.009	−0.083	−0.010	0.038	0.375	0.062	0.278
		(0.139)	(0.041)*	(0.146)	(0.082)*	(0.024)*	(0.090)*	(0.029)*	(0.082)*	(0.024)*				
17	Textiles	0.661	−0.067	0.406	0.018	−0.019	0.149	0.074	−0.093	−0.056	0.732	0.989	0.770	0.788
		(0.049)	(0.012)	(0.043)	(0.033)*	(0.004)	(0.026)	(0.009)	(0.028)	(0.007)				
18	Wearing apparel	0.717	0.256	0.027	0.079	0.007	−0.104	−0.095	0.016	0.088	0.758	1.238	0.387	0.459
		(0.079)	(0.030)	(0.052)*	(0.020)	(0.011)	(0.043)	(0.010)	(0.022)*	(0.027)				
19	Leather and leather products	0.523	−0.082	0.559	0.147	0.010	0.297	0.070	−0.217	−0.080	0.605	0.816	0.661	0.801
		(0.071)	(0.021)	(0.081)	(0.042)	(0.009)*	(0.053)	(0.013)	(0.046)	(0.014)				
20	Wood and cork	0.486	0.026	0.488	0.172	0.051	0.236	0.007	−0.178	−0.057	0.676	1.060	0.693	1.350
		(0.044)	(0.020)*	(0.051)	(0.026)	(0.009)	(0.036)	(0.012)*	(0.028)	(0.014)				
21	Pulp and paper	0.481	0.007	0.512	0.115	0.003	0.122	0.002	−0.117	−0.005	0.294	1.184	0.341	1.202
		(0.069)	(0.010)*	(0.064)	(0.045)	(0.004)*	(0.040)	(0.005)*	(0.042)	(0.006)*				
23	Coke, refined petroleum products and nuclear fuel	0.098	−0.004	0.906	0.057	−0.056	0.099	0.049	−0.106	0.007	0.431	0.869	0.442	0.886
		(0.050)	(0.047)*	(0.047)	(0.038)*	(0.050)*	(0.033)	(0.035)*	(0.025)	(0.032)*				
24	Chemicals	0.791	0.002	0.207	−0.004	0.012	0.031	0.012	−0.008	−0.023	0.060	0.421	0.190	0.401
		(0.067)	(0.089)*	(0.065)	(0.045)*	(0.009)*	(0.042)*	(0.010)*	(0.042)*	(0.006)				

25	Rubber and plastic	0.481	0.007	0.512	0.115	0.003	0.122	0.002	−0.117	−0.005	0.294	1.184	0.341	1.202
	products	(0.069)	(0.010)*	(0.064)	(0.045)	(0.004)*	(0.040)	(0.005)*	(0.042)	(0.006)*				
26	Non-metallic mineral	0.214	0.011	0.775	0.328	0.049	0.396	0.010	−0.338	−0.058	0.247	0.462	0.330	0.467
	products	(0.171)*	(0.022)*	(0.190)	(0.116)	(0.004)	(0.144)	(0.016)*	(0.129)	(0.016)				
27	Basic metal industries	0.646	0.025	0.329	0.114	−0.003	0.110	0.000	−0.113	0.003	0.664	0.792	0.675	0.952
		(0.024)	(0.004)	(0.023)	(0.020)	(0.003)*	(0.019)	(0.003)*	(0.019)	(0.003)*				
28	Metal products,	0.949	0.017	0.035	−0.092	−0.027	−0.009	0.055	0.037	−0.028	0.327	0.232	0.276	0.335
	except machinery	(0.059)	(0.024)*	(0.039)*	(0.048)	(0.008)	(0.021)*	(0.019)	(0.030)*	(0.012)				
29	Machinery and	0.330	0.086	0.583	0.302	−0.050	0.280	0.013	−0.316	0.036	0.479	0.468	0.479	0.470
	equipment n.e.c.	(0.184)*	(0.633)*	(0.139)	(0.127)	(0.014)	(0.074)	(0.047)*	(0.093)	(0.173)*				
31	Electrical machinery	0.756	0.073	0.171	0.085	0.055	0.058	−0.041	−0.044	−0.014	0.179	0.968	0.347	0.946
	and apparatus n.e.c.	(0.032)	(0.011)	(0.031)	(0.022)	(0.007)	(0.020)	(0.009)	(0.019)	(0.005)				
34	Motor vehicles,	0.611	0.097	0.293	0.068	0.052	0.157	0.019	−0.087	−0.070	0.517	0.878	0.818	1.849
	trailers	(0.048)	(0.035)	(0.032)	(0.040)*	(0.072)*	(0.019)	(0.033)*	(0.020)	(0.012)				
35	Other transport	0.971	0.029		−0.145	−0.145		0.145			0.473	1.881		
	equipment	(0.038)	(0.038)*[a]		(0.037)	(0.037)[a]		(0.037)[a]						
36	Furniture:	1.154	−0.114	−0.040	−0.214	−0.045	−0.005	0.127	0.086	−0.082	0.334	0.488	0.646	0.632
	manufacturing n.e.c.	(0.098)	(0.055)	(0.049)*	(0.079)	(0.028)*	(0.021)*	(0.045)	(0.038)	(0.020)				

The figures in parentheses are the standard errors. The asterisk (*) denotes that the coefficient is not statistically significant at 5%.

[a] It includes non-electric energy that is diesel and mazout.

Table 3
Own and cross elasticities for fuels in manufacturing

Code	Sector	ε_{ELEL}	ε_{DD}	ε_{MM}	ε_{ELD}	ε_{DEL}	ε_{ELM}	ε_{MEL}	ε_{DM}	ε_{MD}
15	Food products and beverages	−0.279 (0.104)	−0.780 (0.074)	0.076 (0.115)*	0.226 (0.024)	1.642 (0.175)	0.053 (0.100)*	0.061 (0.115)*	−0.862 (0.147)	−0.137 (0.023)
16	Tobacco	−0.264 (0.133)	−0.923 (0.448)	−0.386 (0.281)*	0.068 (0.047)*	0.788 (0.548)*	0.196 (0.133)*	0.364 (0.247)*	0.134 (0.452)*	0.021 (0.072)*
17	Textiles	−0.233 (0.044)	−1.452 (0.118)	−0.104 (0.119)*	0.138 (0.012)	2.703 (0.230)	0.095 (0.038)	0.320 (0.129)	−1.251 (0.192)	−0.216 (0.033)
18	Wearing apparel	−0.131 (0.026)	−0.830 (0.106)	−1.739 (0.354)	−0.020 (0.013)*	−0.149 (0.099)*	0.142 (0.028)	0.911 (0.178)	0.979 (0.260)	0.828 (0.220)
19	Leather and leather products	−0.006 (0.052)*	−0.715 (0.228)	1.191 (0.368)	0.127 (0.016)	2.574 (0.329)	−0.121 (0.056)	−0.681 (0.316)	−1.859 (0.342)	−0.513 (0.094)
20	Wood and cork	−0.006 (0.034)*	−0.211 (0.123)*	0.650 (0.229)	0.079 (0.015)	0.863 (0.168)	−0.073 (0.036)	−0.358 (0.178)	−0.652 (0.202)	−0.292 (0.091)
21	Pulp and paper	−0.165 (0.069)	−0.768 (0.318)	−0.300 (0.121)	0.016 (0.007)	0.836 (0.353)	0.149 (0.064)	0.303 (0.129)	−0.068 (0.497)*	−0.003 (0.020)*
23	Coke, refined petroleum products and nuclear fuel	−0.985 (0.154)	−2.614 (1.470)*	−0.142 (0.045)	0.234 (0.144)*	1.692 (1.044)*	0.677 (0.103)	0.231 (0.035)	0.914 (0.932)*	0.043 (0.044)*
24	Chemicals	−0.211 (0.057)	−0.572 (0.324)*	−0.648 (0.237)	0.044 (0.015)	1.195 (0.418)	0.167 (0.053)	0.750 (0.240)	−0.623 (0.212)	−0.103 (0.035)
25	Rubber and plastic products	−0.121 (0.037)	−2.187 (0.258)	−0.605 (0.290)	0.030 (0.014)	0.951 (0.456)	−0.034 (0.035)*	−0.284 (0.290)*	−0.088 (0.366)*	−0.023 (0.096)*
26	Non-metallic mineral products	0.160 (0.173)*	−0.139 (0.067)	0.747 (0.538)*	0.075 (0.023)	0.829 (0.256)	−0.236 (0.193)*	−0.590 (0.482)*	−0.689 (0.262)	−0.157 (0.060)
27	Basic metal industries	−0.076 (0.026)	−1.105 (0.130)	−0.249 (0.092)	0.022 (0.004)	0.764 (0.141)	0.055 (0.025)	0.212 (0.096)	0.337 (0.139)	0.037 (0.015)
28	Metal products, except machinery	−0.255 (0.056)	−1.269 (0.102)	−1.062 (0.310)	0.144 (0.022)	1.557 (0.243)	0.111 (0.035)	1.395 (0.442)	−0.287 (0.153)*	−0.333 (0.178)*
29	Machinery and equipment n.e.c.	0.204 (0.150)*	−1.639 (0.186)	2.458 (0.889)	0.086 (0.056)*	1.039 (0.678)*	−0.290 (0.109)	−2.964 (1.118)	0.600 (0.181)	0.506 (0.153)
31	Electrical machinery and apparatus n.e.c.	−0.041 (0.025)*	0.224 (0.152)*	−0.289 (0.217)*	−0.001 (0.011)*	−0.022 (0.202)*	0.042 (0.023)*	0.389 (0.207)*	−0.201 (0.108)*	−0.100 (0.054)*
34	Motor vehicles, trailers	−0.167 (0.054)	−0.528 (0.422)*	0.856 (0.217)	0.196 (0.044)	0.852 (0.192)	−0.028 (0.028)*	−0.235 (0.231)*	−0.324 (0.070)	−0.622 (0.134)
35	Other transport equipment	−0.344 (0.045)	−1.674[(a)] (0.217)		0.344[(a)] (0.045)	1.674[(a)] (0.217)				
36	Furniture: manufacturing n.e.c.	−0.338 (0.088)	−1.702 (0.475)	−1.053 (0.505)	0.200 (0.050)	3.047 (0.763)	0.138 (0.022)	2.941 (0.475)	−1.345 (0.336)	−1.889 (0.472)

The figures in parentheses are the standard errors. The asterisk (*) denotes that the elasticity is not statistically significant at 5%.

as well as electricity and mazout are substitutes, while diesel and mazout are complements in most manufacturing sectors.

These results can be compared to previous studies. Vlachou and Samouilidis (1986) estimated own and cross-price elasticities for electricity, liquid fuels and solid fuels in Greek manufacturing (aggregated in intermediaries, equipment, consumption and total manufacturing), using data for the period 1960–1980. The reported own price elasticities for electricity are: −0.308 in total manufacturing, −0.246 in intermediaries, −0.179 in equipment and −0.125 in consumption. These estimates are very close to the own price elasticities of electricity estimated by this study. Vlachou and Samouilidis (1986) also reported the following own price elasticities for liquid fuels: −0.052 in total manufacturing, −0.015 in intermediaries, −0.309 in equipment and −0.078 in consumption. These estimates are lower than the own price elasticities for diesel and mazout calculated by this study, suggesting a structural change away from liquid fuels in the 1980s and 1990s. It should be also mentioned that Vlachou and Samouilidis (1986) found that electricity and liquid fuels are substitutes in the three major manufacturing sectors. This result suggested, according to the authors, that manufacturing could move away from expensive imported liquid fuels by using electricity, produced by indigenous sources like lignite or renewable energy sources. This actually seems to have happened in the last three decades as captured by the increased share of electricity in the energy consumption of manufacturing.[9]

3.2. Interfactor model

The parameter estimates of the aggregate model are reported in Table 4. The majority (74%) of the estimated coefficients are statistically significant at a 5% level of statistical significance. The R^2s are very high implying that the cost shares, and for that matter the demand for the three productive factors, are fairly well explained by the translog specification.

Price elasticities, calculated at the mean values of cost shares, are presented in Table 5. All own price elasticities are negative, with the exception of two (ε_{KK} in sector 34, and ε_{EE} in sector 36).[10] Own price elasticities show that the demand for capital is inelastic in all sectors; when compared with the demand of labor and the demand of energy, it appears to be more inelastic than the latter in most sectors. The demand for labor is also inelastic in all sectors, except sector 17. The own price elasticities of energy are statistically significant in the majority of the sectors. They are less than one, with the exception of sectors 20,22 and 26.

Although our estimates are not directly comparable to Christopoulos' (2000), we note with caution that our estimates of own price elasticities are higher (in most sectors) than the estimates provided by Christopoulos (2000) for aggregate manufacturing using data for the 1970–1990 period. Christopoulos and Tsionas (2002), however, provided higher own elasticities which are much closer to ours. This might indicate structural changes which started in the 1980s and continued in the 1990s, leading to greater responsiveness of the demand of E, K and L to price changes.

[9] The results found by Christopoulos (2000) for aggregate manufacturing, using data for the period 1970–1990, are, more or less, similar to ours. He found an elastic demand for diesel and substitutability between diesel and electricity, both statistically significant; the demand for electricity was found to be inelastic, but the elasticity was not statistically different form zero.

[10] However, 34.8% of the own price elasticities are not statically different from zero at a 5% level of significance.

Table 4
Parameter estimates of the total cost model, 1982–1998

	Sectors	β_K	β_E	β_L	γ_{KK}	γ_{KE}	γ_{KL}	γ_{LE}	γ_{LL}	γ_{EE}	γ_{LY}	γ_{KY}	γ_{EY}	γ_{TK}	γ_{TE}	γ_{TL}	R^2 S_K	DW S_K	R^2 S_E	DW S_E
15	Food products and	3.239	−0.046	−2.194	0.232	−0.039	−0.193	−0.011	0.203	0.050	0.190	−0.183	−0.007	0.010	−0.001	−0.009	0.995	1.711	0.988	3.111
	beverages	(0.164)	(0.084)*	(0.126)	(0.012)	(0.006)	(0.011)	(0.007)*	(0.091)	(0.006)	(0.015)	(0.017)	(0.009)*	(0.000)	(0.000)	(0.000)				
16	Tobacco	3.442	0.026	−2.468	0.173	−0.006	−0.166	0.001	0.165	0.006	0.097	−0.095	−0.002	0.007	0.000	−0.007	0.966	1.191	0.7968	1.409
		(0.432)	(0.040)*	(0.428)	(0.017)	(0.002)	(0.019)	(0.003)*	(0.02)	(0.003)	(0.027)	(0.027)	(0.002)*	(0.001)	(0.000)*	(0.001)				
17	Textiles	3.306	−0.175	−2.131	0.241	−0.020	−0.221	0.011	0.210	0.009	0.173	−0.189	0.026	0.009	0.000	−0.009	0.951	1.218	0.75	1.058
		(0.184)	(0.070)	(0.130)	(0.017)	(0.009)	(0.012)	(0.009)*	(0.010)	(0.015)*	(0.012)	(0.016)	(0.007)	(0.001)	(0.000)*	(0.001)				
18	Wearing apparel	5.213	0.048	−4.261	0.183	−0.003	−0.180	0.000	0.179	0.003	0.205	−0.203	−0.002	0.013	0.000	−0.013	0.956	1.946	0.17	1.607
		(0.669)	(0.156)*	(0.705)	(0.021)	(0.006)*	(0.022)	(0.005)*	(0.024)	(0.006)*	(0.032)	(0.031)	(0.001)*	(0.001)	(0.000)*	(0.001)				
19	Leather and leather	3.993	−0.241	−2.753	0.202	−0.012	−0.190	−0.001	0.191	0.013	0.117	−0.130	0.013	0.014	0.000	−0.014	0.983	2.149	0.945	2.227
	products	(0.406)	(0.054)	(0.410)	(0.014)	(0.002)	(0.014)	(0.003)*	(0.014)	(0.003)	(0.019)	(0.019)	(0.003)	(0.001)	(0.000)*	(0.001)				
20	Wood and cork	1.808	0.184	−0.991	0.166	−0.014	−0.152	0.038	0.114	−0.024	0.104	−0.013	−0.091	0.011	−0.005	−0.006	0.936	1.330	0.955	2.301
		(0.377)	(0.129)*	(0.389)	(0.028)	(0.010)*	(0.028)	(0.013)	(0.032)	(0.012)	(0.063)*	(0.059)*	(0.022)	(0.001)	(0.001)	(0.001)				
21	Pulp and paper	6.194	−3.634	−1.560	0.241	−0.103	−0.138	−0.017	0.155	0.120	0.043	−0.239	0.196	0.005	−0.003	−0.002	0.962	1.044	0.888	1.093
		(0.849)	(1.026)	(0.709)	(0.016)	(0.017)	(0.013)	(0.031)*	(0.029)	(0.020)	(0.038)*	(0.047)	(0.057)	(0.001)	(0.002)*	(0.001)				
22	Printing and	1.630	0.589	−1.219	0.205	0.005	−0.210	−0.005	0.215	0.000	0.010	0.021	−0.032	0.009	0.001	−0.010	0.991	1.152	0.686	2.236
	publishing	(0.784)	(0.205)	(0.802)*	(0.014)	(0.004)*	(0.014)	(0.005)*	(0.015)	(0.005)*	(0.043)*	(0.042)*	(0.011)	(0.002)	(0.000)*	(0.002)				
23	Coke. refined	2.820	−0.701	−1.119	0.181	−0.069	−0.112	−0.032	0.144	0.101	0.011	−0.058	0.046	0.016	−0.014	−0.002	0.956	1.784	0.948	2.177
	petroleum products	(0.824)	(0.865)*	(0.376)	(0.025)	(0.024)	(0.013)	(0.011)	(0.016)	(0.025)	(0.018)*	(0.046)*	(0.048)*	(0.002)	(0.002)	(0.001)				
	and nuclear fuel																			
24	Chemicals	3.154	−1.212	−0.942	0.196	−0.030	−0.166	−0.010	0.177	0.040	−0.001	−0.065	0.067	0.009	−0.005	−0.004	0.965	0.511	0.970	0.460
		(0.820)	(0.512)	(0.826)*	(0.029)	(0.015)	(0.040)	(0.024)*	(0.058)	(0.011)	(0.065)*	(0.043)*	(0.028)	(0.001)	(0.001)	(0.001)				
25	Rubber and plastic	3.685	0.017	−2.702	0.193	−0.013	−0.181	−0.041	0.222	0.054	0.092	−0.098	0.006	0.010	0.001	−0.011	0.972	2.082	0.898	2.185
	products	(0.532)	(0.274)*	(0.388)	(0.016)	(0.008)*	(0.011)	(0.007)	(0.009)	(0.007)	(0.019)	(0.026)	(0.014)*	(0.000)	(0.000)*	(0.001)				

26	Non-metallic	2.729	4.472	−6.201	0.197	0.042	−0.239	0.073	0.166	−0.115	0.257	−0.029	−0.228	0.016	−0.021	0.005	0.990	1.438	0.936	0.573
	mineral products	(0.975)	(1.339)	(1.479)	(0.024)	(0.020)	(0.020)	(0.051)*	(0.059)	(0.048)	(0.074)	(0.045)*	(0.068)	(0.001)	(0.003)	(0.003)*				
27	Basic metal	1.849	−0.054	−0.795	0.205	−0.070	−0.136	0.014	0.121	0.056	−0.023	0.023	0.001	0.005	−0.007	0.002	0.976	1.284	0.952	1.232
	industries	(0.384)	(0.372)*	(0.263)	(0.022)	(0.031)	(0.016)	(0.020)*	(0.02)	(0.039)*	(0.033)*	(0.049)*	(0.050)*	(0.001)	(0.001)	(0.001)				
28	Metal products.	4.092	0.133	−3.225	0.246	−0.022	−0.224	−0.011	0.235	0.032	0.106	−0.097	−0.009	0.008	0.000	−0.008	0.984	1.785	0.989	1.742
	except machinery	(0.552)	(0.081)*	(0.539)	(0.011)	(0.002)	(0.011)	(0.004)	(0.012)	(0.003)	(0.028)	(0.029)	(0.004)	(0.001)	(0.000)*	(0.001)				
29	Machinery and	5.420	−0.211	−4.209	0.247	−0.009	−0.237	−0.004	0.242	0.014	0.169	−0.180	0.012	0.008	0.000	−0.008	0.888	1.590	0.967	1.957
	equipment n.e.c.	(0.743)	(0.069)	(0.814)	(0.022)	(0.002)	(0.027)	(0.012)	(0.026)	(0.002)	(0.040)	(0.037)	(0.003)	(0.001)	(0.000)	(0.001)				
30	Office machinery	5.259	0.223	−4.482	0.030	−0.039	0.009	−0.011	0.001	0.050	0.190	−0.183	−0.007	0.010	−0.001	−0.009	0.605	1.792	0.430	2.692
	and computers	(1.615)	(0.139)*	(0.149)	(0.012)	(0.006)	(0.011)*	(0.007)*	(0.091)*	(0.007)	(0.008)	(0.017)	(0.009)*	(0.000)	(0.000)	(0.005)*				
31	Electrical machinery	2.591	−0.270	−1.321	0.229	−0.040	−0.189	0.013	0.176	0.027	0.018	−0.023	0.005	0.009	−0.001	−0.008	0.918	0.918	0.905	1.246
	and apparatus n.e.c.	(0.864)	(0.229)*	(0.909)*	(0.046)	(0.012)	(0.049)	(0.015)*	(0.055)	(0.008)	(0.038)*	(0.036)*	(0.010)*	(0.001)	(0.001)	(0.002)				
32	Radio, television	1.705	−0.019	−0.685	0.188	−0.006	−0.182	0.002	0.180	0.005	−0.054	0.055	−0.001	0.014	0.000	−0.014	0.960	0.914	0.950	1.410
	and communication	(0.297)	(0.011)*	(0.284)	(0.033)	(0.001)	(0.032)	(0.001)*	(0.017)	(0.001)	(0.036)*	(0.037)*	(0.001)*	(0.002)	(0.000)	(0.002)				
	equipment and																			
	apparatus																			
33	Medical, precision	5.295	0.070	−4.365	0.235	−0.006	−0.229	−0.001	0.230	0.007	0.205	−0.200	−0.005	0.013	−0.001	−0.012	0.979	1.392	0.921	3.003
	and optical	(0.280)	(0.038)*	(0.270)	(0.011)	(0.002)	(0.011)	(0.003)*	(0.011)	(0.004)	(0.015)	(0.016)	(0.002)	(0.001)	(0.000)	(0.001)				
	instruments																			
34	Motor vehicles,	4.165	−0.149	−3.016	0.259	−0.012	−0.247	−0.002	0.249	0.014	0.100	−0.107	0.007	0.007	0.000	−0.007	0.935	1.020	0.867	1.888
	trailers	(0.609)	(0.043)	(0.595)	(0.025)	(0.002)	(0.027)	(0.003)*	(0.024)	(0.003)	(0.029)	(0.029)	(0.002)	(0.001)	(0.000)*	(0.001)				
35	Other transport	2.469	0.168	−1.638	0.183	−0.002	−0.181	−0.004	0.185	0.006	0.040	−0.032	−0.008	0.015	−0.001	−0.014	0.964	1.293	0.819	1.309
	equipment	(0.515)	(0.137)*	(0.553)	(0.009)	(0.002)*	(0.010)	(0.008)*	(0.013)	(0.007)*	(0.030)*	(0.028)*	(0.008)*	(0.001)	(0.001)	(0.001)				
36	Furniture:	4.564	−0.387	−3.177	0.196	−0.006	−0.190	−0.029	0.219	0.035	0.137	−0.165	0.028	0.011	0.000	−0.012	0.955	1.185	0.673	1.271
	manufacturing n.e.c.	(1.031)	(0.442)*	(0.814)	(0.034)	(0.014)*	(0.027)	(0.012)	(0.026)	(0.010)	(0.040)	(0.051)	(0.023)*	(0.001)	(0.000)*	(0.001)				

The figures in parentheses are the standard errors. The asterisk (*) denotes that the coefficient is not statistically significant at 5%.

Table 5
Price elasticities for capital, labor and energy

	Sectors	ε_{KK}	ε_{LL}	ε_{EE}	ε_{KL}	ε_{LK}	ε_{LE}	ε_{EL}	ε_{KE}	ε_{EK}
15	Food products and beverages	−0.352	−0.610	−0.135	0.012	0.023	0.030	0.158	−0.002	−0.022
		(0.020)	(0.277)	(0.059)	(0.006)	(0.010)	(0.020)*	(0.108)*	(0.011)*	(0.104)*
16	Tobacco	−0.081	−0.166	−0.684	0.072	0.145	0.021	0.371	0.009	0.314
		(0.030)	(0.060)	(0.151)	(0.030)	(0.060)	(0.009)	(0.159)	(0.003)	(0.095)
17	Textiles	−0.016	−1.131	−0.810	−0.032	−0.041	0.115	0.525	0.048	0.286
		(0.003)	(0.243)	(0.172)	(0.023)*	(0.030)*	(0.023)	(0.106)	(0.011)	(0.068)
18	Wearing apparel	−0.138	−0.142	−0.827	0.125	0.122	0.020	0.506	0.013	0.322
		(0.044)	(0.048)	(0.284)	(0.046)	(0.045)	(0.010)	(0.256)	(0.012)*	(0.295)*
19	Leather and leather products	−0.089	−0.126	−0.496	0.086	0.101	0.000	−0.007	0.026	0.503
		(0.026)	(0.032)	(0.123)	(0.026)	(0.031)	(0.006)*	(0.105)*	(0.012)	(0.239)
20	Wood and cork	−0.162	−0.313	−1.248	0.116	0.146	0.167	0.925	0.046	0.324
		(0.053)	(0.078)	(0.156)	(0.055)	(0.069)	(0.031)	(0.172)	(0.019)	(0.131)
21	Pulp and Paper	−0.017	−0.209	−0.099	0.071	0.093	0.116	0.257	−0.054	−0.158
		(0.034)*	(0.081)	(0.117)*	(0.027)	(0.035)	(0.066)*	(0.147)*	(0.040)*	(0.117)*
22	Printing and publishing	−0.088	−0.072	−1.008	0.059	0.064	0.008	0.198	0.029	0.810
		(0.027)	(0.031)	(0.294)	(0.027)	(0.029)	(0.011)*	(0.287)*	(0.007)	(0.206)
23	Coke. Refined petroleum products and nuclear fuel	−0.081	−0.058	−0.247	0.016	0.051	0.008	0.009	0.066	0.239
		(0.040)	(0.032)*	(0.143)*	(0.017)*	(0.057)*	(0.058)*	(0.064)*	(0.036)*	(0.132)*
24	Chemicals	−0.079	−0.137	−0.264	0.051	0.088	0.041	0.177	0.018	0.135
		(0.127)*	(0.038)	(0.108)	(0.068)*	(0.118)*	(0.036)*	(0.157)*	(0.040)*	(0.302)*
25	Rubber and plastic products	−0.090	−0.022	−0.188	0.041	0.065	0.036	0.181	0.000	−0.001
		(0.026)	(0.025)*	(0.103)*	(0.019)	(0.030)	(0.021)*	(0.104)*	(0.014)*	(0.110)*
26	Non-metallic mineral products	−0.113	−0.166	−1.336	−0.090	−0.126	0.179	0.279	0.126	0.275
		(0.051)	(0.178)*	(0.229)	(0.043)	(0.060)	(0.155)*	(0.241)*	(0.044)	(0.095)
27	Basic metal industries	−0.093	−0.282	−0.520	−0.034	−0.056	0.338	0.322	0.127	0.198
		(0.050)*	(0.073)	(0.137)	(0.037)*	(0.060)*	(0.072)	(0.069)	(0.070)*	(0.109)*
28	Metal products. Except machinery	−0.005	−0.021	−0.202	0.004	0.004	0.017	0.166	0.002	0.025
		(0.020)*	(0.027)*	(0.075)	(0.020)*	(0.025)*	(0.009)	(0.086)	(0.003)*	(0.040)*
29	Machinery and equipment n.e.c.	−0.444	−0.478	−0.371	0.002	0.002	0.013	0.274	0.004	0.097
		(0.043)	(0.043)	(0.108)	(0.041)*	(0.044)*	(0.004)	(0.082)	(0.005)*	(0.107)*
30	Office machinery and computers	−0.409	−0.431	−0.006	−0.125	−0.148	−0.026	−0.887	0.107	4.307
		(0.023)	(0.026)	(0.538)*	(0.021)	(0.024)	(0.013)	(0.448)	(0.011)	(0.453)
31	Electrical machinery and apparatus n.e.c.	−0.018	−0.157	−0.243	0.049	0.075	0.084	0.752	−0.034	−0.471
		(0.084)*	(0.047)*	(0.072)*	(0.046)*	(0.071)*	(0.023)	(0.207)	(0.024)*	(0.332)*
32	Radio, television and communication. Equipment and apparatus	−0.050	−0.118	−0.414	0.040	0.082	0.013	0.512	−0.001	−0.097
		(0.045)*	(0.053)	(0.120)	(0.048)*	(0.100)*	(0.004)	(0.171)	(0.002)*	(0.149)*
33	Medical, precision and optical instruments	−0.030	−0.040	−0.684	0.018	0.017	0.023	0.470	0.011	0.215
		(0.024)*	(0.022)*	(0.148)	(0.023)*	(0.022)*	(0.006)	(0.123)	(0.004)	(0.069)
34	Motor vehicles, trailers	0.026	−0.017	−0.310	−0.020	−0.017	0.017	0.424	−0.006	−0.114
		(0.057)*	(0.046)*	(0.118)	(0.055)*	(0.047)*	(0.005)	(0.121)	(0.004)*	(0.079)*
35	Other transport equipment	−0.059	−0.037	−0.737	0.042	0.017	0.021	0.556	0.017	0.181
		(0.033)*	(0.018)	(0.284)	(0.035)*	(0.014)*	(0.011)*	(0.287)*	(0.009)	(0.092)
36	Furniture: manufacturing n.e.c.	−0.092	−0.053	0.222	0.069	0.092	−0.042	−0.542	0.021	0.363
		(0.105)*	(0.043)*	(0.095)	(0.041)*	(0.055)*	(0.025)*	(0.325)*	(0.007)	(0.126)

The figures in parentheses are the standard errors. The asterisk (*) denotes that the elasticity is not statistically significant at 5%.

The estimates of cross-price elasticities show that the productive factors are substitutes in the majority of the sectors. In particular, energy and capital are substitutes in 16 of the 22 sectors under study; however, in six (of these 16) sectors, the cross-price elasticity between K and E is not statistically different from zero. Labor and energy are substitutes in 20 sectors but in nine sectors $\varepsilon_{\mathrm{LE}}$ is not statistically different from zero. As a result, an increase in the price of energy will lead to an increase in the demand for capital and labor as energy will be substituted by these two inputs in production. Capital and labor are substitutes in 17 sectors but only in eight sectors is the cross elasticity between capital and labor statistically significant at a 5% level. All the cross-price elasticities between capital, labor and energy are less than one, indicating weak substitutability or complementarity.

It should be noted that both our (disaggregate) study and Christopoulos' (2000), and Christopoulos and Tsionas' (2002) (aggregate) studies indicate an overall substitutability between K and E, E and L, and K and L in Greek manufacturing. Substitution possibilities are weak. However, our study suggests that they are stronger than those identified by Christopoulos (2000) and closer to those reported in Christopoulos and Tsionas (2002). Interestingly, Caramanis (1979) identified the same substitutability patterns. Moreover, Samouilidis and Mitropoulos (1982) and Donatos and Mergos (1989) also found substitutability between energy and capital in Greek manufacturing.[11]

3.3. The impact of a carbon tax

According to the Ministry for the Environment and the National Observatory of Athens (2000, 41), the industrial sector (extractive industry excluding energy, manufacturing and construction) accounted, as an end-user, for 26% of total CO_2 emissions from fossil fuels in Greece in 1998. About 45% of energy-related CO_2 emissions in industry arose from the direct consumption of fossil fuels in order to meet industrial demands for steam and heat production, while the remaining 55% of industrial needs (operation of furnaces, ovens and lighting) are covered by electricity (ibid.).

Table 6 presents the contribution of each two-digit sector to total CO_2 emissions from manufacturing as an energy end-user in 1998 and it is based on the energy data collected for this study and on the emission factors provided by the Ministry for the Environment and the National Observatory of Athens (2000). We observe that the major CO_2 emissions contributors are sectors 26, 27, 15, 17, 24, 21 and 23. The table also presents the contribution of each energy type to total CO_2 emissions produced by each sector in 1998. We note that electricity is the major contributor in almost all sectors, a fact that is in tandem with the electricity-intensity of the Greek manufacturing mentioned before.

A number of policy instruments are available for reducing CO_2 emissions. One widely discussed option is the carbon tax (see, for instance, Poterba, 1991; Pearce, 1991; Commission of the European Communities, 1991, 1993; Agostini et al., 1992; Mabey and

[11] Calogirou et al. (1997) also provided results regarding substitutability between K, L and E in Greek manufacturing. They concluded that "Allen elasticities show that all factors have high short-run substitutability. In the long run, capital and electricity are complements, as are labor and non-electric energy" (ibid, 490).

Table 6

CO_2 emissions from manufacturing by sector and fuel, 1998

Code	Sectors	Sector share (%) in total CO_2 emissions of manufacturing	Fuel share (%) in total CO_2 emissions of the sector			
			Electricity	Diesel	Mazout	Other
15	Food products and beverages	9.00	47.50	2.28	38.63	11.59
16	Tobacco	0.23	76.98	0.02	23.00	0.00
17	Textiles	4.63	80.20	0.77	17.35	1.68
18	Wearing apparel	0.79	71.65	1.98	26.25	0.12
19	Leather and leather products	0.17	89.06	1.55	7.49	1.90
20	Wood and cork	0.66	83.33	3.62	8.30	4.75
21	Pulp and paper	2.82	65.55	0.81	33.59	0.05
22	Printing and publishing	0.48	97.78	0.34	0.29	1.59
23	Coke, refined petroleum products and nuclear fuel	2.15	36.91	0.00	63.09	0.00
24	Chemicals	4.35	71.96	0.74	16.20	11.10
25	Rubber and plastic products	1.94	93.16	0.37	6.07	0.40
26	Non-metallic mineral products	45.36	19.54	0.66	3.34	76.46
27	Basic metal industries	24.23	89.51	0.32	9.81	0.36
28	Metal products, except machinery	0.89	91.94	1.99	0.94	5.13
29	Machinery and equipment n.e.c.	0.47	91.36	0.79	6.29	1.56
30	Office machinery and computers	0.01	100.00	0.00	0.00	0.00
31	Electrical machinery and apparatus n.e.c.	0.58	84.59	2.12	4.81	8.48
32	Radio, television and communication equipment and apparatus	0.08	100.00	0.00	0.00	0.00
33	Medical, precision and optical instruments	0.05	99.26	0.67	0.00	0.07
34	Motor vehicles, trailers	0.11	58.38	13.20	19.17	9.25
35	Other transport equipment	0.62	92.33	4.71	2.96	0.00
36	Furniture: manufacturing n.e.c.	0.35	97.73	1.68	0.49	0.10
37	Recycling	0.02	87.83	3.23	8.94	0.00
	Total manufacturing	100.00	–	–	–	–

Nixon, 1997; Vassos and Vlachou, 1997a; Weyant, 1999; Shogren and Toman, 2000; IPCC, 2001). For the case of Greece, to the best of our knowledge, a limited number of studies have investigated the impact of a carbon tax on the electricity supply industry

(Vlachou et al., 1996; Vassos and Vlachou, 1997a,b) and on manufacturing (Patsouratis and Souflias, 1995).[12]

In our study, we investigate the impact of a carbon tax on CO_2 emissions from two-digit manufacturing sectors in 1998 on the basis of total price elasticities for each energy type calculated according to the formulae (11) and reported in Table 7. In estimating the impact of the tax, we take the structure of manufacturing as unchanged; this holds true as long as price changes are not large to induce a structural change. This means that only short-to-medium term (5–15 years) effects of a carbon tax can be analysed and also that the carbon tax applied cannot be too high. Furthermore, it should be noted that the impact of a carbon tax estimated in this way is only partial, given that our model is a static production/supply side model for manufacturing. Adjustments induced by the tax at the economy-wide level (which also react back on manufacturing) cannot be captured by this model. Despite these restrictions, our modelling allows us to derive valuable results for manufacturing at a *disaggregate* level. This is quite important in view of the fact that 'bottom-up' and engineering studies advocate that there are unexplored opportunities for improvements in energy efficiency and for shifts to non-carbon intensive fuels.

Although we have applied different levels of carbon taxes on 1998 fuel prices (the last year of our study), for the sake of space, we report here the results of a tax of \$50 per ton of carbon.[13] Since the price of each energy type collected for this study differs by sector, a tax of \$50 per ton of carbon leads to different increases in the price of the same fuel across sectors. The results of a tax of \$50 per ton of carbon are reported in the third column of Table 8 ('*without* electricity restructuring').[14]

A \$50 tax per ton of carbon leads to an overall 17.6% reduction in CO_2 emissions from their 1998 level.[15] In particular, the reduction in CO_2 emissions related to electricity consumed by total manufacturing is 19.1% from their 1998 level, the reduction related to diesel consumption is 8.6% and that related to mazout consumption is 11.3%. The overall 17.6% reduction in CO_2 emissions from their 1998 level decomposes into a 15.4% reduction in CO_2 emissions related to electricity consumption and into a 2.2% reduction in CO_2 emissions related to liquid fuels consumption. These CO_2 reductions are the outcome of energy conservation, interfuel substitution and energy substitution by other factors of production, all triggered by increases in energy prices due to the tax. However, the inelastic demand for energy inputs, the weak substitution possibilities and the heavy dependence of manufacturing on electricity limit the effectiveness of the carbon tax in reducing *direct* CO_2 emissions from manufacturing.

[12] The interesting analysis provided by Patsouratis and Souflias (1995) is not based on any model estimation.

[13] Carbon factors per unit of fuel were obtained (as in the case of emission factors) from the Ministry for the Environment and the National Observatory of Athens (2000). This source is in compliance with the IPCC guidelines for national greenhouse gas inventories.

[14] Notice that the estimates for sectors 22, 30, 32 and 33 are based on energy elasticities calculated by the interfactor models. As already mentioned, energy consumption in these sectors consists, almost in total, of electricity.

[15] Sector 36, which also consumes primarily electricity, does not behave very well since its own price elasticity for energy from the inter-factor model is positive and statistically significant. It exhibits an increase in CO_2 emissions and this seems to be the result of a close-to-zero total own-price elasticity for electricity and the substitutability between electricity and diesel and mazout in the face of price increases.

Table 7
Total price elasticities for energy types

	Sectors	ε^*_{ELEL}	ε^*_{DD}	ε^*_{MM}	ε^*_{ELD}	ε^*_{DEL}	ε^*_{ELM}	ε^*_{MEL}	ε^*_{DM}	ε^*_{MD}
15	Food products and beverages	−0.35	−0.79	0.02	0.22	1.57	−0.01	−0.01	−0.92	−0.15
16	Tobacco	−0.69	−0.96	−0.61	0.03	0.37	−0.03	−0.06	−0.09	−0.01
17	Textiles	−0.83	−1.48	−0.28	0.11	2.10	−0.08	−0.28	−1.43	−0.25
18	Wearing apparel	−0.77	−0.91	−1.84	−0.10	−0.79	0.04	0.27	0.88	0.74
19	Leather and leather products	−0.41	−0.73	1.12	0.11	2.17	−0.19	−1.08	−1.93	−0.53
20	Wood and cork	−0.97	−0.30	0.45	−0.01	−0.10	−0.27	−1.32	−0.85	−0.38
21	Pulp and paper	−0.23	−0.77	−0.33	0.02	0.77	0.12	0.24	−0.10	0.00
23	Coke, refined petroleum, Products and nuclear fuel	−1.05	−2.62	−0.32	0.23	1.63	0.50	0.17	0.74	0.03
24	Chemicals	−0.42	−0.58	−0.69	0.04	0.99	0.12	0.54	−0.67	−0.11
25	Rubber and plastic products	−0.28	−2.19	−0.62	0.02	0.79	−0.05	−0.45	−0.11	−0.03
26	Non-metallic mineral products	−0.74	−0.22	0.39	−0.01	−0.07	−0.59	−1.49	−1.05	−0.24
27	Basic metal industries	−0.48	−1.12	−0.35	0.01	0.36	−0.05	−0.19	0.23	0.03
28	Metal products, except machinery	−0.43	−1.29	−1.08	0.13	1.38	0.10	1.22	−0.30	−0.35
29	Machinery and equipment n.e.c.	−0.11	−1.66	2.43	0.06	0.72	−0.32	−3.28	0.57	0.48
31	Electrical machinery and apparatus n.e.c.	−0.25	0.21	−0.31	−0.01	−0.23	0.02	0.18	−0.22	−0.11
34	Motor vehicles, trailers	−0.29	0.01	−1.08	−0.22	−0.73	0.03	0.19	0.25	0.42
35	Other transport equipment	−0.96	−1.80		0.22	1.06				
36	Furniture: manufacturing n.e.c.	−0.14	−1.69	−1.04	0.21	3.25	0.15	3.14	−1.34	−1.88

Energy intensive sectors such as food and beverages (15), textiles (17), non-metallic products (26) and basic metal industries (27), indicate high reductions in CO_2 emissions due to the tax. In particular, these four sectors account for the 88.3% of the overall reduction in CO_2 emissions from manufacturing. For sectors 26 and 27, this reduction is mainly accounted by the reduction in electricity-related CO_2 emissions. For sectors 15 and 17, the reduction is both attributed to the fall in electricity and mazout related emissions.

These results clearly show the importance of targeting for reduction the CO_2 emissions generated by the electricity consumed by manufacturing. On the other hand, the observed reductions in *direct* emissions indicate that there do not exist ample low cost-effective options for reducing CO_2 emissions from manufacturing. This conclusion is based on the well-established argument in environmental economics that a cost minimizing industrial firm tends to reduce its CO_2 emissions as long as its marginal control cost is less or equal to the tax per unit of emission. In our case, manufacturing firms, following this rule, are able to reduce direct CO_2 emissions (attributable to non-electric energy) from their 1998 level only by 2.2% at a marginal cost less or equal to \$50 per ton of carbon (or its

Table 8
The impact of a carbon tax of $50 per ton of carbon on CO_2 emissions: best estimates[a]

Code	Sectors	Without electricity restructuring	With electricity restructuring
15	Food products and beverages	−3.5	−14.0
16	Tobacco	−15.6	−28.7
17	Textiles	−18.9	−31.9
18	Wearing apparel	−21.5	−33.5
19	Leather and leather products	−11.2	−27.0
20	Wood and cork	−26.0	−38.9
21	Pulp and paper	−2.5	−15.2
22	Printing and publishing	−20.9	−36.7
23	Coke, refined petroleum products and nuclear fuel	−5.5	−12.2
24	Chemicals	−5.8	−20.9
25	Rubber and plastic products	−8.7	−25.8
26	Non-metallic mineral products	−33.6	−44.6
27	Basic metal industries	−21.5	−35.5
28	Metal products, except machinery	−5.4	−23.5
29	Machinery and equipment n.e.c.	−10.0	−26.4
30	Office machinery and computers	0.0	−19.8
31	Electrical machinery and apparatus n.e.c.	−5.0	−22.4
32	Radio, television and communications equipment and apparatus	−8.8	−26.6
33	Medical, precision and optical instruments	−14.6	−31.2
34	Motor vehicles, trailers	−9.5	−21.4
35	Other transport equipment	−16.7	−31.8
36	Furniture: manufacturing n.e.c.	2.8	−17.0
	Total manufacturing	−17.6	−30.5

[a] Percentage change from 1998 CO_2 emissions.

equivalent of a $13.5/tn CO_2)—a cost level which is considered to be on the low side (see, for example, the Ministry for the Environment, 2002, 77).

Renewable energy sources (RES), favored by a carbon tax, are also expected to have a significant contribution to reducing CO_2 emissions from manufacturing. It is interesting to notice that after the introduction of Law 2244/94, establishing incentives for investments in RES, and the Operational Program for Energy, funded by EU, there has been a growing interest for investing in wind energy, small hydro-electric production and in energy conservation by industrial firms.

As it has been noted above, our model estimated by time-series data is not able to capture the (direct) use of natural gas in manufacturing which started only recently, in 1997. However, the penetration of natural gas in manufacturing is expected to replace liquid fuels, especially mazout, and to promote the development of combined heat and power (CHP) generation systems, which have a high-energy efficiency, in industrial firms with a high-energy consumption. Previous studies (Vlachou et al., 1996; Vassos and Vlachou, 1997a,b) have indicated that lignite generation in Greece can be replaced by natural gas, hydro and other renewable generating technologies as well as with coal or lignite technologies with CO_2 removal capabilities, all resulting in reducing CO_2 emissions.

To take into consideration the impact of electricity restructuring (effected independently from any carbon tax policy) on energy-related CO_2 emissions attributed to manufacturing, we accounted for changes in the fuel structure of power production (including natural gas generation), on the basis of the baseline projections of the National Action Plan (NAP) for 2010, officially provided by the Ministry for the Environment (2002). According to these projections, the share of natural gas in electricity generation increases from almost zero in 1995 to 28.4% in 2010. At the same time, the share of lignite generation decreases from 69.6% in 1995 to 47.5% in 2010; the share of liquid fuels decreases from 20.1% to 13%, while that of hydroelectric and other renewable generation remains almost the same, that is 10% in 1995 and 11% in 2010 (Ministry for the Environment, 2002, 26). As a result of these structural changes, the annual average growth rate of CO_2 emissions from electricity generation decreases from 3.1% during the period 1995–2000 to 1.6% during the period 2000–2010. However, while the average factor of CO_2 emissions per MWh is reduced by the year 2010, at the same time, the average cost per MWh increases by 11% approximately, according to our estimations on the basis of the NAP baseline scenario projections and the NAP cost data. When the carbon tax combines with this (independent) restructuring of electricity production, one expects it to become more effective in reducing energy-related CO_2 emissions from manufacturing; however, the cost burden on manufacturing also increases.

The results of a tax of \$50 per ton of carbon *with* electricity generation restructuring are reported in the fourth column of Table 8. A tax of \$50 per ton of carbon results in an overall 30.5% reduction in CO_2 emissions from their 1998 level. A portion of 92.8% of this overall reduction is attributed to electricity consumption and the rest (7.2%) to liquid fuels consumption. The four energy intensive sectors, 15, 17, 26 and 27, account for 82.2% of the overall reduction in CO_2 emissions from manufacturing. Despite the small own and cross-price elasticities of electricity that characterize manufacturing, the impact of electricity price increases (due to its restructuring and the imposition of the carbon tax) and that of lower emissions factor are significant in scale, given the electricity-intensity of the sector.

A sensitivity analysis of the impact of the carbon tax on CO_2 emissions has been conducted. The parameters and elasticities were set to their optimistic (best estimate plus one standard deviation) and pessimistic (best estimate minus one standard deviation) values.[16] The impact of a tax of \$50 per ton of carbon on CO_2 emissions estimated according to the pessimistic and optimistic values of total price elasticities is presented in Table 9.[17] Without electricity restructuring, the overall reduction is 11.3% for the optimistic case and 26.3% for the pessimistic case. In the case of electricity restructuring the reduction ranges between 25.5% (optimistic case) and 38.1% (pessimistic case).

The pessimistic impact of the carbon tax is stronger than the best impact (Table 8). The price increases of energy inputs due to the tax is more effective in reducing CO_2 emissions in the pessimistic case than in the case of best estimates. This is because in the pessimistic case, conservation is higher (higher absolute values of own-price elasticities), while stronger complementarity (higher absolute values of negative cross-price elasticities)

[16] This sensitivity analysis was suggested by a referee and it is gratefully acknowledged.

[17] Tables with pessimistic and optimistic values of parameters and elasticities are available upon request.

Table 9
The impact of a carbon tax of $50 per ton of carbon on CO_2 emissions: optimistic and pessimistic estimates[a]

Code	Sectors	Without electricity restructuring		With electricity restructuring	
		Optimistic	Pessimistic	Optimistic	Pessimistic
15	Food products and beverages	0.5	−9.8	−10.8	−19.7
16	Tobacco	−7.6	−27.1	−22.1	−38.6
17	Textiles	−14.3	−25.4	−28.3	−37.6
18	Wearing apparel	−16.1	−31.6	−29.1	−42.6
19	Leather and leather products	−6.4	−17.3	−23.0	−32.2
20	Wood and cork	−21.4	−31.7	−35.1	−43.8
21	Pulp and paper	1.4	−9.4	−12.0	−21.3
22	Printing and publishing	−14.8	−27.0	−31.7	−41.7
23	Coke. refined petroleum Products and nuclear fuel	−0.8	−11.9	−8.2	−17.9
24	Chemicals	−2.1	−12.0	−17.9	−26.4
25	Rubber and plastic products	−4.9	−13.6	−22.7	−30.0
26	Non-metallic mineral products	−21.0	−51.1	−34.5	−59.8
27	Basic metal industries	−15.5	−29.2	−30.8	−42.0
28	Metal products, except machinery	−1.6	−9.4	−20.4	−26.8
29	Machinery and equipment n.e.c.	−1.7	−21.7	−19.7	−36.6
30	Office machinery and computers	10.9	−11.1	−10.9	−28.8
31	Electrical machinery and apparatus n.e.c.	−2.5	−8.1	−20.3	−25.0
32	Radio, television and communications equipment and apparatus	−6.0	−10.9	−24.6	−28.6
33	Medical, precision and optical instruments	−11.1	−17.2	−28.7	−33.8
34	Motor vehicles, trailers	−0.4	−10.8	−12.6	−22.0
35	Other transport equipment	−9.8	−23.7	−26.0	−37.5
36	Furniture: manufacturing n.e.c.	7.8	−2.4	−12.8	−21.3
Total manufacturing		−11.3	−26.3	−25.5	−38.1

[a] Percentage change from 1998 CO_2 emissions.

results in higher decreases in quantities of complements demanded. On the other hand, lower substitutability (smaller values of positive cross-price elasticities) results in smaller increases in quantities of substitutes demanded in the pessimistic case than in the case of best estimates.

In the optimistic case, a tax of $50 per ton of carbon has a smaller effectiveness in reducing CO_2 emissions than in the case of best estimates. This is because of smaller conservation and weaker complementarity in the face of price increases; moreover, stronger substitutability results in higher increases in quantities of substitutes demanded in the case of optimistic estimates than of best ones. In a few cases such as sectors 15, 21, 30 and 36, we observe increases in CO_2 emissions under the tax resulted from a combination of understandable reasons.[18]

To put our result in a comparative framework, let us first present estimates of the carbon tax required for the European Union (EU) to comply with the prescribed limits on CO_2 emissions under the Kyoto Protocol, calculated by different modeling teams in the USA, Australia, Japan and Europe and compared by the Energy Modeling Forum (EMF) at Stanford University (Weyant, 1999; IPCC, 2001). In particular, the level of the carbon tax estimated by these models (most of which were general equilibrium models) is determined by the difference between the costs of marginal source of supply (including conservation) with and without the target of the Kyoto Protocol to be achieved in 2010. The estimated carbon tax to achieve a 8% reduction in CO_2 emissions from their 1990 level in 2010 ranges from 20 to 966 1990$US/t of C for the EU as a whole. In particular, carbon taxes as calculated by various models are as follows for the EU (in 1990$US/t of C): ABARE-GTEM 665; AIM 198; G-Cubed 227; GRAPE 204; MEGREE3 218; MIT-EPPA 276; MS-MRT 197; Oxford 966; RICE 159; SGM 407; WorldScan 20 (IPCC, 2001, 514).[19] Fig. 1 presents the incremental cost of reducing a ton of carbon for alternative levels of CO_2 emissions in the EU when all reductions are made domestically and by all sectors.

Let us now review the National Action Plan (NAP) of Greece to reduce Greenhouse Gas (GHG) emissions for the period 2000–2010 from their baseline level, developed by the Ministry for the Environment in collaboration with the research team under D. Lalas of the National Observatory of Athens.[20] We are particularly interested in the level of emissions reductions to be achieved by the NAP and in the unit cost of abatement.

The NAP will reduce total GHG emissions in Greece by 12.4% from their baseline level in the year 2010. In particular, the NAP will reduce GHG emissions from electricity generation by 13.1%. In industry (consisted of the extractive sector except from energy, manufacturing and construction), the NAP will reduce total GHG emissions in 2010 by

[18] Sectors 15 and 21 have a large share of mazout in their energy consumption. Sector 15 exhibits a positive, albeit insignificant, total own-price elasticity for mazout; moreover, this sector's relationship between electricity and mazout changes from complementarity in the case of best estimates into substitutability in the case of optimistic estimates. In sector 21, it is the relationship between electricity and mazout that changes from weak complementarity in the case of best estimates into substitutability in the case of optimistic estimates. Sectors 30 and 36 consume exclusively (30) or predominantly (36) electricity. In sector 30, the estimated own-price elasticity for energy from the inter-factor model is not significantly different from zero while energy and capital and labor are substitutes. In sector 36, the total own-price elasticity for electricity is positive but close to zero in the case of optimistic estimates.

[19] Most models calculate carbon taxes for the EU that are higher than those for the USA (ranging from 85 to 419 1990$US/t of C) but lower than those for Japan (ranging from 97 to 1047 1990$US/t of C).

[20] The National Action Plan (NAP) to reduce Greenhouse Gas (GHG) Emissions for the period 2000–2010 was based on the projections of GHG provided by the Energy and Power Evaluation Program (ENEP) model developed by the Argonne National Laboratory (ANL, USA). See, the Ministry for the Environment (2002).

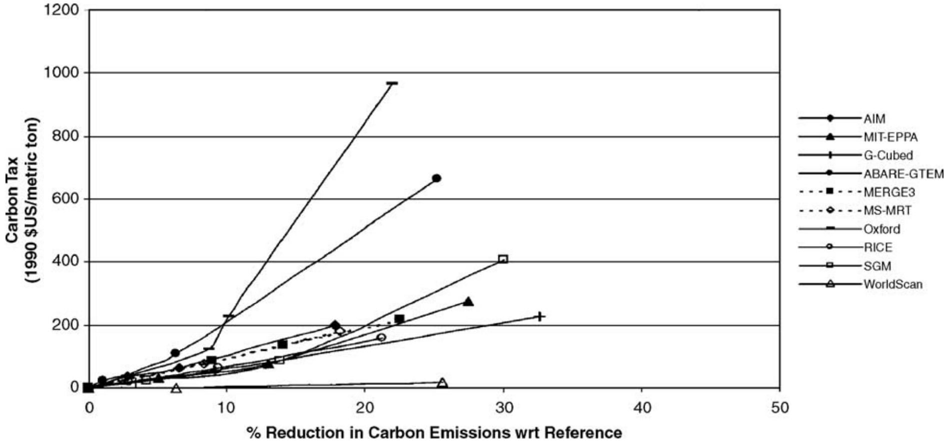

Fig. 1. Marginal cost of carbon emission reductions in the European Union. Source: Weyant (1999) reported in IPCC (2001).

786 kt CO_2-equivalent, i.e., a 5.1% reduction from their baseline level[21]; electricity generation's emissions attributed to the industrial sector through its consumption of electricity are included in the energy sector, not in industry.

The NAP also provides an estimate of the cost of the proposed measures to reduce GHG emissions in constant 1997 dollars (The Ministry for the Environment, 2002, 77). Measures with an average cost of less than \$30/tn CO_2-eq (which is equivalent to \$110/t of C) are considered as low or medium cost measures. The average unit cost of a 5.1% reduction of industrial GHG emissions (in CO_2-eq) from the baseline level in 2010 is \$ 43.2/tn CO_2-eq (which is equivalent to \$ 158.5/t of C). The average unit cost of a 13.1% reduction of GHG emissions (in CO_2 -eq) from the baseline level, discharged by electricity generation in 2010, is \$ 19.5/tn CO_2-eq (which is equivalent to \$ 71.6/t of C).[22] Combining the NAP findings for industry and electricity, the average cost per unit of reduction is estimated to be \$ 21.7/tn CO_2-eq (which is equivalent to \$ 79.5/t of C). In other words, 46.1% of the reduction of the national GHG emissions (in CO_2-eq) from the baseline level in 2010 is achieved by electricity production and industry at an average unit cost of \$79.5/t of C (in 1997 dollars).

It is also interesting to refer to the study by Capros et al. (2001). These authors use the PRIMES Energy Systems Model, a modelling system which simulates a market equilibrium solution for energy supply in the European Union (EU) Member States, to investigate the cost-effective allocation of the GHG emissions reduction target for EU agreed in Kyoto (i.e., −8% from 1990 level by 2008–2012) under alternative scenarios. PRIMES is a static supply-side model, that is a model of a similar nature with our model

[21] This decrease in industrial GHG emissions decomposes in the following components: 163 kt CO_2-eq (20.7%) from natural gas penetration; 340 kt CO_2-eq (43.2%) from the use of solar energy replacing mazout and diesel; 46 kt CO_2-eq (5.8%) from substituting biomass to mazout; 238 kt CO_2-eq (30.2%) from various energy conservation measures.

[22] Moreover, the average unit cost of a 12.4% reduction in total GHG emissions (in CO_2-eq) from the baseline level in 2010 is \$ 13.5 /tn CO_2-eq (which is equivalent to \$50/t of C).

(see also Capros and Mantzos, 2000). Industry in this study is subdivided into nine main sectors. Industrial boilers are allocated to industrial sectors. Emissions from electricity generation are, however, allocated to the energy sector, and not to industry (and other demand sectors) according to its consumption of electricity.

We present here the results of the burden sharing scenario (including the ACEA Agreement),[23] assuming that each Member State achieves its burden sharing target alone.[24] The burden sharing agreement allows Greece to increase its GHGs emissions by 25.0% by 2008–2012.

The results for Greece indicate that a reduction of 7.5% in total industrial (fuel related) CO_2 emissions in 2010 from the baseline level can be achieved at a marginal abatement cost of 11.11 Eur('99)/tCO_2 (which is equivalent to Eur('99) 40.74/t of C, or to \$43.42/t of C in 1999 dollars). At the same marginal cost, the percentage changes from the 2010 baseline level by industrial sectors are as follows: iron and steel, −8.2%; non-ferrous metals, −7.7%; chemicals, −10.4%; building materials, −5.0%; paper and pulp, −11.8%; food, drink and tobacco, −12.4%; other industries, −8.1%. In the energy supply sector, a reduction of 12.5% in (fuel related) CO_2 emissions in 2010 from the baseline level can be achieved at the same marginal abatement cost.[25]

There are considerable differences between the results of the EMF for Europe, those of NAP and of Capros et al. and our study for Greece. However, when compared to others, especially to the two studies referred to Greece, our results seem to fall within a reasonable range. In short, our results show that a carbon tax of \$50/t of C in 1998 dollars, without any electricity restructuring, leads to an overall 17.6% reduction in CO_2 emissions (of which only 2.2% is reduction in direct emissions from manufacturing) from their 1998 level. The optimistic value of this overall reduction is 11.3%, while its pessimistic value is 26.3%. When the carbon tax of \$50/t of C in 1998 dollars is combined with an (independently initiated) restructuring of electricity generation, it leads to a 30.4% reduction of (direct and indirect) CO_2 emissions from their 1998 level in manufacturing. This overall reduction decomposes into a 28.2% reduction in CO_2 emissions related to electricity consumption and into a 2.2% reduction in direct CO_2 emissions from manufacturing.

Assuming that manufacturing firms tend to cost-effectively equate the carbon tax to their (increasing) marginal cost of mitigation, our results seem to fall within the broad range of the marginal abatement cost estimates provided by the other studies. Our sensitivity analysis strengthens such a conclusion. Such comparisons, however, can only

[23] The ACEA Agreement requires European, Japanese and Korean car manufacturers to market more fuel efficient vehicles.

[24] The results of the PRIMES model are combined with the bottom-up analysis carried out by Ecofys and AEA Technology to analyse the potential contribution of the different Member States and sectors in achieving the Kyoto target according to the burden sharing agreement.

[25] For EU as a total, the results of this study indicate that a reduction of 10.2% in total industrial (fuel related) CO_2 emissions in 2010 from the baseline level can be achieved at a marginal abatement cost of 41.84 Eur('99)/tCO_2 (which is equivalent to Eur('99) 153.4/t of C, or to \$163.5/t of C in 1999 dollars). At the same marginal cost, the reductions from the 2010 baseline level by industrial sectors are as follows: iron and steel, 9.9%; non-ferrous metals, 8.0%; chemicals, 12.4%; building materials, 5.4%; paper and pulp, 16.0%; food, drink and tobacco, 11.6%; other industries, 8.6%. Moreover, in the energy supply sector, a reduction of 13.3% in (fuel related) CO_2 emissions in 2010 from the baseline level can be achieved at the same marginal abatement cost.

be quite rough because of the important differences in terms of underlying models, sectoral aggregation, type of emissions reductions targeted (i.e., total GHG as CO_2-equivalent versus CO_2 energy-related) and because of the reduction options permitted by each model.

4. Summary and conclusions

The purpose of this paper has been to empirically estimate the demand for energy in two-digit manufacturing sectors in Greece and evaluate the impact of a carbon tax on energy-related CO_2 emissions as a policy to mitigate global warming.

The empirical findings from the energy sub-model indicate that the demand for each energy type (electricity, diesel and mazout) is inelastic. The demand for diesel exhibits the highest price responsiveness among the three energy types. The cross-price elasticities suggest that electricity and diesel, and electricity and mazout are substitutes, while diesel and mazout are complement in most manufacturing sectors.

In the aggregate translog model, all input demands are overall price-inelastic. The estimates of cross-price elasticities indicate that the productive factors are substitutes in the majority of the sectors. Substitutability between energy and other factors of production suggests energy improvement and conservation possibilities for Greek manufacturing.

Imposing a tax of $50 per ton of carbon, with no independently-initiated electricity restructuring, results in an overall 17.6% reduction in CO_2 emissions from their 1998 level. The sensitivity analysis reveals that this reduction falls within the interval of 11.4% to 26.5%. Significant reductions are evidenced in textiles, not metallic products, basic metal industries and pulp and paper sector. The increase in the energy prices due to the carbon tax induces energy conservation and improvement in energy efficiency, both resulting in a reduction of CO_2 emissions. The inelastic demand for energy inputs, the dependence of manufacturing on lingite-generated electricity and the weak substitution possibilities limit the effectiveness of a carbon tax in reducing CO_2 emissions from manufacturing. When an electricity restructuring towards a less carbon-intensive production structure is permitted, the carbon tax becomes more environmentally effective. In particular, a tax of $50 per tone of carbon results in a 30.5% decrease in total CO_2 emissions from manufacturing; moreover, the sensitivity analysis reveals that this reduction falls within the interval of 25.5% to 38.1%.

A carbon tax is expected to induce a further restructuring of the power supply industry, shifting away from high-carbon fuel technologies. At the same time, a carbon tax will give an incentive to manufacturing firms to use more natural gas and renewable energy resources, replacing, to some extent, conventional fuels.

In conclusion, the production structure of manufacturing sectors identified by our study suggests that there are considerable possibilities to reduce direct and indirect CO_2 emissions if a carbon tax is used as a policy instrument. Since CO_2 emissions are the major contributor to the intensification of the greenhouse effect, the carbon tax is an effective instrument to mitigate global warming in the case of Greek manufacturing which is an electricity-intensive sector. However, the environmental effectiveness and cost-efficiency of a carbon tax with respect to the industrial structure need to be complemented by an analysis of its distributive and macroeconomic consequences (which have not been in the scope of the present analysis) when designing the tax.[26] This is especially true for Greece since a relative high carbon tax may have significant adverse economic effects, while the country's intervention will have a very limited impact on global warming.

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[26] For a discussion of the modelling of macroeconomic effects of carbon taxes in general and in particular under alternative schemes of tax recycling, see, for instance, Mabey and Nixon (1997). With respect to the recycling of the carbon tax revenues back to manufacturing firms, it should be emphasized that it must not take a form that could reduce the environmental effectiveness of a carbon tax, especially when a certain emissions reduction target has to be achieved. Tax recycling should then take the form of a lump sum return or of a subsidy on the basis, for example, of the use of a renewable energy instead of a fossil fuel technology, and not affect the cost-effective behavior of manufacturing firms via the real after-the-recycling marginal abatement cost or tax burden.

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