Energy Demand and the Changing Structure of the UK Chemicals Industry

David Hawdon
and
Jacqueline Read

Surrey Energy Economics Centre

Discussion Paper Number 18 July 1984

ENERGY DEMAND AND THE CHANGING STRUCTURE OF THE UK CHEMICALS INDUSTRY

David Hawdon and Jacqueline Read

University of Surrey

1. Energy Demand and Developments in the Chemical Industry

The Chemicals Industry is important for understanding the demand for hydrocarbons for two reasons. In the first place chemicals has traditionally grown substantially more rapidly than other sectors of the UK economy and succumbed only relatively recently to the general recession. This together with the fact that it is a high intensity energy user for steam raising and special processing makes its development of some significance for the likely growth of energy demand. In the second place however it is the major consumer of hydrocarbons as (non energy) chemical feedstocks in the form of naptha, gas oil and natural and other gas largely for petrochemical production. The "non energy" item in the national energy balance is intrinsically derived from activity levels within chemicals. Thus an integrated model of primary energy requirements will explain a major item usually accorded only cursory treatment in existing models.

1.1 Growth of the Chemical Industry

During the sixties UK chemicals output grew by approximately 6% per year which was about twice as great as that achieved by manufacturing industry in general. Even in the depressed seventies, the industry grew at a comparatively healthy rate of

2.3% per annum whilst overall manufacturing output declined slightly. These achievements were partly due to the expansion of chemicals demand worldwide as requirements for petrochemicals, (including fertilisers), man made fibres and chemicals for industrial applications responded to relatively rapid rates of economic growth. Chemicals production worldwide more than doubled between 1960 and 1970, and made a further 64% gain between 1970 and 1980. As Table 1 shows however, growth rates in all regions were substantially higher than those achieved in the UK, except during the last two years when UK chemicals output has stabilsed rather than fallen as in the rest of Europe and North America. Amongst the reasons put forward for the relatively poor UK performance are (see ref. 1) - a weak home market, lack of international competitiveness due to the strength of sterling vis à vis major competitors like West Germany, and relatively higher energy and feedstock prices. These factors, it is argued, have contributed to an overall lack of profitability in the UK chemicals industry and to lower rates of investment and hence lower growth rates than those experienced by international competitors.

From the point of view of energy demand, changes in the composition of chemical industry output have had an equally profound effect. The leading sector in value terms i.e. in-organic chemicals declined in relative importance (see Table 2) whilst other heavily energy intensive groups like petrochemicals and fertilizers have experienced steep reductions in growth rates since 1973. The expanding pharmaceutical sector has on the other hand contributed little to energy demand although it is an

TABLE 1

CHEMICALS PRODUCTION 1960 - 1982

	1960	1970	1980	1982	GROWTH RATE 1960/70	1970/80	1980/82
WORLD	32	79	130	128.5	9.4	5.1	-0.6
N. AMERICA	38	83	137	130	8.1	5.1	-2.6
EUROPE	31	86	123	118	10.7	3.6	-2.1
ASIA	21	76	134	139.5	13.7	5.8	+2.7
L. AMERICA	28	71	126	141.0	9.8	5.2	+5.8
OCEANIA	32	88	116	112.5	10.6	2.8	-1.5
U.K.	49	87	110	109.7	6.0	2.3	-0.09

Source: UN Monthly Abstract of Statistics Special Table A
Index Numbers of World Industrial Production
UK Monthly Digest of Statistics

TABLE 2

SECTORAL OUTPUT OF UK CHEMICALS INDUSTRY

					Growth Rates (c.p.a.)		
SECTOR	1954	1970	1980	1982	1954/82	1970/80	1980/82
INTENSIVE	56.8	110	107.7	85.5	1.47	-0.21	-10.9
Inorganic	56.8	110	107.7	85.5	1.47	-0.21	-10.9
Organic	18.1	28.7	114.9	121.0	7.02	3.85	2.71
Other	46.0	101.2	117.5	118.9	3.45	1.50	0.59
Dyestuffs	54.9	105.7	97.5	90.2	1.79	-0.80	-3.82
Fertilizers	63.4	86.8	105.1	105.3	1.83	1.93	0.10
LESS INTENSIVE							
Pharmaceutical	15.0	64.1	112.7	118.8	7.67	5.81	2.67
Toilet Prep.	37.2	72.0	102.4	99.0	3.55	3.58	-1.67
Paints	49.7	86.6	111.7	108.8	2.84	2.58	-1.31
Soaps and Det.	73.8	91.9	117.2	117.1	1.66	2.46	-0.04
Other	15.7	80.11	104.86	98.8	6.79	2.73	-2.94
INTENSIVE	40.6	95.5	111.5	108.6	3.588	1.56	-1.32
LESS INTENSIVE	26.7	76.7	108.8	107.2	5.08	3.55	-0.70
TOTAL	32.5	87.2	109.8	107.8	4.38	2.34	-0.96

Source: Business Monitor Series

important component of total value added in the industry. One of the major difficulties in modelling the demand for energy in chemicals is the heterogenous nature of the many hundreds of products produced by its major branches. Available estimates of energy intensities are incomplete and company specific but indicate an enormous range of values from a high 1560 therms of primary energy per tonne for polyvinyl chloride to a net energy production of 6 therms for every tonne of sulphuric acid made, according to one authority (2). In general it is true that organic chemicals are far more energy intensive than inorganics largely due to the fact that the former are based on hydrocarbon feedstocks. It is desirable therefore to provide a disaggregated treatment of chemical sectors on the basis of energy intensities.

1.2 Chemicals - the effects of the existing capital stock

Table 3 indicates the build up of capital equipment in the chemicals industry in the postwar period as well as its use of energy and feedstock. Responding to favourable growth conditions large units of productive capacity were installed throughout the UK in the 1960s and early 1970s. Noteworthy among these developments was the Ethylene plant building programme, begun in 1960 with the construction of plants at Fawley and Carrington, and growing to a peak of 2,110 mt per year capacity in 1981 centred mainly on Wilton and Baglan Bay. This plant is all highly specific to different products of the industry. It is high cost, long life plant which, once in place, significantly determines the overall utilisation of energy. Capital in place therefore, should be incorporated in the model as a constraint on demand adjustment at any moment in time.

TABLE 3

ENERGY, FEEDSTOCKS, OUTPUT, PLANT AND MACHINERY IN UK CHEMICALS

	1954	1960	1970	1980	1981	AV. GROWTH RATE P.A. 1954 - 1981
ENERGY (m. therms)	2344	2642	3016	4130	3980	2.0
FEEDSTOCK						
- PETROLEUM	214.3	718.9	2870.2	1694.7	2034.9	8.7
- N.GAS (m. therms)	-	-	105	1019	1056	23.3
OUTPUT (Index 1975 = 100)	32.5	54.5	87.2	109.9	109.0	4.0
PLANT & MACHINERY (£ m)	2951.7	4485.6	8201.5	12084.3	12439.5	5.5

2. The Model of Demand

2.1 Purpose of the Model

The primary objective of the model is to explain the demand for energy in the chemicals sector in the context of the interrelated demand for capital equipment. This enables the dynamic effects of changes in exogenous variables to be attributed to the proper process - the adjustment of the stock of energy using appliances in the presence of adjustment costs. The demand for energy is seen as responding in the short term to changes in prices of energy, labour, capital and output and in the longer term to capital stock adjustments initiated by the changes in these prices modified by costs of incitement. This approach enables the effects of government policy instruments such as corporation tax, allowances and grants to be assessed properly - and this is important since recent policy emphasis has been on finding grants for conversion of boilers from oil to coal. The model also takes account of the changing energy intensity of chemicals by including disaggregated supply equations. Finally it is relatively self contained as it includes a model explaining the determination of chemical output and the price of chemicals.

2.2 Expectations in the Model

One problem with most existing models of the demand for energy is that little effort is made to allow for the fundamental role of expectations. Current levels of demand for energy and other factors are likely to be based on levels of prices and output which were anticipated at the time decisions were made, rather than on current values. Some models try to allow for this by rather ad hoc distributed lag processes, but the link with expectations is rarely made explicit.

In our work we adopt a modified rational expectations approach although, in the absence of a complete model of the economy, we restrict its application to only the most important explanatory variables. The basic idea behind this approach is that although decision makers can not be assumed to have perfect foreknowledge of future events they may be assumed to be aware of any relevant systematic relationships and to take these into account in the forecasts they make. Thus we can consider the differences between the actual outcome and the expected value of any important explanatory variable as being composed of two parts $e + z$ where e is unsystematic and unpredictable and z is systematic. Now since z is systematic it may, in principle, be modelled and predicted and eliminated from the prediction of the variable. The rational expectation approach is to use a model to obtain predictions of the relevant variable which then become the expected values of those variables in the relevant equations. In our model we generate expected levels of chemicals industry prices and outputs by a simple two equation system estimated by Instrumental Variables. The predicted output level then becomes the appropriate instrument for expected output in the factor demand equations.

2.3 Derivation of the Model

The model is, basically, the model of Berndt, Fuss and Waverman (see ref. 3) adapted to include expected rather than actual values of important variables and extended to allow for the differential effects of changes in the output of high and low energy intensive chemicals subsectors.

We assume that firms in the industry try to minimise the stream (L) of expected variable (G) and fixed costs (F) over time, discounted at a rate which represents the firm's costs of capital (R).

i.e. $\min (L) = e^{-Rt} [G_t + F_t]dt$ (1)

where $G = \sum P_j X_j = G(P_j, K, \dot{K}, QI, QLI)$ (2)

and P_j represents prices of variable factors j, (energy, labour and materials), X_j is quantity of input j, K is capital stock, $\dot{K}$ is the rate of change of K, incorporated to allow for costs of adjustment, $\hat{QI}$ and $\hat{QLI}$ are levels of energy intensive and non intensive chemical outputs anticipated when making energy input decisions,

$F = P_K K$ is the cost of fixed capital services,

where $P_k = [(R+D)(1-A)/(1-T)]C$

where D is the depreciation rate, A is the tax allowance rate,

T is the rate of corporation tax, and C is a capital price index.

Then, by Shepards lemma,

$dG/dP_j = X_j$ = short run demand for factor j.

The demand for capital equipment is found from the Euler condition for an extreme value of (1)

i.e. $\partial L/\partial K - d/dt(\partial L/\partial \dot{K}) = 0$

In order to find factor demand equations suitable for estimation we need to make specific assumptions about the form of G, the variable cost function. It is desirable that this should be of a flexible functional form in order to avoid imposing unnecessary restrictions on the estimates. We choose the quadratic functional form because it yields factor demand functions which predict actual rather than logarithms or other transformation of demand and also because the resulting demand functions are of a simple linear form.

G then is a quadratic flexible cost function

$$= D'\Gamma D$$

where $D = (1, PE, PF_1, PL, PK, QI, QLI, K, \Delta K)$ and Γ is a vector of coefficients

Then the factor demands are

$$E = \partial G/\partial PE = \alpha_E + \gamma_{EE}PE + \gamma_{EF}PF + \gamma_{EL}PL + \gamma_{EQI}QI + \gamma_{EQLI}QLI + \gamma_{EK}K_{-1} \qquad (3)$$

$$F = \partial G/\partial PF = \alpha_F + \gamma_{FE}PE + \gamma_{FF}PF + \gamma_{FL}PL + \gamma_{FQI}QI + \gamma_{FQLI}QLI + \gamma_{FK}K_{-1} \qquad (4)$$

$$K^* = \left[\frac{-1}{\gamma_{KK}}\right](\alpha_K + \gamma_{KE}PE + \gamma_{KF}PF + \gamma_{KL}PL + \gamma_{KI}QI + \gamma_{KQLI}QLI + \gamma PK) \qquad (5)$$

$$\Delta K = M(K^* - K_{-1})$$

where $M = (-0.5)(R - (R^2 + 4\gamma_{KK}/\gamma_{\dot{K}\dot{K}})^{1/2})$, is the speed of adjustment factor. Chemicals output and price expectations are given by

$$\hat{PCPE} = \alpha_p + \gamma_{pp}\,PCPE_{-1} + \gamma_{PQ}Q + \gamma_{PK}K_{-1} \qquad (6)$$

$$\hat{Q} = \alpha_Q + \gamma_{QP}\,PCPE + \gamma_{QG}UKGDP \qquad (7)$$

Where PCPE is price of chemicals export output divided by price of energy UKGDP is UK gross domestic product at constant 1975 prices.

Price expectations are formed in a very simple way according to equation (6). With given levels of capital stock, any increase in industry output is seen as evidence of growing demand and hence of opportunity for higher profit through increased prices. Hence the expected sign of γ_{PQ} is $>$ 0. Conversely, with constant output levels, any increase in the capital stock is taken as a sign that over capacity is likely to develop and this will exert a downward pressure on chemical prices to fixed costs. The sign of γ_{PK} is expected therefore to be negative. Finally, the effect of time lags in the formation of expectations is allowed for by the presence of a lagged endogeneous variable in the equation whose coefficient is expected to lie between 0 and 1.

Output in the chemical sector (equation 7) is expected to increase, when the ratio of the price of chemicals to the price of energy input rises. This reflects an improvement in profit opportunities to which the industry may be expected to respond in the current period. Thus the sign of γ_{QP} is expected to be positive. In line with our previous arguments regarding the behaviour of the industry we would also expect that output would respond positively to changes in the overall level of economic activity as measured by GDP even in the absence of any increase in price. We would expect therefore that the coefficient γ_{QG} would also be positive.

3. The Empirical Results

In order to obtain consistent estimates of the model we use an Instrumental Variable approach developed by McCallum and others (see ref. 4). Consider the demand for energy (equation 3) as a function of expected output and other variables

$$E = \alpha + \gamma_{EQ}Q_t^* + \qquad + \eta_t \text{ where } Q_t^* = \text{expected output}$$

Now actual $Q_t = Q_t^* + Z_t$ where Z is unpredictable with information available at t - 1

$$\text{i.e. } E(Z/I_{t-1}) = 0$$

Substituting for expected output in the energy equation yields

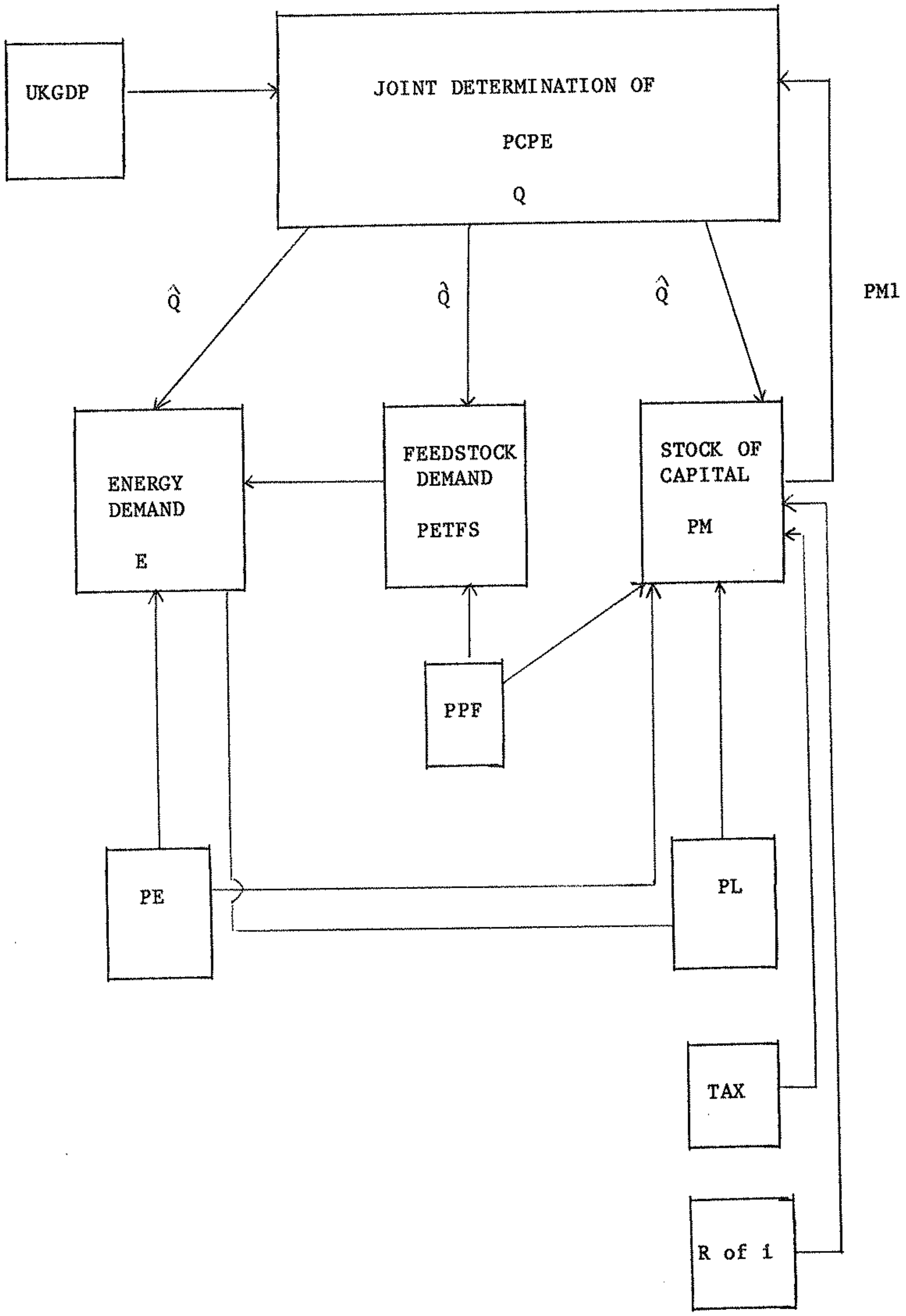
$$E = \alpha + \gamma_{EQ}Q + \qquad + (\eta_t - \gamma_{EQ}Z_t)$$

Unfortunately Q is however correlated with the error term $(\eta_t - \gamma_{EQ}Z_t)$. Consistent estimates however can be obtained by first estimating Q as a function of variables uncorrelated with $(\eta_t - \gamma_{EQ} Zt)$ and then

replacing $\hat{Q}_t$ by forecasts of Qt (Q_t^*) in the demand equations. Q is found from equations (6) and (7) by instrumental variables estimation. The predicted level of output is inserted into the factor demand equations which are then estimated by O.L.S. [It is important to note that the correct procedure is not to estimate the entire model by IV or 2SLS, only the first two equations (see Figure 1 on model structure). This figure also shows the feedback link between capital and the price of chemicals equation].

FIGURE 1

STRUCTURE OF CHEMICALS ENERGY DEMAND MODEL



Results using the above procedure are reported in Table 4 as Model 1. In order to test the 'rational expectations' model, a second set of estimates was made using actual Q instead of Q. The results of this alternative procedure are given in Table 5 (Model 2).

3.1 From the point of view of ease of exposition we look at the output equation (7) first. Here output is an energy weighted sum of an index of highly intensive and one of low intensive chemical outputs. Information on average energy consumption per unit of output was obtained from the Census of Producton for 1980 and used to classify the various subsectors into these two categories. Q_I consists of organic, inorganic and general chemicals, fertilisers, resins and plastics while QLI consists of pharmaceuticals, and other light energy consuming products. Separate models have been developed for each subsector but to simplify model exposition and solution we present only the results for energy weighted total output $Q = W_1 QI + W_2 QLI$. In line with our general view of chemical industry behaviour we make output a function of two variables - the expected price of chemicals relative to the price of energy, and UKGDP to reflect the responsiveness of output to demand pressures consistent with cost minimization. The model was estimated over 1954 to 1981 and performs well in terms of goodness of fit, as measured by R^2 and a lack of autocorrelation. Both price and demand effects are significant and correctly signed with the demand effect confirming that chemicals have traditionally grown at just under twice the rate of UKGDP in the past.

TABLE 4

CHEMICALS ENERGY DEMAND MODEL 1

EQUATION	ESTIMATES	SS	R^2	D.W.	Log Likeli-hood
(6) PCPE	$25.74 + 0.7256\ PCPE_{-1} + 0.42\ \hat{Q} - 0.0052\ K_{-1} + 8.02\ D7374$ (2.77) (10.39) (3.06) (-3.93) (2.28)	307.6		1.97	
(7) Q	$-98.6 + 0.1549\ PCPE + 1.888\ UKGDP$ (-11.02) (2.89) (35.85)	208.5		2.47	
(3) E	$3889.4 + 10.07\ \hat{Q} - 18.5\ PE/PMF - 9.01\ PL/PMF$ (6.5) (1.11) (-3.55) (-2.08) $+0.2011\ K_{-1} - 363.8\ D74K$ (2.9) (-1.6)	703750	94.3	1.03	-175.6
(4) PETFS	$-1217.4 + 70.7\ Q - 32.5\ PPF/PMF - 0.2562\ K_{-1} - 41.44\ T$ (-2.05) (7.03) (-1.45) (-0.755) (-0.342)	0.18×10^7	91.7	1.66	-188.5
(5) ΔK	$m[-7588.4 + 85.98\ PE/PMF - 9.35\ PL/PMF$ (-4.0) (7.67) (-0.54) $+145.67\ PPF/PMF + 117.2\ Q - 5835.9\ TAX - K_{-1}]$ (2.96) (9.59) (-2.29) $m = (-0.5)[R - (R^2 + 0.08)^{0.5}]$	0.58×10^7	97.2	1.7	-203.9

TABLE 5

CHEMICALS ENERGY DEMAND MODEL 2

EQUATION	ESTIMATES	SS	R^2	D.W.	LL
(6) PCPE	$25.74 + 0.7256\ PCPE_{-1} + 0.42\ Q - 0.0052\ K_{-1} + 8.02\ D7374$ (2.77) (10.39) (3.06) (-3.93) (2.28)	307.6		1.97	
(7) Q	$-98.6 + 0.1549\ PCPE + 1.888\ UKGDP$ (-11.02) (2.89) (35.85)	208.5		2.47	
(3) E	$3683.4 + 17.63\ Q - 17.0\ PE/PMF - 10.8\ PL/PMF$ (7.17) (2.43) (-3.2) (-3.21) $+0.14\ PM_{-1} - 522.13\ D74$ (2.43) (-2.36)	581323	95.3	1.09	-173.0
(4) PETFS	$-1571.3 + 67.88\ Q - 71.44\ PPF/PMF + 0.168\ K_{-1} - 178.5\ T$ (-2.9) (8.3) (-3.8) (0.56) (-1.6)	0.14×10^7	93.5	1.15	-185.1
(5) ΔK	$m[-7253.5 + 86.4\ PE/PMF - 1.5\ PL/PMF$ (-3.41) (6.94) (-0.08) $+145.3\ PPF/PMF + 112.1\ Q - 7156.7\ TAX - K_{-1}]$ (2.6) (8.4) (-2.5) $m = (-0.5)[R - (R^2 + 0.08)^{0.5}]$	0.7×10^7	96.6	2.04	-207

3.2 The price of chemicals/price of energy equation (6). In some ways this is a strange equation inserted because the model requires a price expectation term. Time lags are likely to be involved in the formation of price expectations and hence the inclusion of a lagged price of chemicals/price of energy term. A negative relationship is assumed to exist between price and capacity output. This is not so much a demand effect as a capacity utilisation term, however, and accounts for the presence of Q in the model with a positive signed coefficient. Prices are expected to rise only in the presence of high capacity utilisation. Again the model performs well when estimated both in terms of goodness of fit and lack of autocorrelation. The price is seen to respond positively to expected output but negatively to the capital stock. There is little difference between these results and those of the alternative model using Q only (model 2).

3.3 The coefficients of the energy equation equation 3) were as expected although the expected value of output is not significant at the 5% level. The negative coefficient of the price of labour indicating energy-labour complementarity. The inclusion of a dummy variable which takes the value of 1 for 1974 and zero for all other years to account for the oil price rise of the previous year is only just significant but did improve the performance of the model. The coefficient of determination is 94.3% which is reasonable but the D.W statistic of 1.03 indicates the presence of autocorrelation.

The short run own price elasticity for energy of -0.6 suggests that there is a significant response in energy demanded to changes in the price of energy. The short run cross price elasticity of energy with respect to labour indicates a moderate response to changes in the price of labour.

3.4 The Petroleum Feedstock equation (equation 4) shows a significant relationship between the demand for petroleum feedstocks and expected output although the other independent variables are insignificant. We do not find the lack of a significant price coefficient altogether surprising bearing in mind that petroleum feedstocks are an essential item in the production of basic chemicals, but one would have expected either the time trend or the stock of plant and machinery to have been more significant in that they may represent improvements in efficiency due to improved technology. The own price elasticity of Petroleum Feedstocks is -0.2 whilst Petroleum Feedstocks appear to be highly elastic with respect to output.

3.5 As it stands the Capital Equation (equation 5) cannot be estimated using OLS because it is non-linear. We used an iterative procedure, trying varying values for the coefficient of the adjustment parameter $\gamma_{KK}/\gamma_{\dot{K}\dot{K}}$ within the range from 0 to 1, to determine a value which when used in the regression equation minimised the sums of squares of residuals. Specifying a value for $\gamma_{KK}/\gamma_{\dot{K}\dot{K}}$ enabled us to calculate the adjustment parameter, m, for each year and then to transform the dependent variable as follows

$$\frac{\Delta K}{M} + K_{-1} = \alpha_K + \gamma_{KE}\,PE + \gamma_{KF}\,PPF + \gamma_{KL}\,PL + \gamma_{KQ}\,Q + \gamma_{KK}TAX \qquad (8)$$

The equation is now linear and can be estimated using OLS.

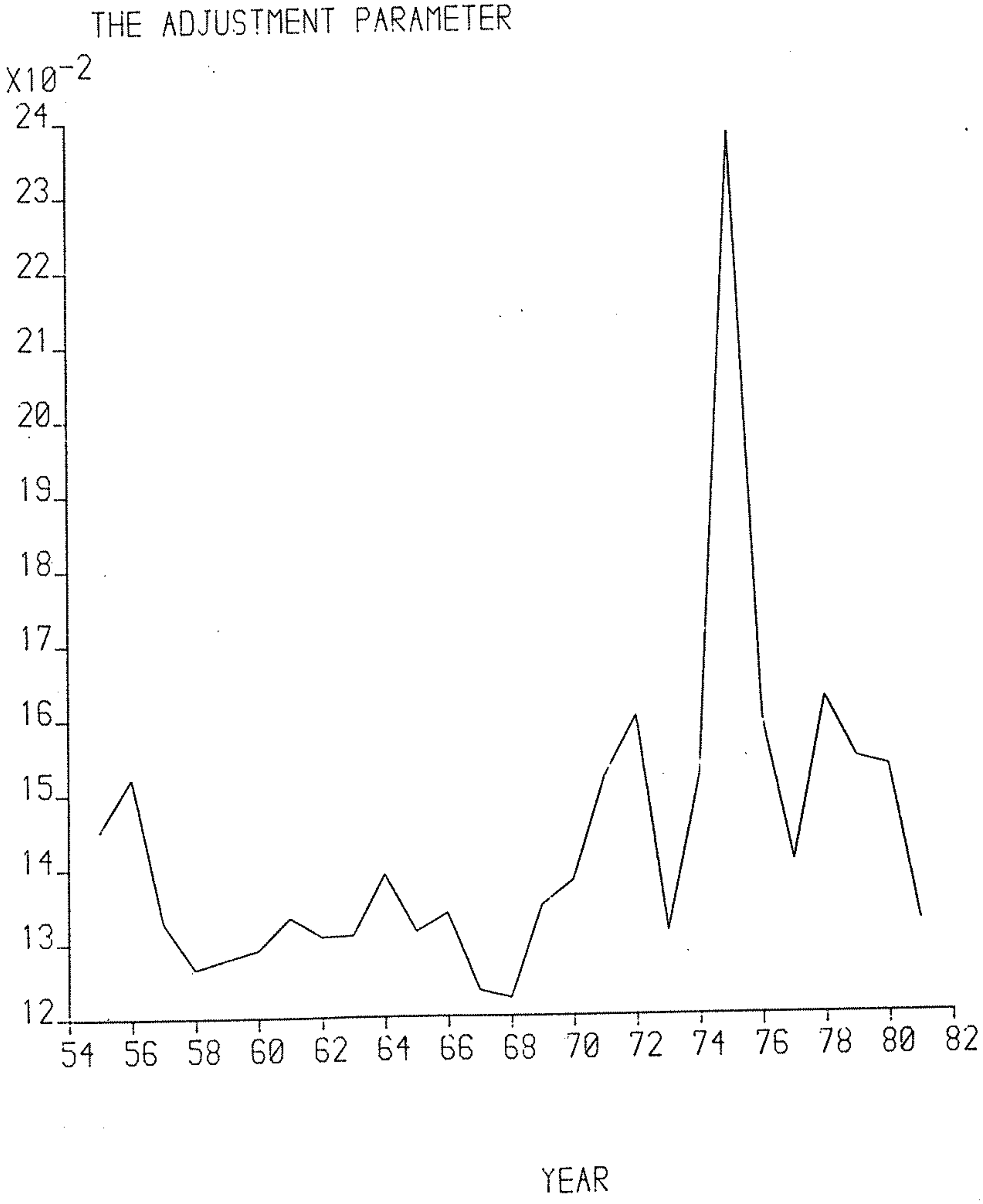
As may be seen from the estimates presented in Table 4 the price of labour was not found to be a significant explanatory variable in the capital equation and its negative coefficient confirms that little evidence could be found for capital/labour substitution in the period. The coefficient of the price of energy on the other hand was positive indicating capital energy substitution in the long run.

Figure 2 shows the values of the adjustment parameter, m, and its movements throughout the period. The adjustment parameter, m, is of course very sensitive to changes in the real rate of interest, R. We can see that in 1975 m appeared to increase sharply, this was due to the fall in the real rate of interest caused by the very high level of inflation in that year. The average value for m over the whole period is 0.1432.

Actual v Expected Output Effects

As the results for model 2 in Table 5 show, the energy equation is somewhat improved by using actual Q, rather than $\hat{Q}$ the R^2 is higher and the D.W. statistic is now in the inconclusive region which implies that although there is not conclusive evidence of 1st-order serial correlation we cannot reject the possibility of it being present. Output is now significant with a t-ratio of 2.43 as compared with 1.11 for Model 1.

FIGURE 2


THE ADJUSTMENT PARAMETER
X10^{-2}
24
23
22
21
20
19
18
17
16
15
14
13
12
54
56
58
60
62
64
66
68
70
72
74
76
78
80
82
YEAR

The feedstock equation is also improved by including actual output. The main change here is that the price of Petroleum Feedstocks becomes more significant as does the time trend. Again the fit improves.

The capital equation on the other hand seems to have been better using the expected output variable. The price effect of labour is however still insignificant. A look at the D.W. statistics for both models shows that in some of the equations there is some question regarding the existence of 1st-order serial co-ordination, particularly the energy and feedstock demand equations. The next stage in our analysis was to try an autocorrelation correction procedure using maximum likelihood methods, but the results from this were not very satisfactory.

3.5 The Model as a Whole

Some impression of how well the model behaves as a whole may be gained by tracing the effects of an increase in the price of energy, cet. par. There is an immediate negative impact on the demand for energy through equation (3). The positive coefficient on the energy price in the capital equation (5) leads to extra investment reflecting the substitutability between capital and energy. Indirect effects now appear as energy demand is affected (positively) by the increase in the capital stock (K_{-1}). The demand for feedstock is, on the contrary, affected negatively by this growth in capital equipment. Further effects may be traced through the price and output expectation equation. Expected prices fall with the growth in capital stock under conditions of constant demand for output (equation 1). Expected output falls in response to lower expected chemical prices (equation 2) and finally causes some reduction in the demand for energy. The net effect on the demand for energy depends crucially on the magnitudes of the estimated coefficient since all their signs are correct.

4. The Development of UK Chemical Energy Demand to Year 2000

One of the practical advantages of having a small subsector model without explicit links to any complete model of the economy is that one can explore a wider range of possible futures. Fewer of the exogeneous variables are predetermined with the larger model or are linked through complex and devious routes whose ultimate destinations are not discernable of the analyst. Even with a small model, however, conditional projection must take into account

(1) The likely relationships between the exogenous variable. Thus for example although PE and UKCGDP do not appear together as exogeneous variables in any one equation there is little doubt that they have interacted historically. It would be imprudent to project simultaneous rapid positive growth in both variables. One way of determining such links is to examine the correlation between growth rates of all exogenous variables in the model over the sample period. On the basis of significant correlations certain links can be established as follows.

NEGATIVE	POSITIVE	INDETERMINATE
UKGDP X PE PE X PPF PE X PPF UKGDPX	PE X PL	PE X RF, TAX UKCGDP, PL,

In all the scenarios, these directional relationships are preserved although judgement is used to determine the exact nature of the relation.

(2) Changes in technologies, etc. which are known to be imminent, must be taken into account in using the model for forecasting.

In this connection the industry's press publishes details of all new plant building programmes in the chemical sector distinguished by type of product. From this data it is possible to build up a picture of which subsectors have been most adversely affected by recent plant closures and in addition those sectors where growth is to be expected in the future. From table (6) we see that more than 6% of capacity in chemicals production has been closed since 1980 (1,771 tonnes) of which almost 67% consisted of highly energy intensity units. This reduction will be more than made up if planned additional units come on stream by 1985 (2630 th. tonnes). These units are however because of their highly energy intensive nature likely to be especially vulnerable to competition from new facilities in OPEC countries (such as Saudi Arabia) where energy prices are maintained below market levels. We can use the model to investigate the energy implications of the ultimate closure of this capacity (say a 9% reduction in HI with a 3% reduction in LI capacity).

TABLE 6

CHEMICALS OUTPUT CAPACITY - EXISTING, CLOSED AND PLANNED

	Thousand tonnes	
Output capacity (1980)	29,500	
Capacity of Plants Closed between 1980 and 1983	1,771	
of which High Energy Intensity		1,178
Low Energy Intensity		593
Planned Additional Capacity	2,630	
High Energy Intensity		2,300
ICI Ag. Div. - Ammonia Plant		500
UKF Ince - Ammonium Nitrate		500 (1984)
ESSO Chemicals - Mossmoran Ethylene		500 (1985)
ICI Ag. Div. - Methanol Plant		800
Low Energy Intensity		330
ICI Ag. Div. - Nitric Acid		330 (1984)
ISC Chem. - Hydrogen Fluoride		-
Albright & Wilsons - Phosphoric Acid Plant		-
Net Potential Expansion over 1980 (excluding completions 1980 - 1983)	859	

Source: Chemfacts UK 1980 and 1983

We investigate two scenarios. In the first scenario all exogenous variables are set to grow at rates representing the averages achieved in the period 1954-1981. We assume however a 1%* per annum improvement in energy efficiency. The results are shown in Table 7. In the second we let capacity fall by 6% and reduce the output effect in the ratio of 2:1, intensive to non intensive production. At the same time we let real interest rates rise by 10% over the 20 year period to reflect pessimism about the ability of governments to control public spending in the long term. Each projection incorporates the effect of one oil price shock although the overall increase in prices is kept at 1954-1981 rates.

The most important results are

(1) In both scenarios, energy demand by the chemicals sector is expected to be greater in both 1990 and 2000 than in 1981. The effect of the capital stock reduction, and reduction in energy intensity is to reduce average growth over the period from 1.53 to 0.58 i.e. by 2/3.

(2) The capital stock expands more rapidly than energy demand - at 4.15% p.a. over the period. The initial capital reduction is made up in the second decade so that both scenarios produce identical stocks in 2000.

(3) The most significant change occurs in feedstock demand. In both scenarios feedstock use continues to grow in the

---

* the actual decline in E/Q over the period 1954-1981 was 1.88% p.a. However since 1970, very little further decline in intensity has occurred.

TABLE 7

ENERGY AND FEEDSTOCK DEMAND TO 2000

(CHEMICALS INDUSTRY)

	1981		1990	2000	AVERAGE GROWTH RATES 81/90	81/2000
ENERGY (mn therms)	3980	(1)	4504	5242	1.38	1.46
		(2)	4507	4279	0.20	0.31
FEEDSTOCK (mn therms)	2035	(1)	2521	2143	2.41	0.27
		(2)	2399	1757	1.85	-0.77
PLANT AND MACHINERY (£ million)	12084	(1)	16494	26158	3.52	4.15
		(2)	16334	26154	3.41	4.15
OUTPUT (1975 = 100)	109		148	191	3.46	3.0
GDP (1975 = 100)	104.5		124.9	155.3	2.0	2.1

(1) Scenario 1
(2) Scenario 2

> 1981-80 period although at a lower rate under scenario 2 (1.85 compared with 2.41 for scenario 1). Peak use is achieved early in this period and thereafter declines, until by 2000 under scenario 1, growth of only 0.27% p.a. (5.3 m) is achieved. Under scenario 2, feedstock use actually declines to 86% of its 1981 level by 2000. This is due to some extent to the negative impact of price changes but mainly to technological improvements in energy efficiency.

It would also be possible to develop scenarios to illustrate an expanding chemical sector. Such a situation might, according to our model, be achieved by a contribution of lower taxes, lower real interest rates and lower energy prices provided that parameter stability could be ensured. The lack of empirical evidence for the rational expectations hypothesis of the model does not however inspire conficence in this direction. In any case the cost of such a policy would be to add to the pressure on energy resources and hence energy prices in the long run.

REFERENCES

1 "Chemicals, Contraction or Growth". Chemicals EDC sector report. National Economics Development Office 1980.

2 Ringwald R M, "Energy and the Chemicals Industry" Chemistry and Industry 1 May 1982 p.281-286.

3 Berndt E R, Russ M A and Wareman L (1979) "Dynamic Models of Costs of Adjustment and Interrelated Factors Demands with an Empirical Application to Energy Demand in U S Manufacturing". Discussion Paper No 79-30. Dept. of Economics, University of British Columbia.

4 McCallum B T, (1976) "Rational Expectations and the Natural Rate Hypothesis. Some Current Estimates". Econometrica 44. 43-52. See also Sheffin S M "Rational Expectations". Cambridge Survey of Economic Literature. 1983.

APPENDIX

A Discussion of the Variables Used in the Model

This section contains a brief discussion of the data used in the estimation of the model and highlights some of the associated problems.

We begin with the endogenous variable, E, total energy consumption in the UK Chemical Industry. There has been much discussion over the problem of aggregating the consumption of individual fuels into total energy consumption. For the purposes of this model we have chosen to aggregate the fuels on the basis of their thermal content unadjusted for thermal efficiencies. The justification for this approach stems partly from the fact that the data is readily available in this form, but also because it is possible that the individual fuel prices themselves may reflect the differences in thermal efficiencies.

The data itself was taken from the UK Digest of Energy Statistics (1) but the problem here is that the official statistics do not differentiate between the use of Natural Gas as a fuel and as a feedstock. Almost fifty per cent of the gas supplied to the Chemical Industry is used for feedstock purposes and we felt that it was important to try and separate this information out and include the N.Gas Feedstock figures in the feedstock demand equation.

Some estimates of the consumption of Natural Gas for feedstock purposes were available from the European Council of Chemical Manufacturers' Federations (CEFIC) (2) and we used these to calculate the total non-feedstock energy consumption. We used this data for our initial estimation of the model but found the results to be rather unsatisfactory. In fact we did have some difficulty in reconciling the CEFIC data with the official statistics and so in the light of this we returned to the original data as given in the digest. Because of this the feedstock demand equation is purely the demand for petroleum feedstocks, which is mainly Naptha but includes some Propane, Butane and Fuel Oil, this data was taken from the UK Digest of Energy Statistics.

The corresponding input price for energy to the Chemical Industry is exogenously determined. We calculated a Divisa Price Index using the prices of individual fuels to the manufacturing sector as a whole and weighting them according to the quantities of each fuel used by the Chemical Industry. For the price index of Petroleum Feedstocks we used the import price of light oil and spirits as a proxy for the price of Naptha. Ideally one would have preferred to use the contract price for Naptha but this is not available.

The price index for Labour was calculated by dividing the expenditure by the Chemical Industry in any one year on Wages and Salaries, as given in the National Income and Expenditure Blue Book, by the number of employees in that year to give an average price of labour for the Chemical Industry. The model requires that all the price indices be normalised with respect to the price of non-energy materials. We have used the Wholesale Price Index for Materials and Fuels Purchased. Obviously this series is not strictly non-energy materials but a closer check on the composition of the series showed that the only energy included in the series is Naptha. It would be possible to have the series recalculated to exclude Naptha but at some cost, and so for the time being we have used the series as it stands.

One of the most important variables in the model is the Output variable, Q, which is endogenously determined. To use the Index of Production for the Chemical Industry would not adequately reflect the changing relative importance in terms of energy intensity of the different sectors of the industry. This is (particularly) important for forecasting purposes since, if the highly energy intensive sectors were to decline then this would have a downward effect on the overall energy demand. Table A1 shows the energy intensities of the different sectors of the industry. Among the highest in terms of therms of energy used per £ sales are Fertilizers, Dyestuffs and Pigments, Inorganics, Other Chemicals and Organics. We have classified the sector into two categories, the highly energy intensive sectors i.e. those listed above and the less energy intensive sectors, being the remainder. For each of these two categories we calculated a separate index of production and included them both in the model. The results were not at all meaningful, however, and this was probably due to the high level of multicollinearity between the two series. The next

TABLE A1

CHEMICALS OUTPUT

Weights Given to Intensive and Less Intensive Sectors

	1980 Energy Use M. Therms	 Sales £m.	Weight Therms/x100.0 £ Sales
Intensive			
Organic Chemicals	930	1455	63.9
Inorganic	650	648	100.3
Other Chemicals	630	820	76.8
Dyestuffs & Pigments	260	223	116.6
Fertilizers	790	363	217.6
Intensive Sector Weight	3260	3509	92.9
Less Intensive			
Pharmaceuticals	140	987	14.2
Toilet Preparations	10	366	2.7
Paints	30	451	6.6
Soaps and Detergents	50	453	11.0
Resins, Synthetic Rubbers & Plastics	250	1031	24.2
Misc. Chemicals	70	909	7.7
Less Intensive Sector Weight	550	4197	13.1
TOTAL	3810	7706	49.4

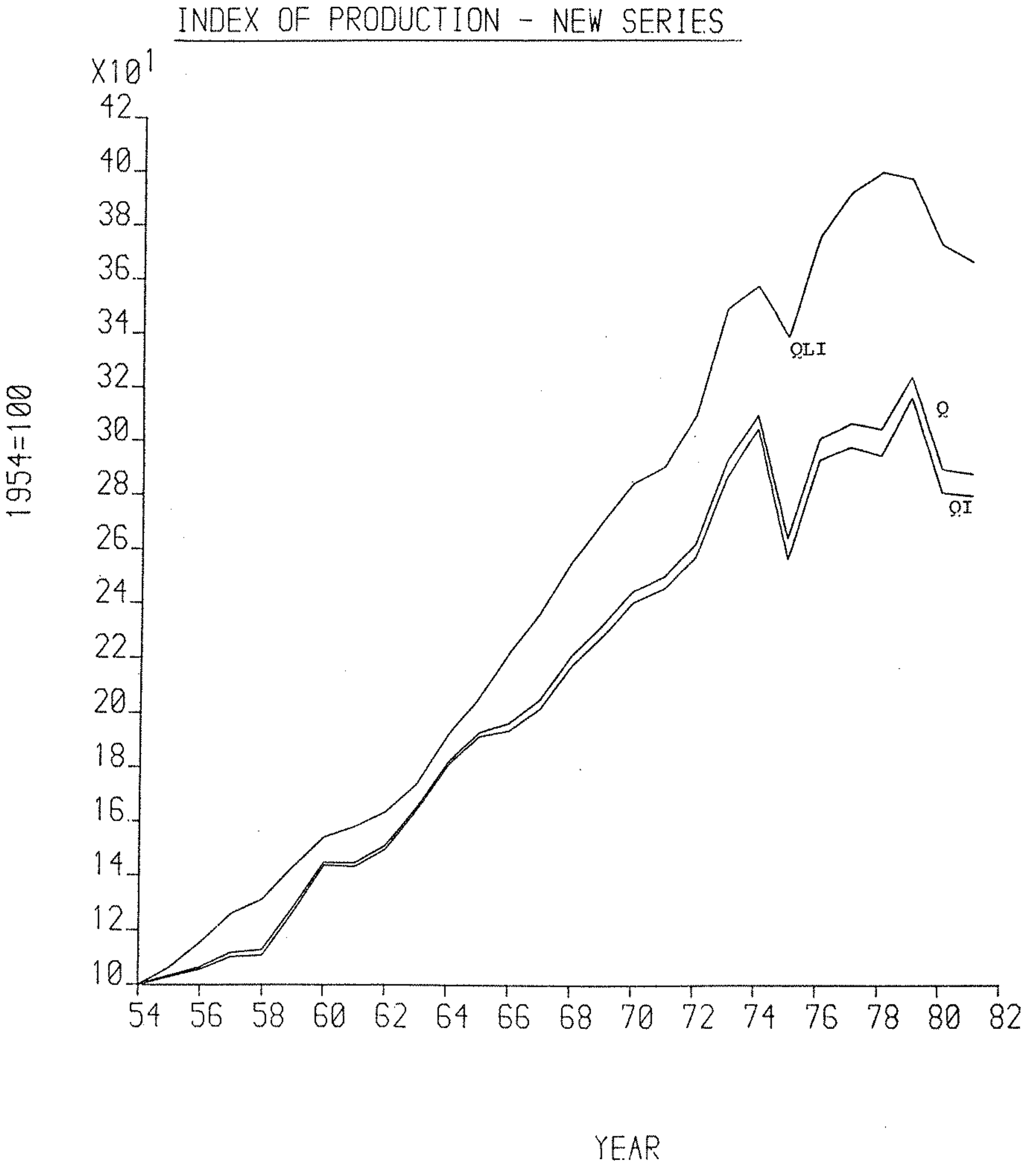
Source: Energy and the Chemical Industry - Jubilee Lecture. R M Ringwald C B E (Chemistry and Industry 1.5.82).

step was to create one series by weighting the index of production for both categories together using the total therms per £ Sales for each category as the weights. Figure A1 shows the output of the less-intensive sector, QLI and of the highly intensive sector, QI, Q is then the energy weighted average.

As our measure of the Capital Stock K, we have used the Gross Capital Stock of Plant and Machinery in the Chemical Industry. In fact, the term 'gross' is somewhat unsteady since the series does allow for the removal of depreciated assets by a "sudden death" process. This preserves the potential link between asset use and energy consumption prior to the disappearance of the asset. It is therefore preferable to the alternative measures of capital stock which employ gradual depreciation methods (e.g. the so called Net Capital Stock series) (3). Energy consumption was most related to the stock of plant and machinery although earlier estimates used total capital stock including buildings and vehicles. Feedstock consumption is of course only related to plant and machinery, therefore we decided to use only plant and machinery for the whole model.

The two remaining variables to be discussed appear only in the Capital Accumulation Equation. These are the rate of return and the user cost of capital. As far as the rate of return was concerned we used two approaches. Initially we assumed that the required rate of return by firms in the chemicals industry must equal the cost of funds available to them and that this cost is a weighted average of the individual sources of funds i.e. preference shares, debentures and equities.

FIGURE A1


INDEX OF PRODUCTION - NEW SERIES
X10^1
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
1954=100
54
56
58
60
62
64
66
68
70
72
74
76
78
80
82
YEAR
QLI
Q
QI

As an alternative estimate we also used the Minimum Lending Rate as the interest rate variable. This nominal rate was then used to calculate the User Cost of the flow of Capital Services as developed by Hall and Jorgenson (4). This user cost of capital services, P_K, is basically the real price of fixed assets to the Chemical Industry, $\hat{C}$, adjusted for depreciation, D, the rate of return R, corporation tax, T, and the present value of investment allowances, A, in the following way

$$P_K = C[(R + D)(1 - A)/(1 - T)]C$$

Initial estimates employing the user cost of capital did not give satisfactory results. Replacing the user cost of capital by its components failed to improve the estimates either. Only one component - corporation tax - proved to be significant and this was used in the subsequent analysis.

REFERENCES

1 Digest of UK Energy Statistics. UK Department of Energy. Annual Series.

2 Energy Statistics. CEFIC.

3 T Griffin. The Stock of Fixed Assets in the United Kingdom: How to Make Best Use of the Statistics. Economic Trends October 1976.

4 R E Hall and D W Jorgenson: Tax Policy and Investment Behaviour. The American Economic Review 1967.