

# WORKING PAPERS IN ECONOMICS

INDUSTRIAL SECTOR INTERFUEL SUBSTITUTION  
FOLLOWING  
THE FIRST MAJOR OIL SHOCK

by

V.B. Hall

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DEPARTMENT OF ECONOMICS



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Fuss (1977), Griffen (1977) and Pindyck (1979) have presented long-run own-price and cross-price elasticities of demand for individual industrial sector fuels, estimated from two-stage translog models. None of their samples includes observations subsequent to the first major oil shock, nor do they seem to have tested directly the homotheticity assumption for their energy sub-models.

We present new evidence on these elasticities for industrial non-energy producing sectors of the seven major OECD countries, and test a number of important restrictions. Our evidence comes from a pooled time series/cross-section sample of 140 observations for 1960-1979,<sup>1</sup> thereby incorporating a substantial number of observations subsequent to that first major oil shock.

1 The Interfuel Substitution Models

The new well-known homothetic translog expenditure shares energy sub-model consistent with two-stage theory,<sup>2</sup> is written for our four fuels seven country<sup>3</sup> data base as

$$SE_i = \beta_i + \sum_j \beta_{ij} \log PE_j \quad i, j = p, g, c, e \quad (1)$$

where  $i, j$  are individual fuel types,  $SE_i$  is the expenditure share of fuel  $i$ , and  $PE_j$  is the actual price of fuel  $j$ . Fuel  $p$  is liquid fuels/petroleum products,  $g$  is gas,  $c$  is solid fuels/coal, and  $e$  is electricity.

The parameter restrictions required by economic theory are

$$\begin{aligned} \sum_i \beta_i &= 1 \\ \sum_j \beta_{ij} &= \sum_i \beta_{ij} = 0 \\ \beta_{ij} &= \beta_{ji} \quad i \neq j \end{aligned} \quad (2)$$

and the corresponding partial own-price ( $\epsilon_{ii}$ ) and cross-price ( $\epsilon_{ij}$ ) elasticities of demand for individual fuels can be written as

$$\epsilon_{ii} = (\beta_{ii}/SE_i) - (1 - SE_i) \quad (3)$$

$$\epsilon_{ij} = (\beta_{ij}/SE_i) + SE_j \quad i \neq j$$

As this homothetic symmetry/equality<sup>4</sup> model (HS) imposes a number of important restrictions, five less restricted models were estimated.<sup>5</sup> All less restricted models incorporated individual country dummy intercepts, and were: a homothetic (DHS) and a non-homothetic (DNHS) symmetry/equality model, a non-homothetic symmetry-unconstrained model (DNHSU), a homothetic (DHU) and a non-homothetic (DNHU) unconstrained<sup>6</sup> or equality model. These six models enable testing of the homotheticity, homogeneity in prices, symmetry, and constancy of intercept across countries assumptions. Tests were conducted using the statistic  $-2 \log \lambda$ , asymptotically distributed as  $\chi^2$  with degrees of freedom equal to the number of restrictions, and where  $\lambda$  is the ratio of the restricted to the unrestricted likelihood function.<sup>7</sup>

## 2 Testing of Restrictions

Table 1 shows that at the 1% level of significance the hypothesis of a common intercept term for all seven countries cannot be accepted. Also, neither the full nor any individual homotheticity, homogeneity and symmetry restrictions are consistent with our data.<sup>8</sup>

Important implications of rejecting homotheticity are that, over the sample period 1960-1979, strict conditions for the applicability of a two-stage model have been violated,<sup>9</sup> and that industrial sector energy volumes have clearly been significant influences over and above individual fuel prices in explaining expenditure shares.<sup>10</sup>

## 3 International Own-price and Cross-price Elasticities of Demand

International (i.e. sample mean) own-price and cross-price elasticities of demand and their t-ratios are presented in Table 2 for the conventionally estimated homothetic symmetry/equality model and our preferred non-homothetic equality model.

The former (DHS) model, despite its restrictions not being consistent with our data, provides plausible<sup>11</sup> long-run own-price elasticities. It suggests that, on average, the demand for coal has remained price elastic (-1.35), for gas inelastic (-.71), for petroleum products quite inelastic (-.24) and for electricity very inelastic (-.09).

TABLE 1  
TESTING OF RESTRICTIONS

Values for Log of Likelihood Function						
Model	HS	DHS	DNHS	DNHSU	DHU	DNHU
Value	512.2	873.1	943.2	977.8	939.8	1003.4

  

Testing of Restrictions						
	Relevant Likelihood Values	Restrictions	-2log $\lambda$	Critical Value of $\chi^2_{0.01}$	Result	
Homotheticity, homogeneity, symmetry and common intercept term		HS-DNHU	27	982.4	47.0	Reject
Common intercept term only		HS-DHS	18	721.8	34.8	Reject
		or NHU-DNHU	18	737.0	34.8	Reject
Homotheticity, homogeneity and symmetry		DHS-DNHU	9	260.6	21.7	Reject
Homotheticity only		DHS-DNHS	3	140.2	11.3	Reject
		or DHU-DNHU	3	127.2	11.3	Reject
Homogeneity and symmetry		DNHS-DNHU	6	120.4	16.8	Reject
Homogeneity only		DNHSU-DNHU	3	51.2	11.3	Reject
Symmetry only		DNHS-DNHSU	3	69.2	11.3	Reject

The ranking of these own-price elasticities is unchanged for the latter (DNHU) model, and their magnitude (especially for petroleum products) has remained reasonably stable across specification. The response of coal is still elastic (-.97), comfortably above that for gas (-.81); while petroleum products and electricity demand remain inelastic (-.26) and very inelastic (-.02) respectively. However, two of these international own-price elasticities seem to have changed over time, reflecting substantial changes in their expenditure shares. For example,<sup>12</sup> Table 3 shows the petroleum products elasticity has risen from -.11 in 1960 to -.27 in 1974 and -.28 in 1979, and that for coal from -.82 to -1.06 and -1.11. Those for gas and electricity remained constant around -.8 and -.01.

TABLE 2

INTERNATIONAL (i.e. SAMPLE MEAN) LONG-RUN OWN-PRICE AND CROSS-PRICE ELASTICITIES\* OF DEMAND AND T-RATIOS

	Homothetic Symmetry/Equality Model (DHS)				Non-homothetic Equality Model (DNHU)			
	Petroleum Products	Gas	Coal	Electricity	Petroleum Products	Gas	Coal	Electricity
Petroleum Products	-.24 [2.93]	.07 [1.92]	.11 [1.33]	.07 [1.88]	-.26 [4.20]	-.18 [5.05]	.08 [1.27]	.41 [5.00]
Gas	.19 [1.92]	-.71 [8.40]	.82 [6.11]	-.29 [4.83]	.26 [1.88]	-.81 [9.85]	.39 [2.69]	.66 [3.55]
Coal	.25 [1.33]	.68 [6.11]	-1.35 [5.43]	.42 [4.93]	.35 [1.85]	1.23 [11.1]	-.97 [5.01]	-1.43 [5.67]
Electricity	.04 [1.88]	-.06 [4.83]	.11 [4.93]	-.09 [5.05]	.01 [ .38]	-.03 [2.73]	.12 [5.43]	-.02 [ .62]

\* For each model, elasticity values presented across the first row give the degree of response of petroleum products demand to a change in the price of each of petroleum products, gas, coal, and electricity. Similar interpretations follow for the remaining three rows.

TABLE 3

## INTERNATIONAL LONG-RUN OWN-PRICE ELASTICITIES OF DEMAND AND T-RATIOS FOR FOUR SELECTED YEARS

Year	Homothetic Symmetry/Equality Model (DHS)				Non-homothetic Equality Model (DNHU)			
	Petroleum Products	Gas	Coal	Electricity	Petroleum Products	Gas	Coal	Electricity
1960	-.08[.62]	-.69[6.68]	-1.02[7.67]	-.08[5.09]	-.11[1.14]	-.82[8.09]	-.82[7.87]	-.02[.64]
1973	-.25[3.57]	-.72[8.68]	-1.58[4.49]	-.09[5.07]	-.27[4.79]	-.81[10.1]	-1.04[3.81]	-.02[.63]
1974	-.26[4.42]	-.71[8.08]	-1.62[4.38]	-.08[4.15]	-.27[6.19]	-.82[9.52]	-1.06[3.65]	-.00[.08]
1979	-.26[4.01]	-.72[12.6]	-1.83[3.89]	-.09[4.29]	-.28[5.64]	-.79[14.2]	-1.11[3.03]	-.01[.17]

The cross-price elasticities of demand in Table 2 are considerably less stable across model specification than the own-price elasticities, presumably due at least in part to symmetry restrictions having to be rejected. They therefore don't achieve further comment.

#### 4 Individual Country Own-price Elasticities of Demand

Own-price elasticities for each of the seven major OECD countries are presented in Tables 4 and 5.

Table 4 shows mean-over-time elasticities derived from both the DHS and DNHU models, and allows comparison of the former with the partial elasticities presented by Pindyck (1979, p.174). Although Pindyck's sample period of 1959 to 1973 consists only of observations prior to the first major oil shock, many of his elasticities are similar to those obtained for the DHS model using observations through to 1979. For example, those involving coal and electricity seem particularly close, as are the petroleum products elasticities for Japan, France, the United Kingdom, and Italy. On the other hand, the gas elasticities are substantially different in all cases.

Conclusions of particular note from Table 4 for the preferred DNHU model would be: the petroleum products elasticities of around  $-.2$  to  $-.3$  for six of the countries are remarkably uniform, but for the United States there is no correctly signed statistically significant<sup>13</sup> value; the gas elasticities are very stable around  $-.7$  to  $-.8$  for all countries except Japan, which fails to register a statistically significant value; for coal, all seven elasticities are significant, but range from  $-.8$  for the United Kingdom up to  $-1.2$  in the United States and Italy; no country has exhibited an electricity elasticity which is statistically significant.

For those interested in still more detailed results, Table 5 extends the individual country information of Table 4 by providing own-price elasticities for four important years within the sample period. These are 1960 (well before the first major oil shock), 1973 and 1974 (around the time of that shock), and 1979 (substantially after the first shock but not incorporating any data reflecting the second major oil shock). As expected, these results are consistent with the patterns highlighted above for the mean year and mean individual country own-price elasticities.

TABLE 4

## INDIVIDUAL COUNTRY LONG-RUN OWN-PRICE ELASTICITIES OF DEMAND AND T-RATIOS

		Pindyck (1979, p.174)	Model DHS	Model DNHU
United States	Petroleum Products	-1.10[3.93]	.23[1.20]	.18[1.25]
	Gas	-1.26[5.78]	-.68[18.8]	-.72[20.6]
	Coal	-2.17[4.34]	-2.06[3.51]	-1.17[2.55]
	Electricity	-.13[2.67]	-.06[4.27]	-.00[.16]
Japan	Petroleum Products	-.20[1.54]	-.26[4.12]	-.28[5.78]
	Gas	-1.49[10.6]	.28[.48]	-.41[.73]
	Coal	-1.32[8.80]	-1.42[5.09]	-.99[4.56]
	Electricity	-.12[6.00]	-.08[5.09]	-.02[.64]
West Germany	Petroleum Products	.03[.17]	-.24[3.08]	-.26[4.40]
	Gas	-2.31[6.79]	-.62[4.06]	-.80[5.39]
	Coal	-1.09[10.9]	-1.10[7.07]	-.86[7.11]
	Electricity	-.12[6.00]	-.09[4.72]	-.01[.42]
France	Petroleum Products	-.20[1.67]	-.26[4.09]	-.28[5.74]
	Gas	-1.49[10.6]	-.68[5.95]	-.81[7.34]
	Coal	-1.04[10.4]	-1.25[5.96]	-.93[5.68]
	Electricity	-.16[5.33]	-.08[4.03]	-.00[.01]
United Kingdom	Petroleum Products	-.22[1.83]	-.23[2.63]	-.25[3.81]
	Gas	-1.38[11.5]	-.72[12.8]	-.79[14.4]
	Coal	-1.12[10.2]	-1.00[7.81]	-.81[8.06]
	Electricity	-.15[5.00]	-.04[1.67]	.06[1.39]
Italy	Petroleum Products	-.29[2.90]	-.26[4.07]	-.28[5.72]
	Gas	-1.30[13.0]	-.70[7.18]	-.82[8.60]
	Coal	-1.49[8.28]	-2.32[3.23]	-1.23[2.19]
	Electricity	-.13[6.50]	-.08[5.09]	-.02[.64]
Canada	Petroleum Products	-.81[9.00]	-.16[1.50]	-.19[2.31]
	Gas	-.33[1.83]	-.69[6.74]	-.82[8.14]
	Coal	-1.80[5.00]	-1.65[4.28]	-1.07[3.53]
	Electricity	-.14[4.67]	-.05[3.51]	.01[.30]

TABLE 5

## INDIVIDUAL COUNTRY INDIVIDUAL YEAR LONG-RUN OWN-PRICE ELASTICITIES OF DEMAND AND T-RATIOS

	Homothetic Symmetry/Equality Model (DHS)					Non-homothetic Equality Model (DNHU)				
	Petroleum Products	Gas	Coal	Electricity	Petroleum Products	Gas	Coal	Electricity		
United States										
1960	.90[2.87]	-.67[19.9]	-1.95[3.67]	-.05[3.72]	.82[3.46]	-.71[21.7]	-1.14[2.75]	.00[.17]		
1973	.22[1.17]	-.68[18.5]	-1.95[3.67]	-.06[4.31]	.17[1.22]	-.73[20.3]	-1.14[2.75]	-.00[.18]		
1974	-.17[1.57]	-.70[17.3]	-1.90[3.76]	-.08[5.09]	-.19[2.41]	-.74[19.0]	-1.13[2.86]	-.02[.64]		
1979	-.15[1.38]	-.66[20.7]	-2.74[2.93]	-.09[5.02]	-.18[2.16]	-.69[22.4]	-1.32[1.81]	-.02[.60]		
Japan										
1960	-.16[1.52]	.01[.03]	-1.00[7.88]	-.08[5.06]	-.19[2.35]	-.53[1.19]	-.80[8.15]	-.02[.62]		
1973	-.26[4.51]	.59[.81]	-1.60[4.45]	-.09[5.06]	-.27[6.30]	-.28[.39]	-1.05[3.75]	-.02[.62]		
1974	-.24[4.77]	1.11[1.14]	-1.64[4.31]	-.09[4.61]	-.25[6.65]	-.05[.05]	-1.06[3.57]	-.01[.35]		
1979	-.24[4.74]	.90[1.03]	-1.84[3.87]	-.09[4.91]	-.25[6.61]	-.14[.16]	-1.11[3.01]	-.02[.54]		
West Germany										
1960	.09[.55]	.47[.70]	-.75[9.67]	-.09[4.71]	.05[.39]	-.33[.51]	-.63[10.4]	-.01[.41]		
1973	-.25[3.24]	-.68[5.97]	-1.34[5.45]	-.09[5.07]	-.27[4.62]	-.81[7.36]	-.97[5.03]	-.02[.63]		
1974	-.26[4.25]	-.67[5.50]	-1.30[5.71]	-.08[4.04]	-.28[5.94]	-.81[6.96]	-.95[5.36]	-.00[.02]		
1979	-.26[3.81]	-.72[8.59]	-1.36[5.35]	-.09[4.44]	-.28[5.38]	-.81[10.1]	-.97[4.90]	-.01[.26]		

TABLE 5 (CONTINUED)

		Homothetic Symmetry/Equality Model (DHS)				Non-homothetic Equality Model (DNHU)			
		Petroleum Products	Gas	Coal	Electricity	Petroleum Products	Gas	Coal	Electricity
France	1960	-.20[2.15]	-.54[2.86]	-.94[8.34]	-.09[4.51]	-.23[3.18]	-.77[4.16]	-.77[4.16]	-.01[.30]
	1973	-.26[4.20]	-.70[7.02]	-1.43[5.02]	-.09[4.35]	-.28[5.90]	-.82[8.44]	-1.00[4.48]	-.01[.20]
	1974	-.23[4.79]	-.70[6.93]	-1.46[4.92]	-.03[1.33]	-.25[6.68]	-.82[8.34]	-1.01[4.35]	.07[1.59]
	1979	-.21[4.76]	-.72[8.68]	-1.87[3.81]	-.01[.24]	-.22[6.64]	-.81[10.1]	-1.12[2.93]	.10[2.24]
United Kingdom	1960	.14[.82]	-.73[11.3]	-.67[9.96]	.05[1.55]	.10[.76]	-.80[12.8]	-.56[10.8]	.17[3.30]
	1973	-.26[3.57]	-.72[13.1]	-1.26[5.90]	-.07[2.94]	-.27[5.07]	-.79[14.7]	-.94[5.60]	.02[.63]
	1974	-.25[4.65]	-.72[12.4]	-1.57[4.53]	-.03[1.29]	-.26[6.48]	-.79[13.9]	-1.04[3.85]	.07[1.62]
	1979	-.25[3.35]	-.66[20.4]	-1.55[4.61]	-.03[1.29]	-.27[4.77]	-.70[22.1]	-1.03[3.95]	.07[1.62]
Italy	1960	-.24[3.12]	-.69[6.45]	-2.07[3.50]	-.07[4.59]	-.26[4.47]	-.81[7.85]	-1.17[2.53]	-.01[.34]
	1973	-.25[4.53]	-.70[6.93]	-2.35[3.20]	-.09[4.80]	-.27[6.33]	-.82[8.34]	-1.23[2.15]	-.01[.47]
	1974	-.23[4.80]	-.67[5.78]	-1.79[3.96]	-.07[2.91]	-.24[6.69]	-.81[7.16]	-1.10[3.11]	.05[.65]
	1979	-.26[4.21]	-.72[13.2]	-2.64[2.99]	-.09[4.39]	-.28[5.91]	-.79[14.8]	-1.29[1.88]	-.01[.22]
Canada	1960	-.32[.24]	-.41[1.59]	-1.31[5.62]	-.02[1.91]	-.07[.64]	-.72[2.86]	-.96[5.24]	.03[1.25]
	1973	-.18[1.75]	-.69[6.45]	-2.10[3.47]	-.04[2.88]	-.20[2.65]	-.81[7.85]	-1.18[2.49]	.02[.67]
	1974	-.26[3.73]	-.69[6.83]	-2.29[3.26]	-.08[4.98]	-.28[5.27]	-.82[8.24]	-1.22[2.23]	-.02[.58]
	1979	-.24[2.93]	-.73[11.5]	-2.10[3.47]	-.08[5.03]	-.26[4.21]	-.80[13.0]	-1.18[2.49]	-.02[.61]

### 5 Principal Conclusions

Strict conditions for a two-stage translog expenditure shares model are violated. A single-stage homothetic symmetry/equality model is rejected in favour of a non-homothetic equality model. International own-price elasticities derived from the latter for petroleum products, gas, coal and electricity are  $-.26$ ,  $-.81$ ,  $-.97$  and  $-.02$ , little changed from  $-.24$ ,  $-.71$ ,  $-1.35$  and  $-.09$  for the former. Both models are consistent with gas and electricity long-run elasticities having remained close to constant over time, but with the petroleum products and coal elasticities having risen between 1960 and 1979.

## FOOTNOTES

- \* Axel Mittelstädt and Palle Scheide Andersen have given valuable advice. Philippe Hainault, Maurice Peat and Charlotte Vannereau provided excellent computing and research assistance.
1. All data come from published and unpublished OECD sources.
  2. Fuss (1977), Griffen (1977), Pindyck (1979).
  3. When individual country intercept dummies are incorporated,  $\beta_i$  is replaced by  $\sum_{k=1}^7 \beta_{ik} D_k$ , where the k are the United States, Japan, West Germany, France, the United Kingdom, Italy and Canada.
  4. Terminology is as in Griffen (1977, pp.763-764).
  5. Functional forms other than the translog have not been estimated.
  6. Restrictions remaining are therefore the adding-up restrictions  $\sum_i \beta_i = 1$  and  $\sum_i \beta_{ij} = 0$ . Monotonicity was checked for each observation and no statistically significant negative expenditure share values were detected.
  7. See, for example, Desai (1976, p.64), who also provides (pp.100-101) some cautionary comments on use of the test procedure.
  8. It seems unlikely that rejection of these hypotheses need be qualified in the light of recent work on the bias of asymptotic tests by Laitinen (1978) and Meisner (1979). The absolute difference between all relevant  $-2 \log \lambda$  and  $\chi_{0.01}^2$  values seems very convincing.
  9. See Fuss (1977, p.91), "Homotheticity is a necessary and sufficient condition for the validity of the two-stage procedure".
  10. This important result is confirmed when the 20 time series observations for each of the seven countries individually are regressed. See Hall (1982).
  11. For example, they have the same ranking, and compare more than favourably in magnitude with seven country averages of Pindyck's (1979, p.174), partial elasticities for 1959-1973. These are -1.43, -1.26, -.40, and -.13.
  12. Results for the DHS model are consistent with these basic behaviour patterns over time, despite some absolute magnitudes differing somewhat.
  13. Statistical significance has been taken as at the 5% level.

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