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Substitution Elasticities between Capital, Labour, Material, Electricity and Fossil Fuels in German Producing and Service Sectors

Henrike Koschel

Non-technical summary

Substitutional relationships between energy and nonenergy inputs in production are one of the key factors for the economic impacts of an ecological tax reform. However, today there are few empirical studies available which deal with detailed substitution patterns in the German economy, refer to both producing and service sectors, and account for disaggregated energy inputs.

The main objective of this paper is to further clarify empirically the substitutional relationships in the German economy. Using a translog cost function, price and substitution elasticities between capital, labour, material, electricity, and fossil fuels are estimated for four sector aggregates: energy supply, energy- and nonenergy-intensive manufacturing, and service sectors. The data basis consists of pooled time series and cross sections over the period 1978-90 and for nearly fifty sectors reported by the German national account statistics.

Except for the service sectors, the estimated own-price elasticities of all factor demands are below 0.5 (in absolute terms). In particular, electricity and fossil fuel demand are found to be relatively price inelastic. Empirical results indicate that labour and capital are substitutes in all sectors and that capital and material generally are better substitutes for fossil fuels than labour. However, in the service sectors and the nonenergy-intensive manufacturing sectors, capital and materials are more difficult to substitute for electricity than labour. In practice, there may be a number of reasonable explanations for energy-labour substitutability. One possibility is that with higher energy prices more engineers are engaged, which search for and implement energy-saving measures, for example in the area of thermal isolation of buildings.

Results support the hypothesis of energy-capital substitutability and that sectoral technologies are characterised by non-homothetic, non-constant-returns-to-scale production functions.

In addition, the paper provides estimates of sectoral substitution elasticities between input aggregates which fit with the nested production structure of the computable general equilibrium model GEM-E3. As statistical tests show, an aggregation of inputs is consistent with empirical data only in particular cases, so that elasticities, which have been derived from multi-stage estimation, incorporate some degree of uncertainty. Applying an ecological tax reform scenario to the GEM-E3 single-country version for Germany indicates that model results react to a variation of substitution elasticities in production, but, all in all, the model proves to be relatively stable within a plausible range of values.

Substitution Elasticities between Capital, Labour, Material, Electricity and Fossil Fuels in German Producing and Service Sectors

Henrike Koschel (ZEW)

Abstract: In this paper, substitutional relationships between capital, labour, material, electricity, and fossil fuels in German producing and service sectors are estimated using a translog cost function. Estimates are based on a pooled time-series cross-sectional data sample for the period 1978-90 and nearly 50 sectors reported by the national account statistics. Results indicate that, except for the service sectors, own-price elasticities of all factor demands are below 0.5 (in absolute terms). In terms of the Morishima elasticity of substitution, labour and capital are substitutes in all sectors. Labour is generally a substitute for electricity, but not for fossil fuels. Results also support the hypothesis of capital-energy substitutability and that the German economy is characterised by a non-homothetic, non-constant-returns-to-scale production function. Substitution elasticities between input aggregates are estimated based on the nesting structure which underlies the computable general equilibrium model GEM-E3. Testing for weak homothetic separability restrictions, however, yields that input aggregation is allowed only in particular cases. Simulations with the GEM-E3 model demonstrate that the impacts of an ecological tax reform respond to a variation of substitution elasticities, but, all in all, the model proves to be relatively stable within a plausible range of values.

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1 Introduction

As the theoretical literature indicates, the production structure and the elasticity of substitution between input factors are important determinants of the labour market effects of an ecological tax reform that raises energy taxes in production and reduces labour income taxes. The more easily labour can be substituted for energy compared to other production factors such as capital, the higher the chance is that employment increases (Bovenberg/van der Ploeg 1998, Bovenberg 1999).

In policy discussions on the double dividend, computable general equilibrium (CGE) models have proved to be useful, particularly when theoretical models no longer can be solved analytically, i.e. when too many production inputs, production sectors, market distortions etc. are involved. However, the meaningfulness of CGE model results for policy-decision makers decisively depends on the empirical validity of numerical parameter values incorporated, such as substitution elasticities in production. In energy-economy CGE modeling a common approach is to use nested CES (constant elasticity of substitution) production functions which account for different degrees of substitutability between input factors on different nesting levels. Whereas in CGE models CES distribution parameters are calibrated against benchmark data, CES substitution elasticities have to be specified outside the model. Typically, CGE modelers simply take econometric estimates from the literature. These are, however, unlikely to be compatible with their models' sectoral production structure.

Looking into the econometric literature on substitution elasticities between energy and nonenergy inputs, one can find a substantial number of empirical studies which have been published since the energy crisis in the 70's. Most of them rely on homothetic *KLEM* (capital, labour, energy, material) or *KLE* translog cost functions and use highly aggregated data, often for the whole U.S. manufacturing sector. Substitutability relationships are mainly measured by the (constant-output) Allen partial elasticity of substitution.[1]

[1] Examples for translog applications are Berndt/Wood (1975), Griffin/Gregory (1976), Halverson (1977), Pindyck (1979), Turnovsky/Donnelly (1984), Chung (1987), Kintis/Panas (1989), Grant (1993), Betts (1997), and Casler (1997).

There are, however, only a few empirical studies available dealing with detailed substitutional relationships in the German economy. Most of them are restricted to manufacturing sectors and consider only one single energy input aggregate.[2]

The objective of this paper is twofold: Firstly, to contribute to a further empirical clarification of sectoral substitutional opportunities in the German economy, and secondly, to improve the empirical basis of the CGE model GEM-E3 and its power to simulate 'ecological tax reform' scenarios.[3]

Using a translog cost function, sectorally differentiated substitution elasticities are estimated of a non-nested and a three-level nested production function with capital, labour, material, electricity, and fossil fuels. This flexible functional form is applied, since, in contrast to the CES, it does not impose a priori restrictions with respect to substitution patterns, separable structures and economies of scale on the underlying technology.

This work stands against previous studies in the field of substitution elasticities in that it includes not only nearly all producing industries, but also service sectors in Germany. In addition to this, it gives up the assumption of the existence of an energy aggregate, but uses disaggregated energy data for electricity and fossil fuels. Furthermore, it measures substitutability in terms of the Morishima elasticity of substitution.[4]

The remainder of this paper is organised as follows: In Section 2, substitution elasticities and economies of scale are estimated for a non-nested translog cost function. The data basis is constituted by pooled time series and cross sections for (West) Germany over the period 1978-90. Section 3 presents estimates of a three-level nested translog cost function and provides statistical test results for weak separability restrictions. In Section 4, the sensitivity of GEM-E3 model results to substitution patterns in production is tested. Finally, Section 5 contains the main conclusions.

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[2] The majority of these studies were published in the 80's (see e.g. Friede 1980, Nakamura 1984, Unger 1986, Natrop 1986, or Peren 1990). Recently published studies are Kemfert/Welsch (1998) and Falk/Koebel (1999). Whereas in the former, substitution elasticities are estimated directly from a two-level nested CES *KLE* production function, in the latter, a normalised quadratic cost function with heterogeneous labour is applied.

[3] The multi-region, multi-sectoral GEM-E3 model has been developed on behalf of the European Commission (DG XII) at the ZEW together with several other European research institutes. See Capros et al. (1997) for a detailed model description and Capros et al. (1999) for some recent model applications.

[4] The advantages of the Morishima elasticity of substitution over the commonly-used Allen elasticity of substitution are pointed out in Blackorby/Russell (1989).

2 Estimating substitution elasticities with a non-nested five-input cost function

2.1 Econometric model

We employ a flexible translog cost function in order to estimate substitution elasticities between capital (*K*), labour (*L*), nonenergy material (*M*), electricity (*EL*) and fossil fuels (*F*). Expanding the log of total production costs $\ln C(\mathbf{p},x,t)$ in a second-order Taylor series yields:[5]

$$\begin{aligned}\ln C(\mathbf{p},x,t) &= \alpha_0 + \sum_i \beta_i \ln p_i + \frac{1}{2}\sum_i \sum_j \beta_{ij} \ln p_i \ln p_j + \beta_x \ln x + \frac{1}{2}\beta_{xx}(\ln x)^2 \\ &+ \sum_i \beta_{ix} \ln p_i \ln x + \beta_t t + \beta_{xt} t \ln x + \frac{1}{2}\beta_{tt} t^2 + \sum_i \beta_{it} t \ln p_i, \;\; i,j = K,L,M,EL,F,\end{aligned} \tag{2.1}$$

where p_i and p_j denote factor prices, x the level of real output and t a time trend reflecting technical progress. Applying Shephard's Lemma leads to the factor share system:

$$s_i := \frac{\partial \ln C}{\partial \ln p_i} = \beta_i + \sum_j \beta_{ij} \ln p_j + \beta_{ix} \ln x + \beta_{it} t, \;\; i,j = K,L,M,EL,F\,. \tag{2.2}$$

For empirical implementation, the restrictions of symmetry of cross-price derivatives and linear homogeneity in prices are imposed:

$$\beta_{ij} = \beta_{ji}, \; \sum_i \beta_i = 1, \; \sum_i \beta_{ij} = \sum_j \beta_{ij} = \sum_i \beta_{ix} = \sum_i \beta_{it} = 0, \;\; i,j = K,L,M,EL,F. \tag{2.3}$$

In addition to (2.3), two further regularity conditions required by microeconomic theory are monotonicity of the cost function and concavity in factor prices. Although it can be easily examined whether the cost function is non-decreasing in input prices by analysing whether fitted cost shares are non-negative, concavity conditions are more difficult to be checked and, if they are not satisfied, to impose. A necessary and sufficient condition for global concavity in factor prices is the negative semi-definiteness of the Hessian matrix of second-order partial derivatives of the cost function with respect to input prices. In

5 A definition of the non-homothetic translog cost function with technical progress can be found in Diewert/Wales (1987:46).

Section 2.3, results of the unrestricted translog cost model and of the locally concavity restricted translog cost model are presented.[6]

Stochastic terms are added to equations (2.1) and (2.2) which are assumed to be independently and identically multivariate and normally distributed with mean vector zero and constant non-singular covariance matrix for each equation. In order to avoid singularity of the disturbance covariance matrix, the share equation of material is dropped. Maximum-likelihood estimates of the parameters are computed with TSP 4.4.

For estimation, 49 sectors reported in the German national account statistics are pooled into four sector groups: energy supply, energy-intensive manufacturing, nonenergy-intensive manufacturing, and service sectors (see Table A-2 in Appendix III). In order to restrict the number of free parameters, it is assumed that the slopes of the derived demand functions are identical within each sector aggregate.

2.2 Data

Yearly data on prices and cost shares of material, capital, labour, electricity and fossil fuels are compiled from German national account statistics and input-output tables of 1978-90. Due to the short time period, time-series cross-sectional data are used. The sample contains the agriculture and forestry sector and nearly all producing and service sectors recorded by the statistical office (data construction follows Falk/Koebel 1999, see Appendix I).

Figure 1 gives an impression of the development of aggregated prices and quantities over the period 1978-90. In all sector aggregates the development of fossil fuel prices clearly reflects the oil crisis, which led to a sharp price increase from 1978 on. After a peak in 1985, prices fell down again, but stopped and stayed at a higher level. In contrast, electricity prices remained relatively uninfluenced by the oil crisis (prices increased relatively steadily by a total of 40% during 1978 to 1990) as electricity production is mainly based on brown and hard coal, produced in Germany, whereas the share of oil in total fuel inputs is less than 10%.[7]

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[6] In contrast to global concavity, local concavity requires only that the functional form is curvature correct at a single data point, typically the point of approximation. Local concavity is imposed on the translog cost function by means of a Cholesky factorization (see Lau 1978 and Jorgenson/Fraumeni 1981).

[7] The cost share of oil in total inputs in electricity production was 7.2% in 1980, 3.3% in 1985, and 2.8% in 1990 (BMWi 1993, 1998).

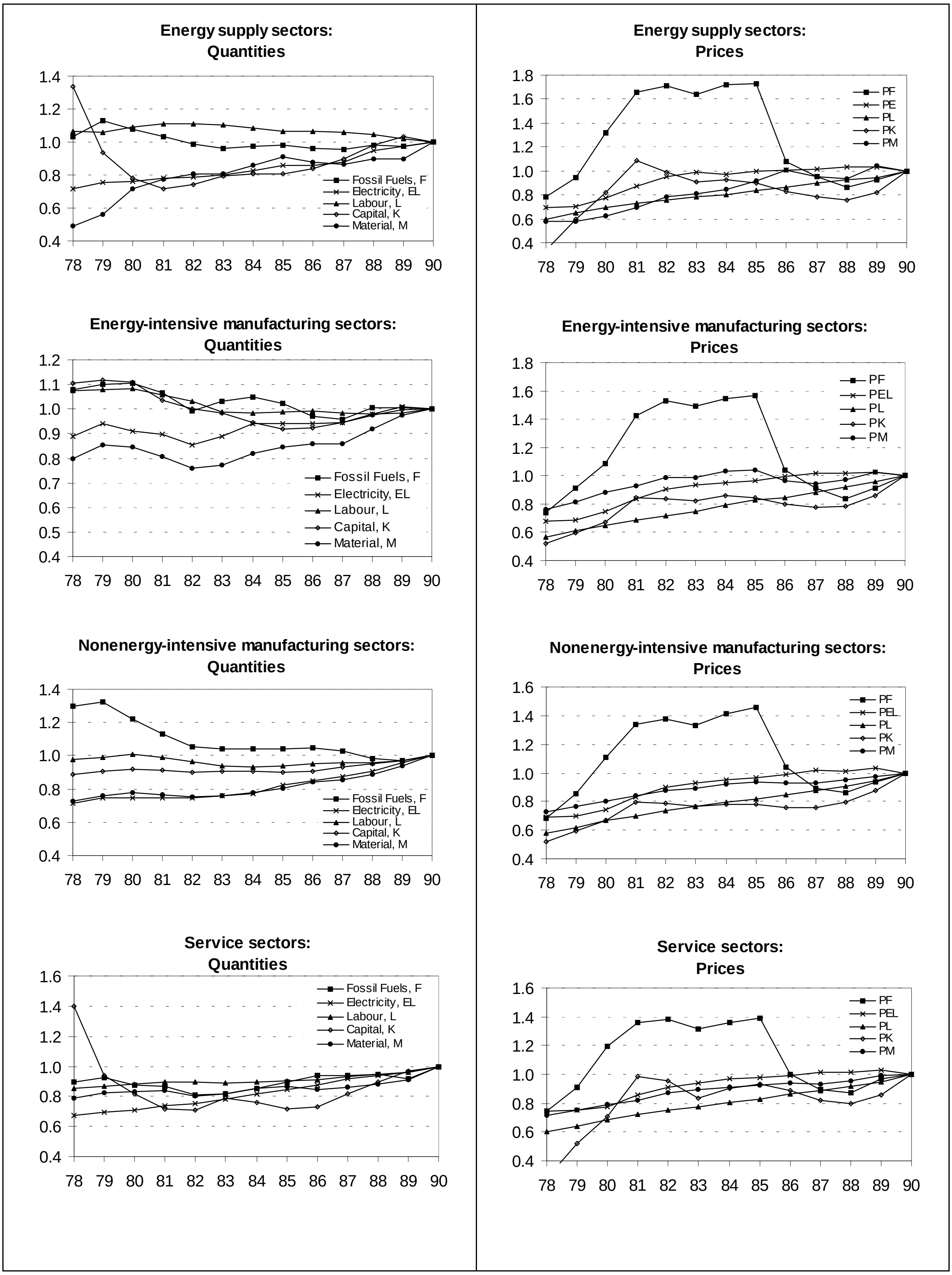

Figure 1: Development of input quantities and prices in sector aggregates

Note: Quantitiy and price indices for 1978-90 are normalised at unity in 1990. For data construction see Appendix I.

Cost shares calculated for the entire German economy and for the four sector groups are listed in Table 1.[8] All in all, the figures indicate that cost shares were relatively stable over the period. Remarkably, cost shares of fossil fuels are smaller in 1990 than in 1978 in all sector groups, whereas for electricity they are slightly higher. Most striking is the substantial increase of the cost share of material in the energy supply sectors aggregate which is associated with a significant decrease in the cost share of fossil fuels. This is primarily the consequence of price effects (due to the development of fossil fuel prices between 1978 and 1990) and of the high share of fossil fuels in total inputs in this sector group (particularly in the 'mineral oil' sector).

Table 1: Cost shares, for all sectors and sector aggregates [%]

	year	Fossil fuels (F)	Electricity (EL)	Labour (L)	Capital (K)	Material (M)
All sectors	78	4.42	1.44	21.70	7.41	65.03
	84	6.04	1.56	20.25	8.28	63.87
	90	3.11	1.53	21.30	8.96	65.11
Energy supply sectors	78	43.04	3.07	15.78	16.73	21.38
	84	44.84	2.51	10.98	13.90	27.77
	90	27.03	3.15	12.73	18.79	38.31
Energy-intensive manufacturing sectors	78	4.45	2.27	25.18	12.38	55.71
	84	6.48	2.41	23.03	12.54	55.54
	90	3.41	2.30	25.15	13.14	55.99
Nonenergy-intensive manufacturing sectors	78	1.10	0.82	29.99	5.97	62.13
	84	1.34	0.89	28.75	6.78	62.24
	90	0.66	0.89	28.34	6.97	63.14
Service sectors	78	2.08	1.39	15.73	5.76	75.04
	84	2.55	1.55	15.47	7.04	73.39
	90	1.69	1.51	16.60	7.91	72.29

2.3 Empirical results

2.3.1 Curvature conditions

Own- and cross-price elasticities are computed from cost shares, evaluated at 1990 data, and from parameter estimates. The aggregated elasticities, presented in the following, are calculated as the weighted sum of sectoral elasticities,

8 Table A-1 in Appendix II reports that cost shares vary among sectors, indicating sectoral differences in factor intensities and production technologies.

whereas a sector's share in total input quantity serves as weight.[9] Two ways of aggregation are considered: firstly, elasticity values which are insignificant at a 5% level enter aggregation at zero (value I). Secondly, all estimates, whether they are significantly different from zero or not, are used to compute the weighted aggregated elasticity (value II).

Table 2 depicts sectorally aggregated own-price elasticities, calculated from the *concavity unrestricted* translog cost function. In the majority of cases, elasticities show the expected sign; however, significantly positive own-price elasticities of electricity demand are computed for the service sectors. Additionally, the own-price elasticity of fossil fuel demand is significantly positive for all sector groups, apart from the energy supply sectors, for which negative values are obtained.

Even if positive own-price elasticities are inconsistent with neoclassical theory, they are a common finding in empirical applications of *KLEM* models to German data and in interfuel substitution studies (cf. Nakamura 1984:201, Jones 1996:815). According to Friede (1980:87), who also computed positive own-price elasticities for West German producing sectors in 1954-67, positive own-price elasticities can be attributed to: 1. statistical errors (e.g. positive values are statistically insignificant); 2. data errors (in particular in cases where the input, e.g. fossil fuels, is unimportant for production); and 3. errors in model assumptions (e.g. with respect to the underlying postulate of cost-minimising behaviour). In practice, it is quite difficult to identify the source of error. Deviations from cost-minimising behaviour might be, for example, attributed to energy or environmental policy regulations,[10] to information and transaction costs, or to physical constraints which prevent input quantities to adjust to their (long-run) optimal level (see Conrad/Unger 1987). However, data errors seem to be the most obvious explanation for the existence of significantly positive own-price elasticities of fossil fuel demand in the service sectors and in the nonenergy-intensive manufacturing sectors, as these sectors are characterised by cost shares of fossil fuels below 5%.

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9 See Falk/Koebel (1999:5f.) for a theoretical founding of this aggregation procedure for own- and cross-price elasticities over individual industries. This procedure guarantees that sectorally aggregated own- and cross-price elasticities sum up to zero ($\sum_j \varepsilon_{ij} = 0$).

10 Note that for the energy supply sectors, own-price elasticities are negative (indicating cost-minimising behaviour) although this sector group (in particular the 'electricity' sector) has been affected heavily by environmental laws and other energy policy regulations in the 80's.

Table 2: Own-price elasticities, at 1990 data (non-nested, concavity unrestricted)

	Energy supply sectors			Energy-intensive manufact. sectors		
	value I	value II	sig. cas.*	value I	value II	sig. cas.
ε_{KK}	-0.399	-0.399	4	-0.334	-0.334	15
ε_{LL}	-0.000	-0.085	0	-0.133	-0.133	15
ε_{MM}	-0.399	-0.399	4	-0.059	-0.059	15
$\varepsilon_{EL,EL}$	-0.230	-0.230	4	-0.000	-0.012	0
ε_{FF}	-0.281	-0.281	4	0.397	0.397	15
	Nonenergy-intens. manufact. sectors			Service sectors		
	value I	value II	sig. cas.	value I	value II	sig. cas.
ε_{KK}	-0.275	-0.275	19	-1.047	-1.047	11
ε_{LL}	-0.155	-0.155	19	-0.760	-0.760	11
ε_{MM}	-0.117	-0.117	19	-0.230	-0.230	11
$\varepsilon_{EL,EL}$	-0.000	0.081	0	0.648	0.648	11
ε_{FF}	0.277	0.277	19	0.406	0.406	11

* t-statistics at a 5% level.

In the following, in order to be able to interpret the estimates in an economically sensible way, *local concavity* restrictions are imposed by replacing the substitution parameters β_{ij} in equations (2.1) and (2.2) by a Cholesky factorization. Table 3 shows that the estimates, which are obtained when positive Cholesky values are restricted to zero, are all negative and below unity (in absolute terms), with the exception of capital demand in the service sectors. The monotonicity of the cost function – with exception of two minor sectors (‘printing and publishing’ and ‘office and data processing’), for which slightly negative fitted cost shares of fossil fuels are computed – is satisfied at 1990 data.

The responsiveness of input demand to a change of own prices is highest for capital and labour in the service sectors. On the whole, the estimates are in accordance with the results in the econometric literature. Hamermesh (1993), for example, derived a range for ε_{LL} in the aggregate of –0.75 to –0.15. He reports own-price elasticities of capital ε_{KK} and material ε_{MM} which are (in absolute values) below unity and thus also consistent with my estimates. The estimates of Hesse/Tarkka (1986) are in conformity with my results, too. On the basis of pooled individual country time-series data for two periods, 1960-72 and 1973-80, the authors obtained that for Germany‘s manufacturing industry the highest demand response is for capital. They calculated estimates of –0.59 for ε_{KK}, –0.2 for ε_{LL}, –0.36 for $\varepsilon_{EL,EL}$, and –0.09 for ε_{FF} for the second period. However, compared to estimates of own-price elasticities of fossil fuels and electricity demand produced by Halverson (1977) for aggregate U.S. manufacturing, or by Jones (1996) for industrial energy consumption of the G7 countries, my estimates of ε_{FF} and $\varepsilon_{EL,EL}$ are relatively small in absolute terms. Both authors yield a higher sensitivity of energy demand to energy prices; they computed elasticities around –1 or even higher negative values.

Table 3: Own-price elasticities, at 1990 data (non-nested, concavity restricted)

	Energy supply sectors			Energy-intensive manufact. sectors		
	value I	value II	sig. cas.*	value I	value II	sig. cas.
ε_{KK}	-0.399	-0.399	4	-0.358	-0.358	15
ε_{LL}	-0.000	-0.085	0	-0.144	-0.144	15
ε_{MM}	-0.399	-0.399	4	-0.065	-0.065	15
$\varepsilon_{EL,EL}$	-0.230	-0.230	4	-0.000	-0.039	0
ε_{FF}	-0.281	-0.281	4	-0.000	-0.023	0
	Nonenergy-intens. manufact. sectors			**Service sectors**		
	value I	value II	sig. cas.	value I	value II	sig. cas.
ε_{KK}	-0.306	-0.306	19	-1.057	-1.057	11
ε_{LL}	-0.249	-0.249	19	-0.821	-0.821	11
ε_{MM}	-0.139	-0.139	19	-0.234	-0.234	11
$\varepsilon_{EL,EL}$	-0.000	-0.040	0	-0.000	-0.042	0
ε_{FF}	-0.000	-0.022	0	-0.000	-0.037	0

* t-statistics at a 5% level.

2.3.2 Substitution patterns

Table 4 depicts aggregated cross-price elasticities and Table 5 aggregated Morishima elasticities of substitution (MES); for the sake of simplicity, both are expressed only in terms of value II. The aggregated MES is calculated from sectorally aggregated own- and cross-price elasticities according to $\sigma_{ij}(\mathbf{p},x,t)=\varepsilon_{ji}(\mathbf{p},x,t)-\varepsilon_{ii}(\mathbf{p},x,t)$. It measures the percentage change in the ratio of input *j* to input *i* when the price of input *i* changes by 1%, keeping output constant.

Empirical results indicate that, in the majority of cases, inputs are substitutes in terms of both cross-price elasticity and MES. Complementary relationships can be observed in exceptional cases only for input pairs with either electricity or fossil fuels involved. However, capital and labour, capital and material, and material and labour are always substitutable.[11]

[11] Hesse/Tarkka (1986) also obtained some complementarity relationships between energy and capital or labour in whole German manufacturing industry. The authors found that – measured by the Allen substitution elasticity – capital and electricity are statistically insignificant and fossil fuels and electricity are significant complements for the period

Substitution patterns with respect to magnitude and sign differ widely between the four sector aggregates. Remarkably, the degree of substitutability is primarily marked for the service sectors aggregate. Here, MES above unity indicate strong substitutional relationships between capital and labour, capital and electricity, capital and fossil fuels, capital and material, and labour and electricity.

On the basis of cross-price elasticities, electricity and capital are statistically significant complements for the energy-intensive manufacturing sectors aggregate ($\varepsilon_{K,EL} = -0.028, \varepsilon_{EL,K} = -0.154$) and the nonenergy-intensive manufacturing sectors aggregate ($\varepsilon_{K,EL} = -0.028$, $\varepsilon_{EL,K} = -0.220$). Fossil fuels and capital, however, are characterised by positive cross-price elasticities in all sector aggregates.

Statistically insignificant negative cross-price elasticities between labour and electricity are computed for the energy supply sectors aggregate ($\varepsilon_{L,EL} = -0.012$, $\varepsilon_{EL,L} = -0.050$) and the energy-intensive manufacturing sectors aggregate ($\varepsilon_{L,EL} = -0.005$, $\varepsilon_{EL,L} = -0.054$). The computed cross-price elasticity for labour and fossil fuels is negative in all four sector aggregates as well, but significant values are calculated only for the nonenergy-intensive manufacturing sectors and the service sectors aggregate. Here, the cross-price elasticity is close to zero when the fossil fuels' price changes. Estimates are around –0.5 when the wage rate varies.

Besides, complementary patterns may exist between electricity and material in the nonenergy-intensive manufacturing sectors aggregate, for which, however, estimated cross-price elasticities are insignificant ($\varepsilon_{M,EL} = -0.003$, $\varepsilon_{EL,M} = -0.189$). The service sectors aggregate, in contrast, is characterised by significantly negative cross-price elasticities ($\varepsilon_{M,EL} = -0.013, \varepsilon_{EL,M} = -0.622$).

Insignificant cross-price elasticity estimates for the energy supply sectors aggregate may indicate a complementary interrelation between fossil fuels and electricity ($\varepsilon_{F,EL} = -0.002$, $\varepsilon_{EL,F} = -0.013$). Possible technical reasons for this complementarity may be grid losses in the electricity sector: If fossil fuel input decreases due to increased fuel prices, electricity production and grid losses are reduced as well. Statistically speaking, the latter are expressed as a reduction of

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1960-72 ($\sigma_{K,EL}$ = -0.36, $\sigma_{F,EL}$ = -11.46). For the period 1973-80, only labour and fossil fuels are found to be (statistically insignificant) complements (σ_{LF} = -0.14).

own consumption of electricity. Thus, higher fuel prices may correspond with lower electricity demand in the electricity sector.

Table 4: Cross-price elasticities, at 1990 data (non-nested, concavity restricted)

	Energy supply sectors		Energy-intensive manufact. sectors		Nonenergy-intensive manufact. sectors		Service sectors	
	value II	sig. cas.*	value II	sig. cas.	value II	sig. cas.	value II	sig. cas.
ε_{KL}	0.026	0	0.223	15	0.045	0	0.316	11
$\varepsilon_{K,EL}$	0.012	4	-0.028	15	-0.028	19	0.008	0
ε_{KF}	0.023	0	0.040	0	0.001	0	0.023	0
ε_{KM}	0.339	4	0.124	15	0.287	19	0.710	11
ε_{LK}	0.037	0	0.110	15	0.011	0	0.163	11
$\varepsilon_{L,EL}$	-0.012	0	-0.005	0	0.014	19	0.053	11
ε_{LF}	-0.017	0	-0.019	0	-0.011	19	-0.055	11
ε_{LM}	0.077	0	0.058	0	0.235	19	0.660	11
$\varepsilon_{EL,K}$	0.067	4	-0.154	15	-0.220	19	0.045	0
$\varepsilon_{EL,L}$	-0.050	0	-0.054	0	0.431	19	0.579	11
$\varepsilon_{EL,F}$	-0.013	0	0.003	0	0.019	0	0.039	0
$\varepsilon_{EL,M}$	0.225	4	0.244	15	-0.189	0	-0.622	11
ε_{FK}	0.016	0	0.159	0	0.012	0	0.117	0
ε_{FL}	-0.008	0	-0.156	0	-0.477	19	-0.541	11
$\varepsilon_{F,EL}$	-0.002	0	0.002	0	0.025	0	0.034	0
ε_{FM}	0.276	4	0.018	0	0.461	19	0.426	0
ε_{MK}	0.163	4	0.028	15	0.032	19	0.085	11
ε_{ML}	0.026	0	0.026	0	0.105	19	0.152	11
$\varepsilon_{M,EL}$	0.019	4	0.010	15	-0.003	0	-0.013	11
ε_{MF}	0.191	4	0.001	0	0.005	19	0.010	0

* t-statistics at a 5% level.

In contrast to the cross-price elasticity approach, the MES concept supports the hypothesis of capital-energy substitutability.[12] This might be of interest for policy makers as substitutability implies that an increase of fossil fuel or electricity prices simultaneously leads to a reduction of energy consumption and to a growing capital stock (given constant output).

[12] Whether capital and energy are complements or substitutes in production was the main focus in the literature of the 70‘s and 80‘s (see Kintis/Panas 1989, Apostolakis 1990 and Thompson/Taylor 1995).

Table 5: Morishima elasticities of substitution, at 1990 data (non-nested, concavity restricted)

	Energy supply sectors		Energy-intensive manufact. sectors		Nonenergy-intens. manufact. sectors		Service sectors	
	value II	sig. cas.*	value II	sig. cas.	value II	sig. cas.	value II	sig. cas.
σ_{LK}	0.111	0	0.367	15	0.294	18	1.136	11
σ_{KL}	0.436	4	0.468	15	0.317	19	1.220	11
$\sigma_{EL,K}$	0.242	4	0.011	0	0.012	1	0.050	5
$\sigma_{K,EL}$	0.467	4	0.204	10	0.085	6	1.102	11
σ_{FK}	0.304	3	0.062	0	0.023	0	0.060	0
σ_{KF}	0.415	4	0.517	15	0.318	9	1.174	11
$\sigma_{EL,L}$	0.218	2	0.034	0	0.054	18	0.094	11
$\sigma_{L,EL}$	0.035	0	0.090	2	0.680	19	1.400	11
σ_{FL}	0.264	3	0.004	1	0.010	1	-0.019	4
σ_{LF}	0.076	0	-0.012	0	-0.228	2	0.280	6
$\sigma_{F,EL}$	0.268	3	0.026	0	0.040	0	0.075	0
$\sigma_{EL,F}$	0.228	4	0.042	0	0.066	0	0.076	9
σ_{KM}	0.562	4	0.386	15	0.337	19	1.141	11
σ_{MK}	0.738	4	0.189	15	0.426	19	0.943	11
σ_{LM}	0.111	0	0.170	15	0.354	19	0.973	11
σ_{ML}	0.476	4	0.123	6	0.374	19	0.894	11
$\sigma_{EL,M}$	0.249	4	0.050	0	0.038	0	0.029	1
$\sigma_{M,EL}$	0.624	4	0.309	15	-0.050	0	-0.388	8
σ_{FM}	0.472	4	0.024	0	0.026	0	0.047	0
σ_{MF}	0.674	4	0.083	0	0.600	19	0.660	10

* t-statistics at a 5% level.

Whereas for the energy supply sectors all MES are positive, complementary relationships exist for the other three sector aggregates. The MES – aggregated over all (insignificant) sectoral estimates of σ_{LF} in the energy-intensive manufacturing sectors – is negative when the wage rate changes ($\sigma_{LF} = -0.012$). The aggregated σ_{LF} is also negative for the nonenergy-intensive manufacturing sectors ($\sigma_{LF} = -0.228$); the aggregated σ_{FL} is slightly negative for the service sectors aggregate ($\sigma_{FL} = -0.019$). Excluding insignificant values from sectoral aggregation in the latter two cases still leads to negative MES.

Furthermore, electricity and material are complements in the service sectors aggregate ($\sigma_{M,EL} = -0.388$) as well as in the nonenergy-intensive manufacturing sectors aggregate ($\sigma_{M,EL} = -0.050$). For the latter, however, the sectoral elasticities are all insignificant.

According to the literature on ecological tax reforms, a central question is whether labour is a better substitute for the taxed energy input than other input factors such as capital or materials. Table 6 roughly summarises the empirical evidence gained from the estimations of substitutability relationships between energy and nonenergy inputs (assuming a variation of the price of electricity or fossil fuels). The ranking is independent of whether substitutability is measured in terms of cross-price elasticity, Morishima substitution or Allen substitution elasticity.

Table 6: Ranking of substitution elasticities between energy and nonenergy inputs

	Ranking: substitutability between					
	fossil fuels			**electricity**		
Sector aggregates	labour	capital	material	labour	capital	material
Energy supply sectors	3	2	1	3	2	1
Energy-intensive manufact. sectors	3	1	2	2	3	1
Nonenergy-intensive manufact. sectors	3	2	1	1	3	2
Service sectors	3	1	2	1	2	3

1: highest degree of substitutability, 3: lowest degree of substitutability.

For the energy supply sectors and the energy-intensive manufacturing sectors aggregate, both electricity and fossil fuels are more substitutable to material, and (with exception of electricity in the energy-intensive manufacturing sectors) to capital than to labour. The nonenergy-intensive manufacturing sectors and service sectors are characterised by a higher degree of substitutability between fossil fuels and materials or capital respectively, than between fossil fuels and labour, whereas labour is easier to substitute for electricity than capital or material.

Thus, for the energy supply sectors and the energy-intensive manufacturing sectors, which are responsible for more than 50% of total energy consumption in 1990, a relatively low substitution of labour for energy can be expected from higher energy taxation. For the other sector aggregates, at least an electricity price increase would induce substitution processes which primarily favour labour demand.[13]

[13] These empirical results contradict, for example, the theoretical model assumptions made in a paper of Bovenberg/de Mooij (1994:657) on ecological tax reforms. The authors choose a production structure which is supposed to account for energy-capital complementarity and for a higher degree of substitutability between labour and energy than between labour and capital. In a recent paper, however, the authors refer to the study of Hesse/Tarkka

2.3.3 Homotheticity and returns to scale

The estimations allow for an additional check whether the typical assumption of constant returns to scale in CGE models can be supported empirically. For this purpose, sectoral economy-of-scale elasticities (λ)[14] are computed from the estimated parameters and are depicted in the following table:

Table 7: Economies-of-scale elasticities, at 1990 data (concavity restricted)

	λ	t-stat*		λ	t-stat
Energy supply sectors			Service sectors		
No.**			No.		
7	0.73	-6.08	51	1.80	3.75
8	1.52	3.94	52	1.64	4.46
11	2.83	2.68	54	1.06	1.33
15	1.76	4.10	55	0.99	-0.10
			56	1.18	7.97
Nonenergy-intensive			57	1.31	7.63
manufact. sectors			60	1.26	7.34
No.			61	1.14	4.04
16	1.23	6.64	64	1.17	4.71
17	1.14	4.87	65	1.16	3.90
25	1.13	6.07	66	1.45	4.04
26	1.19	3.20	Energy-intensive manufact. sectors		
27	1.06	3.51	No.		
28	1.13	2.24	1	1.01	0.40
29	0.95	-1.28	12	1.04	2.32
30	0.95	-2.01	14	0.99	-0.37
31	1.02	0.56	18	1.01	0.95
34	0.89	-3.77	19	1.04	1.90
35	0.87	-4.60	20	1.03	2.36
36	0.89	-10.48	21	1.00	0.38
40	0.83	-5.98	22	1.01	1.10
41	0.85	-12.54	23	1.02	1.43
42	0.82	-11.77	24	1.00	0.11
43	0.85	-6.81	32	1.01	0.51
44	0.79	-14.18	33	1.00	-0.22
45	0.76	-12.72	37	1.01	0.59
46	0.80	-7.95	38	1.01	0.26
			39	1.00	0.02

* t-statistics for the null hypothesis that λ=1, i.e. constant returns to scale.
** Sectoral classification see Table A-2 in Appendix III.

(1986) and concede that in European countries, compared to capital, labour seems to be a poorer substitute for energy (de Mooij/Bovenberg 1998:30f.).

14 λ is defined as the inverse of the elasticity of total costs with respect to output (see Berndt 1991).

Table 7 reveals that the null hypothesis of constant returns to scale (λ=1) is supported only for 17 sectors (mainly energy-intensive manufacturing). For the remaining 32 sectors, the elasticity of returns to scale is significantly different from unity, indicating that increasing or decreasing returns to scale prevail.

The majority of energy supply and service sectors are characterised by increasing returns to scale (λ is significantly greater than 1). Among the group of nonenergy-intensive manufacturing sectors empirical evidence is mixed: Increasing returns to scale are computed for six sectors, whereas decreasing returns to scale are obtained for eleven sectors. For two further sectors of this sector group, the constant-returns-to-scale hypothesis cannot be rejected.

Results of the Wald test statistics are depicted in Table 8.[15] Whereas, as previously mentioned, for 17 sectors the null hypothesis (i.e. constant returns to scale) cannot be rejected on empirical grounds, the hypothesis that the pooled sectors are jointly homothetic or homogeneous in output is rejected at a 5% level of significance for all four sector groups. All in all, the estimates suggest that the German economy is characterised by a non-homothetic production function with non-constant returns to scale.

Table 8: Homotheticity and homogeneity: Wald chi-square test statistics

Wald test statistic		Energy supply sectors	Energy-intensive manufact. sectors	Nonenergy-intensive manufact. sectors	Service sectors
Homotheticity	Chi-square value*	203,94	77,79	266,22	92,52
Homogeneity	Chi-square value**	208,38	79,33	282,21	102,95

*Critical value at the 5% level is 12.59 (6 degrees of freedom).

** Critical value at the 5% level is 14.07 (7 degrees of freedom).

[15] The degree of freedom for the Wald test statistic in the case of homotheticity is equal to six (β_{ix}=0, $i=K,L,M,EL,F$ $\beta_{xt}=0$) and in the case of homogeneity equal to seven (β_{ix}=0, $i=K,L,M,EL,F$ $\beta_{xx}=\beta_{xt}$=0).

3 Estimating substitution elasticities with a three-level nested five-input cost function

3.1 Econometric model

Whereas the previous section more generally dealt with substitution patterns in the German economy, the objective of this section is to estimate substitution elasticities that fit with the nested production structure of the GEM-E3 model.

The GEM-E3 model includes 18 production sectors which are characterised by four-level nested CES production functions with labour, capital, and 18 intermediate inputs. These intermediates consist of electricity, an input aggregate of three fossil fuel components (coal, oil gas), and an input aggregate of 14 nonenergy material components. The following figure clarifies the levels of nesting:

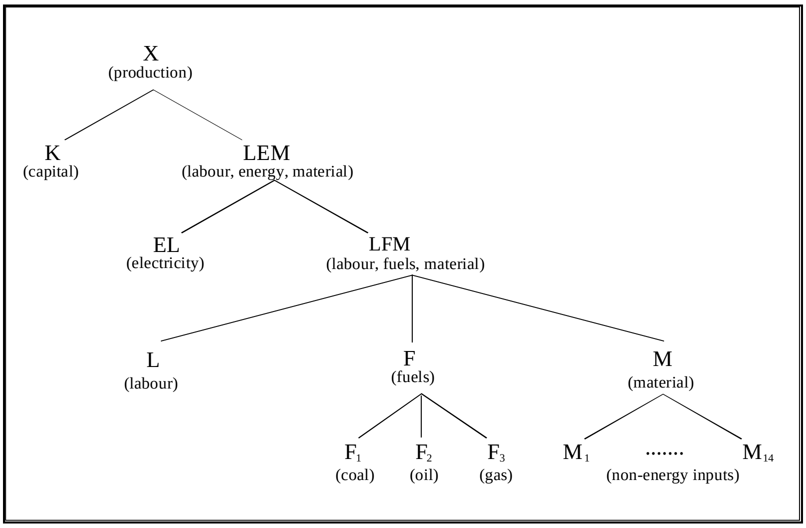

Figure 2: Nested production and factor price scheme of GEM-E3

This production structure assumes that firms at the bottom level minimise costs by choosing optimal quantities of fossil fuels (F_1, F_2, F_3) and material (M_1,...,M_{14}) components within the fossil fuel (*F*) and material (*M*) composite. It is assumed that the marginal rates of substitution between coal, gas, and oil and between nonenergy input pairs are independent of the level of quantities of inputs demanded outside these aggregates. In the second step, firms choose the cost-minimising mix of labour (*L*), the fossil fuels aggregate (*F*), and the material aggregate (*M*), in the third step the cost-minimising mix of the *LFM* bundle and electricity (*EL*) and, finally at the top level, the optimal mix of the *LEM* aggregate and capital (*K*). This four-level nested CES production function implicitly assumes weak homothetic separability, that is, the cost function is weakly separable in prices and output (cf. Chambers 1988).

Assuming weak homothetic separability of the production function opens up the possibility of multistage estimation of production decisions using consistent input aggregates. The three-stage estimation procedure, described in the following, represents an extension of the two-stage estimation procedure applied in Fuss (1977). Due to a lack of data, substitution interrelations among coal, oil and gas and among the several material components are not examined.

First nesting level: K-LEM (third stage of estimation)

Consider the first nesting level of the GEM-E3 producer model. Imposing weak homothetic separability in the LEM aggregate leads to the production function $x = f(LEM(L, M, EL, F, t), K, t)$, where LEM is assumed to be a linear homogeneous aggregator function. The dual cost function is then weakly separable in the same partition: $C = h(p_{LEM}(p_L, p_M, p_{EL}, p_F, t), p_K, x, t)$. p_{LEM} is an aggregate price index which is equal to the minimum cost per unit of the separable LEM aggregate and which is independent of the level of *LEM*. The derived factor share system is estimated with respect of prices for capital use (p_K) and the price index for the separable input aggregate *LEM* (p_{LEM}). p_{LEM} is generated in the second estimation stage.

Second nesting level: LFM-EL (second stage of estimation)

Due to the assumption that the cost function of the LEM aggregate is linear homogeneous in LEM, the unit cost function can be approximated by the following translog unit cost function:[16]

$$\ln p_{LEM} = \alpha_0 + \sum_i \beta_i \ln p_i + \frac{1}{2} \sum_i \sum_j \beta_{ij} \ln p_i \ln p_j + \sum_i \beta_{it} \ln p_i \cdot t \,,$$

where $i, j \in \{LFM, EL\}$. The share equation for electricity is estimated with respect to electricity prices (p_{EL}) and estimates of p_{LFM} which are generated in the first estimation stage.

[16] The assumption of linear homogeneity of the sub-aggregate cost function in *LEM* is a necessary assumption in order to ensure that the value of output is equal to the value of inputs. Linear homogeneity implies, in addition to homotheticity and homogeneity, that $_{LEM}$ = 1. Thus, *ln(LEM)* appears on the right hand side of the equation of the log of total costs. Subtracting *ln(LEM)* from the left hand side leads directly to the unit cost function of the aggregate *LEM*, i.e. to the translog price function. Linear homogeneity conditions are also imposed at the third nesting level.

Third nesting level: L-F-M (first stage of estimation)

The translog unit cost function of the LFM aggregate, which is assumed to be linear homogeneous in the level of LFM , is represented by

$$\ln p_{LFM} = \alpha_0 + \sum_i \beta_i \ln p_i + \frac{1}{2} \sum_i \sum_j \beta_{ij} \ln p_i \ln p_j + \sum_i \beta_{it} \ln p_i \cdot t \,,$$

where $i, j \in \{L, F, M\}$. The translog system of the two cost-share equations for labour and fossil fuels is estimated on the basis of exogenous prices of labour (p_L), fossil fuels (p_F) and nonenergy materials (p_M).

3.2 Empirical results

3.2.1 Substitution patterns

Table 9 depicts aggregated MES that are derived from aggregated own- and cross-price elasticities for GEM-E3 sectors[17] and contrasts them with the previously used values in the GEM-E3 model. For every sector, the substitution elasticity between labour, fossil fuels and material (σ_{LFM}) has been calculated as the weighted sum of MES between individual input pairs.

Whereas for some sectors considerable differences exist between the previously used and the econometric estimates, both are nearly equivalent for others. The importance of these differences with respect to GEM-E3 model results will be analysed in Section 4.

[17] Table A-3 in Appendix IV depicts estimates of own- and cross-price elasticities aggregated with respect to the sectoral breakdown in the GEM-E3 model.

Table 9: Morishima elasticities of substitution, at 1990 data (three-stage estimation)

	Agriculture (1)		Previously used values	Solid Fuels (2)		Previously used values
	value I	value II	in GEM-E3	value I	value II	in GEM-E3
σ_{LFM}	0.334	0.361	0.5	0.359	0.377	0.5
$\sigma_{EL,LFM}$	0.000	-0.002	0.2	0.121	0.121	0.2
$\sigma_{K,LEM}$	0.164	0.164	0.3	0.553	0.553	0.4
	Liquid Fuels (3)		Previously used values	Natural Gas (4)		Previously used values
	value I	value II	in GEM-E3	value I	value II	in GEM-E3
σ_{LFM}	0.320	0.406	0.5	0.321	0.367	0.5
$\sigma_{EL,LFM}$	0.377	0.377	0.2	3.817	3.817	0.2
$\sigma_{K,LEM}$	1.961	1.961	0.4	0.673	0.673	0.4
	Electricity (5)		Previously used values	Ferrous/Non Ferrous Ore (6)		Previously used values
	value I	value II	in GEM-E3	value I	value II	in GEM-E3
σ_{LFM}	0.347	0.377	0.5	0.266	0.297	0.5
$\sigma_{EL,LFM}$	0.075	0.075	0.2	0.000	-0.002	0.4
$\sigma_{K,LEM}$	0.343	0.343	0.3	0.454	0.454	0.4
	Chemical Products (7)		Previously used values	Other Energy-Intens. (8)		Previously used values
	value I	value II	in GEM-E3	value I	value II	in GEM-E3
σ_{LFM}	0.263	0.280	0.5	0.246	0.291	0.5
$\sigma_{EL,LFM}$	0.000	-0.002	0.4	0.000	-0.002	0.4
$\sigma_{K,LEM}$	0.454	0.454	0.4	0.442	0.442	0.4

	Electrical Goods (9)		Previously used values	Transport Equipment (10)		Previously used values
	value I	value II	in GEM-E3	value I	value II	in GEM-E3
σ_{LFM}	0.585	0.585	0.5	0.794	0.794	0.5
$\sigma_{EL,LFM}$	0.000	-0.032	0.2	0.000	-0.031	0.2
$\sigma_{K,LEM}$	0.291	0.291	0.4	0.278	0.278	0.4
	Other Equipment (11)		Previously used values	Consumer Goods (12)		Previously used values
	value I	value II	in GEM-E3	value I	value II	in GEM-E3
σ_{LFM}	0.600	0.600	0.5	0.723	0.723	0.5
$\sigma_{EL,LFM}$	0.000	-0.032	0.2	0.000	-0.017	0.2
$\sigma_{K,LEM}$	0.314	0.314	0.4	0.283	0.283	0.4
	Building (13)		Previously used values	Telecomm. Services (14)		Previously used values
	value I	value II	in GEM-E3	value I	value II	in GEM-E3
σ_{LFM}	0.499	0.499	0.5	0.710	0.710	0.5
$\sigma_{EL,LFM}$	0.000	-0.279	0.2	0.495	0.495	0.2
$\sigma_{K,LEM}$	0.450	0.450	0.4	0.471	0.471	0.4
	Transports (15)		Previously used values	Credit and Insurance (16)		Previously used values
	value I	value II	in GEM-E3	value I	value II	in GEM-E3
σ_{LFM}	0.823	0.867	0.5	0.826	0.826	0.5
$\sigma_{EL,LFM}$	0.373	0.373	0.2	0.808	0.808	0.2
$\sigma_{K,LEM}$	0.736	0.736	0.4	0.970	0.970	0.3
	Other Market Services (17)		Previously used values			
	value I	value II	in GEM-E3			
σ_{LFM}	1.545	1.546	0.5			
$\sigma_{EL,LFM}$	0.359	0.359	0.2			
$\sigma_{K,LEM}$	2.513	2.513	0.3			

3.2.2 Testing for weak homothetic separability

In order to examine whether the nested production structure given in Figure 2 can be justified empirically, the sectoral production functions are tested with respect to weak homothetic separability conditions.[18] For every sector aggregate, the validity of several separability structures is tested using the Wald test statistic.

First, let me turn to the results obtained from tests with the *service sectors* aggregate. Compared to the other sector groups, this aggregate contains a higher number of individual sectors, which allow for consistent input aggregation. Table 10 depicts for the service sectors aggregate only those Wald test statistics which are below the critical value, indicating that weak homothetic separability is accepted at a 5% level of significance.[19] For example, for seven service sectors, (*K*,*M*), (*K*,*F*), and (*K*,*L*) form weakly homothetically separable groups; for six service sectors, weak homothetic separability of (*K*,*M*,*EL*), (*EL*,*M*), and (*K*,*EL*) cannot be rejected.

In the other sector aggregates, separability is statistically rejected for the majority of individual sectors. In the *energy supply sectors* aggregate, only for the 'electricity' (7) sector is the restriction of weak homothetic separability not rejected for (*K*,*L*,*EL*) and for (*F*,*M*). Besides, the 'mineral oil' (15) sector allows for consistent aggregation of *K* and *EL*.

With exception of the sectors 'fine ceramics' (19) and 'glass' (20), the sectors pooled into the *energy-intensive manufacturing sectors* aggregate reveal a production structure that is weakly homothetically separable in energy: Testing for (*F*,*EL*)-separability yields Wald test statistics below the critical value of 9.49. For five further sectors, namely 'fabricated metals' (24), 'precision and optical instruments' (32), 'iron and steel' (33), 'paper and paper products' (38), and 'priniting and publishing' (39), *L* and *F* turn out to be weakly homothetically separable. For two other sectors, 'non-ferrous metals' (22) and

[18] See Denny/Fuss (1977:407ff.). Assume a five-input production function which is weakly homothetically separable in partition a^1 and which is expressed by $x = f(f^1(a^1, t), a_5, t)$, where $a^1 = \{a_1, a_2, a_3, a_4\}$ and f^1 is a homothetic micro-production function. According to Chambers (1988:115) and the theorem of duality, this production function corresponds to the cost function $C = g(g^1(p^1, t), p_5, x, t)$, $p^1 = (p_1, p_2, p_3, p_4)$ which is weakly separable in the 'extended' partition $\{p^1, p_5, x\}$. The parameter restrictions for weak homothetic separability of the underlying production function, which have to be imposed on the translog cost function, are: $\beta_i \beta_{j5} = \beta_j \beta_{i5}$, $\beta_i \beta_{jx} = \beta_j \beta_{ix}$, $i, j = 1,...4$.

[19] The chi-square critical value at the 5% level of significance is 12.59 (6 degrees of freedom) and 9.49 (4 degrees of freedom).

‘pulp, paper and board’ (37), the aggregation of *K* and *EL* can be reasoned on empirical grounds as well.

Table 10: Testing for weak homothetic separability in the service sector aggregate (Wald chi-square test statistics)

Separability structure	Sector No.* 51	52	54	55	56	57	60	61	64	65	66
					Chi-square value						
(L,EL,F,M),K											
(K,EL,F,M),L						8.77	9.30	8.50	5.70		4.80
(K,L,F,M),EL											
(K,L,EL,M),F											
(K,L,EL,F),M											
(EL,F,M),K,L						10.32	6.95				12.55
(L,F,M),K,EL											
(L,EL,M),K,F											
(L,EL,F),K,M											
(K,F,M),L,EL	11.36	11.89					11.33				7.34
(K,EL,M),L,F						8.09	4.98	5.15	6.34	9.88	3.41
(K,EL,F),L,M						6.76	10.93		4.43		
(K,L,M),EL,F											
(K,L,F),EL,M						11.77	7.54	6.62	4.91		4.58
(K,L,EL),F,M								11.25	8.90		8.15
					Chi-square value						
(F,M),K,L,EL		9.44					8.13			2.99	4.85
(EL,M),K,L,F					3.82	7.24	0.95	3.60		5.97	3.71
(EL,F),K,L,M				9.35	7.75	1.41	6.83	1.83			
(L,M),K,EL,F											
(L,F),K,EL,M											
(L,EL),K,F,M											
(K,M),L,EL,F	4.76	4.82				4.96	4.77	5.55	5.08		2.56
(K,F),L,EL,M	7.38	7.09				6.50	7.92	5.95	3.66		3.29
(K,EL),L,F,M		6.99				6.06	6.61	7.68	3.67		4.93
(K,L),EL,F,M	4.55	4.30				6.11	4.29	4.43	4.18		4.02

* Sectoral classification see Table A-2 in Appendix III.

Among the sectors pooled into the *nonenergy-intensive manufacturing sectors* aggregate, only for the sectors ‘office and data processing’ (27), ‘automobiles and parts’ (28), ‘shipbuilding’ (29), and ‘electrical appliances’ (31) are Wald test statistics below 9.49 calculated in the case of (*F,M*)-separability. For the sectors ‘airospace equipment manufacturing and repairing’ (30), ‘musical instruments and toys’ (34), ‘wooden furniture’ (36), and ‘leather’ (40) a consistent aggregation of *EL* and *M* can be justified.

The empirical results indicate that at a 5% test level weak homothetic separability of labour, material and energy (*LEM*) is rejected statistically in all sector aggregates.[20] Basically, this implies that the multistage estimation procedure applied in Section 3 and the nesting structure used in the GEM-E3 producer model are not consistent with German data.[21] But, as empirical results do not suggest any alternative first-stage nesting, we will proceed with the separability structure given in GEM-E3. In the next section, the estimates, depicted in Table 9, are introduced into the nested-CES specification of the GEM-E3 producer model. They provide the basis for sensitivity analyses with respect to substitution patterns in production.

4 Sensitivity of GEM-E3 model results to substitution patterns in production

The sensitivity of GEM-E3 model results to the choice of substitution elasticities in production is tested by applying a simple ecological tax reform scenario to the standard version of the single-country GEM-E3 model of Germany.[22] This standard version is calibrated against a benchmark data set for Germany which includes a number of pre-existing factor- and commodity-market tax distortions. Invested (physical) capital is internationally and sectorally immobile. Because sectoral capital stocks are quasi fixed, capital supply is completely inelastic in the short run. However, capital is supplied with some degree of elasticity in the long run. The labour market is neoclassical with flexible wages and homogeneous and internationally immobile labour. Household behaviour is described by a representative household that receives labour and capital income. According to the Armington assumption, domestic supply of intermediate goods, including energy and nonenergy materials, is imperfectly elastic.[23] The balance of payments is assumed to be flexible, implying that the real long-term interest rate and nominal exchange rates are fixed. Admittedly, both a flexible balance of payments and an internationally immobile capital stock are reasonable assumptions in particular for mid- or short-term analysis.

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[20] See also Turnovsky/Donnelly (1984:59), who tested for weak separability restrictions in the Australian iron and steel industry using a *KLEM* translog cost function. *K-LEM* separability is rejected at a 5% level as well, whereas *E -KLM* separability is accepted.

[21] Actually, *K-LEM* separability assumes that substitutional possibilities between labour, fossil fuels and material do not depend on the installation of new capital. This is, of course, a critical assumption.

[22] See Capros et al. (1997) for a detailed model description.

[23] The Armington concept of national product differentiation is more or less a standard assumption in CGE models. By assuming that domestic demand is a CES aggregate of imports and domestically produced and demanded commodities, it relaxes the small-open-economy assumption of fixed world market prices (cf. Koschel/Schmidt 1998).

Simulation results, given in Table 11, are based on the assumption that Germany reduces CO_2 emissions by imposing an endogenous tax on CO_2 emissions of housholds and firms. A linear reduction path of CO_2 emissions at a total of 20% (compared to the base year) over a 10-year period is assumed. Revenue-neutrality is operationalised by a fixed ratio of public deficit to GDP. Additional tax revenues are used to equally cut the rate of social security contributions of employees and employers. We refrain from applying a baseline scenario in order to clarify the effects of changed substitution elasticity values independently of their effects on the baseline scenario.[24]

Table 11 considers several cases of parameter specifications. The first and second three columns show the results of the two standard cases, which are based on the previously-used (best-guess) elasticity values incorporated in the GEM-E3 producer model and on the econometric estimates of Table 9.[25] The next six columns refer to results which are obtained when the substitution elasticities of all nesting levels are either halved or doubled.

Table 11: Sensitivity of model results to changed substitution elasticities (ecological tax reform scenario, in percentage changes from base year)

	Previously-used estimates			**Econometric estimates**								
	Standard case			Standard case			Halved values			Doubled values		
	1. year	5. year	10. year	1. year	5. year	10. year	1. year	5. year	10. year	1. year	5. year	10. year
Gross domestic product	0.04	0.11	0.00	0.03	0.07	-0.10	0.07	0.20	0.06	0.00	-0.02	-0.18
Employment	0.12	0.59	1.27	0.15	0.65	1.33	0.22	1.05	2.31	0.09	0.38	0.73
Domestic production	-0.14	-0.75	-1.76	-0.19	-0.96	-2.24	-0.17	-0.93	-2.40	-0.21	-0.93	-2.01
Domestic demand	-0.13	-0.68	-1.58	-0.16	-0.83	-1.98	-0.14	-0.82	-2.20	-0.17	-0.79	-1.74
Private investment	-0.03	-0.17	-0.52	-0.02	-0.20	-0.73	-0.01	-0.22	-0.96	0.00	-0.09	-0.39
Private consumption	0.09	0.35	0.50	0.12	0.43	0.59	0.15	0.54	0.63	0.09	0.31	0.45
Real net income	0.09	0.36	0.52	0.12	0.45	0.61	0.16	0.56	0.66	0.09	0.33	0.47
- Real net labour income	0.43	1.96	3.92	0.53	2.23	4.19	0.77	3.42	6.85	0.35	1.38	2.46
- Real net non-labour income	-0.19	-0.96	-2.29	-0.21	-1.02	-2.36	-0.35	-1.80	-4.48	-0.12	-0.54	-1.18
Real consumer wage	0.31	1.36	2.61	0.38	1.57	2.82	0.54	2.34	4.44	0.26	1.00	1.72
Real producer wage	-0.10	-0.55	-1.37	-0.07	-0.41	-1.12	-0.17	-1.02	-2.80	-0.03	-0.20	-0.54
Exports	-0.22	-1.17	-2.77	-0.37	-1.71	-3.67	-0.32	-1.57	-3.52	-0.39	-1.72	-3.50
Imports	-0.21	-1.05	-2.40	-0.29	-1.37	-3.04	-0.28	-1.45	-3.38	-0.28	-1.25	-2.64
Current account per GDP*	0.0003	0.0013	0.0028	0.0002	0.0012	0.0030	0.0004	0.0021	0.0055	0.0001	0.0006	0.0016
Terms of trade	0.10	0.55	1.32	0.18	0.84	1.81	0.15	0.75	1.66	0.19	0.84	1.74
CO_2 tax rate (ECU'85/tn CO_2)**	4.4	23.8	60.8	4.4	22.6	57.0	8.1	45.0	123.2	2.4	11.4	26.9
CO_2 tax revenue per GDP*	0.38	1.87	4.21	0.38	1.77	3.92	0.70	3.52	8.41	0.21	0.90	1.86
CO_2 emissions	-2.00	-10.00	-20.00	-2.00	-10.00	-20.00	-2.00	-10.00	-20.00	-2.00	-10.00	-20.00

* in value figures, absolute difference from baseline
** in value figures

24 Assuming different substitution elasticities leads not only to differences in policy effects, but also to different growth rates of baseline CO_2 emissions or GDP.

25 Estimated elasticity values of zero and negative values have been replaced by 0.1 in order to keep the GEM-E3 model solvable.

Table 11 illustrates that the GEM-E3 standard model for Germany produces a double dividend in terms of lower CO_2 emissions and higher employment within a wide range of substitution elasticities: If we calibrate the model against the estimates of Table 9, a rise in private income of 0.61% and in employment of 1.33% is realised, if CO_2 emissions fall by 20%.[26] Basically, this is in line with the numerical results of de Mooij/Bovenberg (1998:30), who also obtained a double dividend in a model with fixed capital.

Overall labour demand increases due to substitution processes in response to changed relative prices of labour and fossil fuels. Compared to the case of previously-used elasticity values, the standard case of the econometric estimates implies a higher level of consumption, real net income, real consumer wage, and higher employment, but a lower level of GDP, domestic production, private investment, exports, and imports.

Obviously, higher substitution elasticities (doubled values) generate lower CO_2 tax rates and lower ratios of CO_2 tax revenues to GDP. The former is the direct result of the higher price sensitivity of input demand functions caused by higher degrees of substitutability in production. Thus, significantly lower tax rates are required to realise a given CO_2 emissions reduction (cf. Kemfert/Welsch 1998).

In all cases, the real consumer wage rate steadily increases with higher CO_2 emission reduction rates, whereas real net non-labour income (capital income) is reduced. Assuming a neoclassical labour market, where labour supply depends positively on the real consumer wage[27] and negatively on real non-labour income, both effects stimulate labour supply. As household's real disposable income increases, private consumption goes up. Due to the lower producer wage rate, labour demand expands. Strictly speaking, the substitution effect, which favours labour demand, dominates the negative output effect (domestic production decreases in all cases of parameter choice due to higher production costs).

The development of GDP is explained by the development of consumption, investment and net exports. Both real exports and real imports are reduced, the

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[26] Applying the same scenario to the GEM-E3 model also yields positive employment effects when not all, but only the substitution elasticities of the first ($\sigma_{K,LEM}$) or of the third (σ_{LFM}) nesting level are either halved or doubled. As it is intuitively plausible, employment effects are at highest for halved $\sigma_{K,LEM}$ values (employment rises by 1.75%) and lowest for doubled $\sigma_{K,LEM}$ values (employment rises only by 0.93%).

[27] According to empirical evidence, the uncompensated wage elasticity of German labour supply incorporated in the GEM-E3 model is assumed to be slightly positive, i.e. a rise in the after-tax wage boosts employment.

former because of increased production costs, the latter because of lower domestic demand. Due to the Armington assumption which underlies the specification of Germany's and the rest of the world's import demand, imports are imperfect substitutes for domestically produced goods. Thus, export demand of the rest of the world is imperfectly price elastic and higher production costs in German export sectors can partially be shifted abroad. GDP shows positive growth rates, which, at the beginning, increase with the strong rise in consumption levels. With increasing CO_2 tax rates, however, exports lose some of its international competitiveness and progressively decline. This effect increasingly slows down GDP growth. Germany‘s terms of trade and net exports per GDP increase in all cases. This is possible because in the standard GEM-E3 model version, the balance of payments is flexible, i.e. imbalances have no feedbacks on the German economy.

5 Conclusions

In this paper, substitution elasticities between capital, labour, material, electricity, and fossil fuels were estimated using a translog cost function. Empirical basis was a pooled time-series cross-sectional data sample for 49 German producing and service sectors over the period 1978-90.

The empirical results can be summarised as follows:

(1) Positive Morishima elasticities of substitution below unity are obtained for the majority of sectors and input pairs. This indicates an overall dominance of weak substitutability relationships. Due to the high absolute own-price elasticity of capital demand in the service sectors, strong substitutes were calculated in particular in the service sectors aggregate for input pairs involving capital. The results support the hypothesis that capital and energy are substitutes.

(2) Negative Morishima elasticities of substitution are computed between labour and fossil fuels in the energy-intensive and nonenergy-intensive manufacturing sectors (when the wage rate changes), in the service sectors (when the fossil fuel price varies), and between material and electricity in the nonenergy-intensive manufacturing and the service sectors (when the price of material varies). Only for the two latter sector aggregates does labour seem to be a better substitute for electricity than capital or material; in most other cases, labour is more difficult to substitute for energy than material or capital. In practice, there may be a number of reasonable explanations for energy-labour substitutability. One possibility is that with higher energy prices more engineers are engaged, which search for and

implement energy-saving measures, for example in the area of thermal isolation of buildings.

(3) Estimation of sectoral economy-of-scale elasticities yields the result that only for 17 of 49 sectors can the hypothesis of constant returns to scale not be rejected at a 5% level of significance, indicating that the majority of sectors are described by decreasing or increasing returns to scale. Testing for homotheticity and homogeneity shows that the aggregates are characterised by non-homothetic and non-homogeneous production functions.

(4) In order to improve the empirical basis of the computable general equilibrium model GEM-E3, substitution elasticities were estimated for a three-level nested production function. A comparison with the values previously used in GEM-E3 indicates considerable numerical differences for some sectors. Testing for weak homothetic separability restrictions proves that inputs can be aggregated only in exceptional cases. Thus, the econometric estimates of the multi-stage estimation are surrounded by some uncertainty, and sensitivity tests are required.

(5) The numerical simulations with the GEM-E3 model reveal that the macroeconomic impacts of an ecological tax reform in Germany are relatively insensitive (in terms of the sign) with respect to a change of substitution elasticities in production. Positive labour market effects are obtained for a wide range of values. The interpretation of simulation results indicates, however, that price elasticities of labour supply and demand and assumptions concerning the foreign closure, also play a key role for the employment impacts of an ecological tax reform.

Appendix

I Data

Input prices and quantities are constructed following Falk/Koebel (1999:22ff.):

Electricity and fossil fuels

As sectorally disaggregated data for electricity and fossil fuels are not available from national account statistics, expenditures and quantities (in terajoule) are drawn from input-output tables.[28] In order to provide consistency of input-output energy data with national account data, the following adjustments are required for each sector:[29]

$$(p_i a_i)_{78}^{NA} = (p_i a_i)_{78}^{IO} \cdot \frac{(p_x x)_{78}^{NA}}{(p_x x)_{78}^{IO}} \ , \qquad i = EL, F$$

$$(p_i a_i)_{t}^{NA} = (p_i a_i)_{t}^{IO} \cdot \frac{(p_i a_i)_{78}^{NA}}{(p_i a_i)_{78}^{IO}} \ , \qquad i = EL, F \ , \ \ t = 1978,...,1990 \, .$$

This adjustment formula assumes that differences in output x between the national account and the input-output concept do not change over time, but can be represented by the discrepancy in 1978. The prices of electricity and fossil fuels are derived by dividing expenditures by quantities, both defined in terms of the input-output classification. This input-output energy deflator $p_{i,t}^{IO}$ is used to approximate the national account energy deflator $p_{i,t}^{NA}$, which is normalised to one in 1990 (the year of approximation). The quantity indices for electricity and fossil fuels are obtained by dividing expenditures for electricity and fossil fuels by the standardised price deflator:

$$a_{i,t}^{NA} = \frac{(p_i a_i)_{t}^{NA}}{p_{i,90}^{IO}} \, . \qquad i = EL, F \ , \ \ t = 1978,...,1990 \, .$$

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[28] Energy data are based on unpublished input-output tables, which have been provided by the Federal Statistical Office, Germany.

[29] The concepts of input-output tables and national account statistics are not fully compatible. In contrast to the input-output tables, which follow a functional classification scheme (breakdown of sectors by commodities), national account data are classified according to the institutional principle (breakdown of sectors according to institutional units).

Nonenergy material

Nonenergy material inputs contain intermediate inputs other than energy. Expenditures for nonenergy material are obtained by subtracting energy expenditures $\sum_i (p_i a_i)_t^{NA}$, $i = F, EL$, from material expenditures. Quantities of nonenergy materials in 1990 prices are calculated in a similar way. The deflator for nonenergy materials is computed as the ratio between nonenergy material expenditures and quantities in 1990 prices.

Labour

As data on actual working hours in each of the 49 sectors are not available, the quantity of labour is approximated by the total number of employees. For each sector and year, the price for labour is calculated by dividing gross wage income of employed persons by the number of employees. Wages are normalised to unity in 1990. Labour quantities (in prices of 1990) are obtained by dividing gross wage income by normalised wages.

Capital

Capital is assumed to be variable. According to Jorgenson (1974), sectoral user costs of capital are calculated as:

$$p_{K,t} = (1 + r_t) \cdot p_{I\,t} - (1 - \delta_t) \cdot p_{I\,t+1},$$

where r_t denotes the nominal interest rate, $p_{I\,t}$ and $p_{I\,t+1}$ represent the price of gross investment at t and $t+1$, and δ_t the depreciation rate. Nominal interest rates are provided by the Deutsche Bundesbank. δ_t is computed as follows:

$$\delta_t = (NK_t - NK_{t+1} + I_t) / NK_t,$$

where NK_t denotes real net capital stock and I_t gross investment in constant prices. The price index for gross investment $p_{I\,t}$ is derived by dividing gross investment in actual prices by gross investment in constant prices. The quantity of capital is computed by dividing capital costs, $p_{K,t} \cdot NK_t$, by the 1990 normalised user-cost price index of capital.

II Sectoral cost shares

Table A-1: Sectoral cost shares [%]

Sectors	Year	Fossil fuels (F)	Electricity (EL)	Labour (L)	Capital (K)	Materials (M)
Agriculture, Forestry and Fishing (1)	78	4.5	1.4	10.9	31.9	51.4
	84	4.8	1.4	9.9	33.7	50.0
	90	3.4	1.5	10.4	39.5	45.2
Electricity Production and Distance District Heating (7)	78	28.6	4.3	16.1	24.7	26.3
	84	25.4	3.7	12.3	22.5	36.1
	90	18.1	4.1	12.9	25.7	39.3
Gas (8)	78	58.4	0.1	7.1	8.9	25.5
	84	55.9	0.1	3.9	6.0	34.0
	90	41.5	0.1	7.0	12.4	39.0
Coal Mining (11)	78	24.5	2.9	40.4	11.5	20.7
	84	23.5	3.4	37.5	13.0	22.6
	90	16.2	3.4	37.8	15.7	27.0
Other Mining (12)	78	2.8	2.1	22.6	21.2	51.3
	84	3.5	1.7	21.1	18.8	54.8
	90	1.6	1.5	17.9	19.9	59.2
Chemical Products (14)	78	6.3	2.9	23.7	9.0	58.1
	84	10.6	2.8	22.3	8.0	56.4
	90	5.2	2.6	25.4	9.5	57.2
Mineral Oil (15)	78	75.1	1.1	4.3	6.3	13.2
	84	75.1	0.8	2.8	3.7	17.6
	90	48.0	1.2	3.4	3.9	43.6
Synthetic Resins and Plastic (16)	78	0.8	1.7	29.0	7.5	61.0
	84	0.8	1.9	25.9	7.5	64.0
	90	0.4	2.1	27.7	8.3	61.6
Rubber Processing (17)	78	1.8	2.0	33.7	8.3	54.2
	84	2.1	2.1	31.1	8.2	56.5
	90	1.0	1.9	30.7	8.6	57.8
Extraction of Sand, Gravel, Stone (18)	78	6.4	3.0	27.1	11.8	51.6
	84	7.7	3.1	25.1	11.5	52.6
	90	4.4	3.2	25.3	11.5	55.6
Fine Ceramics (19)	78	6.5	2.2	48.5	9.8	33.0
	84	7.6	2.4	45.4	10.9	33.8
	90	3.9	2.3	43.4	11.5	38.9
Glass (20)	78	7.3	2.8	33.3	10.4	46.2
	84	12.1	3.3	28.7	11.9	44.0
	90	4.5	3.6	28.6	12.8	50.5
Iron and Steel (21)	78	5.1	1.4	26.1	11.2	56.1
	84	6.2	1.7	23.8	12.2	56.1
	90	5.0	1.8	25.1	10.9	57.2
Non-Ferrous Metals (22)	78	1.7	5.7	17.1	7.0	68.6
	84	2.3	5.2	13.8	6.2	72.4
	90	1.2	4.9	16.0	7.0	70.9
Foundry (23)	78	2.5	3.0	41.3	9.0	44.1
	84	2.6	4.9	37.3	9.3	46.0
	90	1.5	3.5	38.0	9.6	47.4
Fabricated Metal (24)	78	1.0	1.7	29.4	7.0	60.9
	84	1.3	2.0	28.3	7.9	60.5
	90	0.6	2.0	29.6	7.5	60.3
Steel, Light Metal, Rail Machinery (25)	78	0.9	0.5	30.2	3.9	64.4
	84	1.4	0.7	34.8	5.7	57.3
	90	0.7	0.6	33.0	5.1	60.6

continued Table A-1

Sectors	Year	Fossil fuels (F)	Electricity (EL)	Labour (L)	Capital (K)	Materials (M)
Machinery (26)	78	0.7	0.7	35.8	5.6	57.2
	84	0.9	0.8	34.6	6.5	57.2
	90	0.4	0.8	34.4	6.5	57.9
Office and Data Processing (27)	78	0.3	0.8	34.2	15.1	49.6
	84	0.3	0.8	26.4	12.1	60.4
	90	0.1	1.0	27.2	10.6	61.1
Automobiles and Parts (28)	78	0.9	0.9	26.5	6.0	65.8
	84	1.0	0.9	25.8	7.9	64.5
	90	0.5	0.8	23.0	7.8	67.9
Shipbuilding (29)	78	0.5	1.1	35.7	6.7	56.0
	84	0.6	1.1	28.9	8.0	61.5
	90	0.3	1.0	27.3	6.7	64.7
Airospace Equipment Manufacturing and Repairing (30)	78	0.6	0.8	43.5	5.0	50.1
	84	0.5	0.8	38.9	6.9	52.9
	90	0.2	0.7	36.3	6.8	56.0
Electrical Appliances (31)	78	0.7	0.8	37.7	5.7	55.1
	84	0.9	0.8	35.3	6.6	56.4
	90	0.4	0.8	34.4	7.4	57.1
Precision and Optical Instruments (32)	78	0.6	0.9	42.8	5.2	50.5
	84	0.8	1.0	39.0	6.6	52.6
	90	0.4	0.9	38.1	7.2	53.4
Iron, Steel, and Steel Products (33)	78	1.1	1.0	33.4	6.7	57.8
	84	1.3	1.2	31.2	7.6	58.7
	90	0.6	1.3	31.4	7.6	59.1
Musical Instruments and Toys (34)	78	0.6	1.1	31.4	6.1	60.8
	84	0.7	1.2	29.1	8.3	60.7
	90	0.4	1.3	28.5	9.0	60.9
Timber Processing and Wood Products (35)	78	2.2	3.0	21.3	9.2	64.3
	84	2.3	3.2	21.3	10.0	63.2
	90	1.3	3.3	20.6	10.2	64.6
Wooden Furniture (36)	78	1.1	0.9	31.2	5.9	61.0
	84	1.3	1.1	31.7	7.0	58.9
	90	0.8	1.1	30.2	6.3	61.7
Pulp, Paper and Board (37)	78	4.7	6.2	24.1	11.5	53.5
	84	6.4	6.7	18.4	10.2	58.2
	90	4.0	6.8	19.0	13.0	57.2
Paper and Paper Products (38)	78	1.1	0.8	28.6	7.8	61.7
	84	1.5	1.0	24.3	8.4	64.8
	90	0.6	1.0	23.5	8.3	66.6
Printing and Publishing (39)	78	0.4	1.0	40.6	8.7	49.2
	84	0.6	1.3	36.7	10.3	51.1
	90	0.3	1.3	34.7	10.3	53.4
Leather (40)	78	0.8	0.7	28.8	6.9	62.8
	84	0.9	0.8	25.2	7.1	66.1
	90	0.5	0.8	22.6	7.7	68.4
Textiles (41)	78	1.4	1.8	28.1	8.9	59.8
	84	2.0	2.1	25.2	9.2	61.5
	90	1.0	2.4	24.7	9.9	62.1
Clothing (42)	78	0.6	0.5	28.7	3.8	66.5
	84	0.8	0.5	26.3	4.3	68.1
	90	0.4	0.5	23.8	4.1	71.1

continued Table A-1

Sectors	Year	Fossil fuels (F)	Electricity (EL)	Labour (L)	Capital (K)	Materials (M)
Food (43)	78	1.2	1.1	13.2	4.5	80.1
	84	1.6	1.2	12.6	4.9	79.7
	90	1.0	1.3	14.5	5.8	77.5
Beverages (44)	78	2.3	1.1	20.3	13.1	63.2
	84	3.2	1.3	18.0	14.5	63.1
	90	1.7	1.2	16.2	15.2	65.6
Tobacco (45)	78	0.6	0.8	21.2	7.5	70.0
	84	0.7	0.7	17.4	8.7	72.5
	90	0.3	0.7	14.3	7.8	76.9
Building and Construction (46)	78	1.8	0.1	39.6	5.2	53.4
	84	2.1	0.1	38.6	5.1	54.0
	90	1.1	0.1	36.6	4.6	57.5
Wholesale Trade (51)	78	1.8	0.9	6.4	1.5	89.4
	84	2.2	1.0	6.1	1.7	89.0
	90	1.7	1.2	7.4	2.2	87.5
Retail Trade (52)	78	2.0	2.5	11.3	3.0	81.1
	84	2.7	3.1	12.0	3.6	78.7
	90	1.8	2.9	11.7	4.1	79.6
Railways (54)	78	2.8	3.8	45.6	34.2	13.5
	84	3.5	4.9	40.5	39.3	11.9
	90	1.7	4.8	35.6	44.5	13.4
Water Transport (55)	78	10.0	0.3	19.2	29.1	41.4
	84	16.0	0.2	15.7	29.7	38.5
	90	8.7	0.2	18.7	28.7	43.8
Postal Services (56)	78	0.7	0.5	53.0	32.1	13.7
	84	0.7	0.7	45.2	39.3	14.1
	90	0.5	0.7	36.9	43.2	18.6
Other Transport (57)	78	7.2	0.6	24.7	11.9	55.6
	84	8.4	0.5	21.7	12.4	56.8
	90	5.3	0.4	23.3	12.0	59.0
Banking and Finance (60)	78	0.4	0.6	48.7	11.2	39.1
	84	0.5	0.7	46.6	13.3	38.9
	90	0.3	0.7	48.5	14.1	36.4
Insurance (61)	78	0.4	0.5	39.2	9.4	50.5
	84	0.4	0.6	33.7	12.5	52.8
	90	0.2	0.6	29.2	13.3	56.7
Hotels, Catering and Public Houses (64)	78	1.5	2.7	21.8	8.2	65.8
	84	1.7	3.0	22.8	9.9	62.6
	90	0.9	2.5	23.9	9.8	62.9
Education, Science and Culture (65)	78	1.0	0.8	29.7	23.3	45.2
	84	1.0	0.9	29.5	29.6	39.0
	90	0.6	0.8	30.3	31.5	36.9
Health and Sanitary Services (66)	78	1.3	0.4	39.4	8.0	50.8
	84	1.2	0.4	34.8	10.4	53.3
	90	0.5	0.3	29.0	8.5	61.7

III Sectoral classification

Table A-2: Sectoral breakdown (national account system – GEM-E3 system)

National account (NA) sectors	No.	GEM-E3 sectors	No.	Sectoral aggregation for estimation (pooling)
Agriculture and Forestry	1	Agriculture	1	Energy-intens. manufacturing
Electricity Production	7	Electricity	5	Energy supply
Gas	8	Natural Gas	4	Energy supply
Coal Mining	11	Solid Fuels	2	Energy supply
Other Mining	12	Other Energy-Intens. Ind.	8	Energy-intens. manufacturing
Chemical Products	14	Chemical Products	7	Energy-intens. manufacturing
Mineral Oil	15	Liquid Fuels	3	Energy supply
Synthetic Resins and Plastic	16	Consumer Goods	12	Nonenergy-intens. manufacturing
Rubber Processing	17	Consumer Goods	12	Nonenergy-intens. manufacturing
Sand, Gravel, Stone	18	Other Energy-Intens. Ind.	8	Energy-intens. manufacturing
Fine Ceramics	19	Other Energy-Intens. Ind.	8	Energy-intens. manufacturing
Glass	20	Other Energy-Intens. Ind.	8	Energy-intens. manufacturing
Iron and Steel	21	Ferrous and Non Ferrous Ore	6	Energy-intens. manufacturing
Non-Ferrous Metals	22	Ferrous and Non Ferrous Ore	6	Energy-intens. manufacturing
Foundry	23	Ferrous and Non Ferrous Ore	6	Energy-intens. manufacturing
Fabricated Metal	24	Other Energy-Intens. Ind.	8	Energy-intens. manufacturing
Steel, Light Metal	25	Other Equipment Goods Ind.	11	Nonenergy-intens. manufacturing
Machinery	26	Other Equipment Goods Ind.	11	Nonenergy-intens. manufacturing
Office and Data Processing	27	Other Equipment Goods Ind.	11	Nonenergy-intens. manufacturing
Automobiles and Parts	28	Transport Equipment	10	Nonenergy-intens. manufacturing
Shipbuilding	29	Transport Equipment	10	Nonenergy-intens. manufacturing
Aerospace Equipment	30	Transport Equipment	10	Nonenergy-intens. manufacturing
Electrical Appliances	31	Electrical Goods	9	Nonenergy-intens. manufacturing
Precision and Optical Instr.	32	Other Energy-Intens. Ind.	8	Energy-intens. manufacturing
Iron, Steel and Steel Products	33	Other Energy-Intens. Ind.	8	Energy-intens. manufacturing
Musical Instruments and Toys	34	Consumer Goods	12	Nonenergy-intens. manufacturing
Timber Processing and Wood	35	Consumer Goods	12	Nonenergy-intens. manufacturing
Wooden Furniture	36	Consumer Goods	12	Nonenergy-intens. manufacturing
Pulp, Paper and Board	37	Other Energy-Intens. Ind.	8	Energy-intens. manufacturing
Paper and Paper Products	38	Other Energy-Intens. Ind.	8	Energy-intens. manufacturing
Printing and Publishing	39	Other Energy-Intens. Ind.	8	Energy-intens. manufacturing
Leather	40	Consumer Goods	12	Nonenergy-intens. manufacturing
Textiles	41	Consumer Goods	12	Nonenergy-intens. manufacturing
Clothing	42	Consumer Goods	12	Nonenergy-intens. manufacturing
Food	43	Consumer Goods	12	Nonenergy-intens. manufacturing
Beverages	44	Consumer Goods	12	Nonenergy-intens. manufacturing
Tobacco	45	Consumer Goods	12	Nonenergy-intens. manufacturing
Building and Construction	46	Building and Construction	13	Nonenergy-intens. manufacturing
Wholesale Trade	51	Other Market Services	17	Service sectors
Retail Trade	52	Other Market Services	17	Service sectors
Railways	54	Transports	15	Service sectors
Water Transport	55	Transports	15	Service sectors
Postal Services	56	Telecommunication	14	Service sectors
Other Transports	57	Transports	15	Service sectors
Banking and Finance	60	Credit and Insurance	16	Service sectors
Insurance	61	Credit and Insurance	16	Service sectors
Hotels, Catering, Publ. Houses	64	Other Market Services	17	Service sectors
Education, Science, Culture	65	Other Market Services	17	Service sectors
Health and Sanitary Services	66	Other Market Services	17	Service sectors

IV Price elasticities

Table A-3: Own- and cross-price elasticities, at 1990 data (three-stage estimation)

	Agriculture (1)			Solid Fuels (2)			Liquid Fuels (3)			Natural Gas (4)			Electricity (5)			Ferrous/Non Ferrous Ore (6)		
	value I	value II	sig. cas.*	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.
Third nesting level																		
ε_{FF}	0.000	-0.005	0	-0.480	-0.480	1	-0.190	-0.190	1	-0.202	-0.202	1	-0.372	-0.372	1	0.000	-0.008	0
ε_{LL}	-0.418	-0.418	1	0.000	-0.022	0	0.000	-0.291	0	0.000	-0.129	0	0.000	-0.052	0	-0.262	-0.262	3
ε_{MM}	-0.108	-0.108	1	-0.356	-0.356	1	-0.259	-0.259	1	-0.267	-0.267	1	-0.206	-0.206	1	-0.120	-0.120	3
ε_{FL}	0.000	-0.080	0	0.000	-0.032	0	0.000	-0.013	0	0.000	-0.013	0	0.000	-0.025	0	0.000	-0.123	0
ε_{LF}	0.000	-0.026	0	0.000	-0.014	0	0.000	-0.179	0	0.000	-0.080	0	0.000	-0.032	0	0.000	-0.017	0
ε_{FM}	0.000	0.085	0	0.512	0.512	1	0.202	0.202	1	0.215	0.215	1	0.397	0.397	1	0.000	0.131	0
ε_{MF}	0.000	0.006	0	0.306	0.306	1	0.223	0.223	1	0.229	0.229	1	0.177	0.177	1	0.000	0.007	0
ε_{LM}	0.444	0.444	1	0.000	0.036	0	0.000	0.471	0	0.000	0.209	0	0.000	0.084	0	0.279	0.279	3
ε_{ML}	0.102	0.102	1	0.000	0.050	0	0.000	0.036	0	0.000	0.038	0	0.000	0.029	0	0.113	0.113	3
Second nesting level																		
$\varepsilon_{EL,EL}$	0.000	0.002	0	-0.117	-0.117	1	-0.373	-0.373	1	-3.812	-3.812	1	-0.070	-0.070	1	0.000	0.002	0
$\varepsilon_{LFM,LFM}$	0.000	0.000	0	-0.005	-0.005	1	-0.005	-0.005	1	-0.005	-0.005	1	-0.005	-0.005	1	0.000	0.000	0
$\varepsilon_{EL,LFM}$	0.000	-0.002	0	0.117	0.117	1	0.373	0.373	1	3.812	3.812	1	0.070	0.070	1	0.000	-0.002	0
$\varepsilon_{LFM,EL}$	0.000	0.000	0	0.005	0.005	1	0.005	0.005	1	0.005	0.005	1	0.005	0.005	1	0.000	0.000	0
First nesting level																		
ε_{KK}	-0.099	-0.099	1	-0.466	-0.466	1	-1.885	-1.885	1	-0.589	-0.589	1	-0.249	-0.249	1	-0.411	-0.411	3
$\varepsilon_{LEM,LEM}$	-0.065	-0.065	1	-0.087	-0.087	1	-0.076	-0.076	1	-0.084	-0.084	1	-0.094	-0.094	1	-0.043	-0.043	3
$\varepsilon_{K,LEM}$	0.099	0.099	1	0.466	0.466	1	1.885	1.885	1	0.589	0.589	1	0.249	0.249	1	0.411	0.411	3
$\varepsilon_{LEM,K}$	0.065	0.065	1	0.087	0.087	1	0.076	0.076	1	0.084	0.084	1	0.094	0.094	1	0.043	0.043	3

	Chemical Products (7)			Other Energy-intensive (8)			Electrical Goods (9)			Transport Equip. (10)			Other Equip. (11)			Consumer Goods (12)		
	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.
Third nesting level																		
ε_{FF}	0.000	-0.005	0	0.000	-0.016	0	0.394	0.394	1	0.351	0.351	3	0.387	0.387	3	0.175	0.175	11
ε_{LL}	-0.254	-0.254	1	-0.215	-0.215	10	-0.388	-0.388	1	-0.560	-0.560	3	-0.402	-0.402	3	-0.631	-0.631	11
ε_{MM}	-0.128	-0.128	1	-0.125	-0.125	10	-0.256	-0.256	1	-0.216	-0.216	3	-0.251	-0.251	3	-0.209	-0.209	11
ε_{FL}	0.000	-0.078	0	0.000	-0.249	0	-1.758	-1.758	1	-1.564	-1.564	3	-1.728	-1.728	3	-0.782	-0.782	11
ε_{LF}	0.000	-0.016	0	0.000	-0.014	0	-0.020	-0.020	1	-0.029	-0.029	3	-0.021	-0.021	3	-0.033	-0.033	11
ε_{FM}	0.000	0.083	0	0.000	0.265	0	1.364	1.364	1	1.213	1.213	3	1.340	1.340	3	0.607	0.607	11
ε_{MF}	0.000	0.008	0	0.000	0.007	0	0.009	0.009	1	0.008	0.008	3	0.009	0.009	3	0.008	0.008	11
ε_{LM}	0.270	0.270	1	0.228	0.228	10	0.408	0.408	1	0.590	0.590	3	0.423	0.423	3	0.663	0.663	11
ε_{ML}	0.120	0.120	1	0.118	0.118	10	0.246	0.246	1	0.208	0.208	3	0.241	0.241	3	0.201	0.201	11
Second nesting level																		
$\varepsilon_{EL,EL}$	0.000	0.002	0	0.000	0.002	0	0.000	0.032	0	0.000	0.030	0	0.000	0.032	0	0.000	0.017	0
$\varepsilon_{LFM,LFM}$	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0
$\varepsilon_{EL,LFM}$	0.000	-0.002	0	0.000	-0.002	0	0.000	-0.032	0	0.000	-0.030	0	0.000	-0.032	0	0.000	-0.017	0
$\varepsilon_{LFM,EL}$	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0
First nesting level																		
ε_{KK}	-0.411	-0.411	1	-0.400	-0.400	10	-0.270	-0.270	1	-0.256	-0.256	3	-0.292	-0.292	3	-0.262	-0.262	11
$\varepsilon_{LEM,LEM}$	-0.043	-0.043	1	-0.042	-0.042	10	-0.021	-0.021	1	-0.022	-0.022	3	-0.021	-0.021	3	-0.021	-0.021	11
$\varepsilon_{K,LEM}$	0.411	0.411	1	0.400	0.400	10	0.270	0.270	1	0.256	0.256	3	0.292	0.292	3	0.262	0.262	11
$\varepsilon_{LEM,K}$	0.043	0.043	1	0.042	0.042	10	0.021	0.021	1	0.022	0.022	3	0.021	0.021	3	0.021	0.021	11

continued Table A-3

	Building (13)			Telecomm. Serv. (14)			Transports (15)			Credit and Insurance (16)			Other Market Services (17)		
	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.	value I	value II	sig. cas.
Third nesting level															
ε_{FF}	0.142	0.142	1	0.000	-0.067	0	0.000	-0.009	0	0.000	-0.188	0	0.000	-0.036	0
ε_{LL}	-0.378	-0.378	1	-0.358	-0.358	1	-0.731	-0.731	3	-0.490	-0.490	2	-1.707	-1.707	5
ε_{MM}	-0.263	-0.263	1	-0.782	-0.782	1	-0.420	-0.420	3	-0.510	-0.510	2	-0.307	-0.307	5
ε_{FL}	-0.631	-0.631	1	-1.355	-1.355	1	-0.189	-0.189	3	-3.811	-3.811	2	-0.725	-0.725	5
ε_{LF}	-0.020	-0.020	1	-0.018	-0.018	1	-0.036	-0.036	3	-0.024	-0.024	2	-0.084	-0.084	5
ε_{FM}	0.490	0.490	1	1.422	1.422	1	0.199	0.199	3	3.999	3.999	2	0.761	0.761	5
ε_{MF}	0.010	0.010	1	0.037	0.037	1	0.020	0.020	3	0.024	0.024	2	0.014	0.014	5
ε_{LM}	0.398	0.398	1	0.376	0.376	1	0.766	0.766	3	0.514	0.514	2	1.791	1.791	5
ε_{ML}	0.254	0.254	1	0.745	0.745	1	0.400	0.400	3	0.486	0.486	2	0.292	0.292	5
Second nesting level															
$\varepsilon_{EL,EL}$	0.000	0.279	0	-0.489	-0.489	1	-0.367	-0.367	3	-0.802	-0.802	2	-0.353	-0.353	5
$\varepsilon_{LFM,LFM}$	0.000	0.000	0	-0.006	-0.006	1	-0.006	-0.006	3	-0.006	-0.006	2	-0.006	-0.006	5
$\varepsilon_{EL,LFM}$	0.000	-0.279	0	0.489	0.489	1	0.367	0.367	3	0.802	0.802	2	0.353	0.353	5
$\varepsilon_{LFM,EL}$	0.000	0.000	0	0.006	0.006	1	0.006	0.006	3	0.006	0.006	2	0.006	0.006	5
First nesting level															
ε_{KK}	-0.429	-0.429	1	-0.267	-0.267	1	-0.592	-0.592	3	-0.836	-0.836	2	-2.391	-2.391	5
$\varepsilon_{LEM,LEM}$	-0.021	-0.021	1	-0.204	-0.204	1	-0.144	-0.144	3	-0.134	-0.134	2	-0.121	-0.121	5
$\varepsilon_{K,LEM}$	0.429	0.429	1	0.267	0.267	1	0.592	0.592	3	0.836	0.836	2	2.391	2.391	5
$\varepsilon_{LEM,K}$	0.021	0.021	1	0.204	0.204	1	0.144	0.144	3	0.134	0.134	2	0.121	0.121	5

* t-statistics at a 5% level. Sectoral classification: see Table A-2 in Appendix III.

Note: For the *L-F-M* estimation model local concavity restrictions are imposed when estimating the service sectors and the energy-intensive manufacturing sectors aggregate. No concavity restrictions are imposed on the group of energy supply sectors, since for these – as in the non-nested case – all computed own-price elasticities are negative. However, the group of nonenergy-intensive manufacturing sectors as well as the *LFM-EL* and *K-LEM* estimation models of all sectoral aggregates (first and second nesting levels) are not restricted to local concavity, even if significantly positive own-price elasticities are calculated for fossil fuel demand in several GEM-E3 sectors such as Electrical Goods (9), Transport Equipment (10), Other Equipment Goods (11), Consumer Goods (12), and Building (13). Whereas for nine sectors insignificant price elasticities at the second nesting level (*LFM-EL*) are obtained, the price elasticities at the first nesting level (*K-LEM*) are statistically significant without exception.
Values I refer to elasticity aggregates that are obtained when sectoral elasticity values which are insignificant at a 5% level enter aggregation with zero, whereas values II are calculated as the weighted sum of all – significant and insignificant – sectoral price elasticity values.
For four of 49 sectors, the fitted cost shares of fossil fuels (at 1990 data) are negative, but only slightly below zero. These are the sectors (27), (32), (39), and (60), which all are characterised by very small cost shares of fossil fuels (below 0.5% in 1990, see Table A-1 in Appendix II). In all other input components, however, the estimated translog cost function increases monotonously.

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