The Demand for Energy by UK Manufacturing Industry

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1. INTRODUCTION

The question of the degree to which industrial consumers respond to fluctuations in the relative prices of energy and non-energy inputs has received considerable attention in recent years. Until the first major oil price shock of 1973/74 attention had focussed primarily on capital-labour substitutability, and the effect this has had in the determination of income shares and economic growth. In the past energy was not seen as a potential constraint to future growth, and was generally excluded from analyses of factor substitution and distribution. Along with raw materials it was regarded as a separable input which could be ignored in growth forecasting and macro-economic projections.[1] Not surprisingly this has now changed. The role of depletable resources in present and future production, and the influence of depletion profiles on the production and consumption possibilities of firms and individuals is seen as increasingly relevant. In particular, the question of whether consumption eventually approaches zero as resources are depleted, or whether growth is always feasible, has been analysed by several writers under assumptions concerning, for example, production techniques, differential extraction costs and the probability of developing backstop technologies.[2] Fundamental to this is the issue of capital-resource and capital-energy substitutability. Not surprisingly the feasibility of continued growth under energy constraints depends largely on whether capital and energy are substitutes. However the relevant empirical evidence is inconclusive. The relationship between energy and capital has been analysed in both econometric and engineering contexts. Berndt and Wood (1975) and Berndt and Jorgenson (1973) for U.S. industry, Fuss (1977) for Canada, Magnus (1979) for the Netherlands, and Swain and Friede (1976) for West Germany, all report energy-capital complementarity. Yet, Griffin and Gregory (1976) and Pindyck (1979) for the OECD area, and Cowing (1974), Ohta (1975) and Halvorsen and Ford (1979) for the U.S. report energy-capital substitutability. Naturally these studies differ in terms of model specification, method of estimation, time period, data set, etc, and some degree of variability in results is to be expected. The chief problem, however, has been to reconcile these results. It is clear that despite Berndt and Wood's (1979) recent attempts, in which they distinguish between gross and net capital-energy elasticity concepts, the question remains unresolved and a consensus has yet to be achieved.[3]

The issues of energy price sensitivity and efficient energy pricing are particularly important in the United Kingdom, an economy with relatively large supplies of indigenous energy resources. It is necessary to take into account the pattern of distortions within and between the energy-producing and energy-consuming sectors of the economy, as well as those social objectives which are deemed to be relevant. For this to be possible a reliable set of estimates, describing the sensitivity of demand for energy types to changes in their own and other factor prices, is required. Unfortunately as in the case of capital-energy substitutability the empirical evidence is mixed and the results difficult to interpret. Nordhaus (1976), Peterson (1979), Pindyck (1979), Uri (1979) and Wigley and Vernon (1982) agree that prices are important determinants of the pattern of energy demand in U.K. industry. However, estimates of the size and direction of influence, and the manner in which prices affect the process of adjustment of the stock of energy-using appliances through time, varies considerably. This theoretical distinction between the short and long run has been made operational in the past through the introduction of various ad hoc lagged adjustment mechanisms or through the use of pooled cross-sectional data, under the assumption that this represents equilibrium positions. It is possible that a significant amount of the variation in the reported results stems from these differences in approach. Recent work by Denny, Fuss and Waverman (1979) (hereafter DFW), and Berndt, Morrison and Watkins (1981) (hereafter BMW), has incorporated explicitly the costs of adjusting the stock of energy-using appliances into the energy demand decision, under the assumption of inter-temporal maximising behaviour by producers. In this case the distinction between the short and long run elasticities of demand which are derived from these models is based firmly on an explicit economic maximising process, rather than through an arbitrarily imposed lagged adjustment mechanism.

The purpose of this paper is to present estimates of demand elasticities for energy subtypes and for aggregate energy for U.K. manufacturing industry, using an adapted version of the DFW model. This seems the logical approach to take, since the

DFW methodology represents a significant advance in the modelling of energy demand. By assuming that firms maximise the present value of profits rather than minimise the present value of costs we are able to derive a system of variable-factor demand and fixed-factor accumulation equations, within which the possibilities for correlation between the explanatory variables are reduced and the statistical structure more appropriate. Results for the period 1948-81 confirm the influence of price on the demand for individual energy types and on the demand for energy as an aggregate input. In the long run the demand for gas and petroleum by U.K. industry appears to be significantly price elastic. Hence, despite this change in approach, energy demand by manufacturing industry is confirmed as price sensitive.

The plan of this paper is as follows. In Section 2 we present a brief diagrammatic representation of the distinction between short and long run, and between "partial" and "full" elasticities of demand for energy. This is done in order to provide a clear picture of what the derived elasticities actually represent. In Section 3 we present a model of the demand for energy as an aggregate input under the assumption that U.K. firms maximise the discounted value of profits, and an energy submodel based on a translog approximation to the underlying cost function. Results of estimation, policy implications and conclusions are contained in Sections 4 and 5.

2. LONG RUN AND SHORT RUN INTERFUEL AND FACTOR SUBSTITUTION:

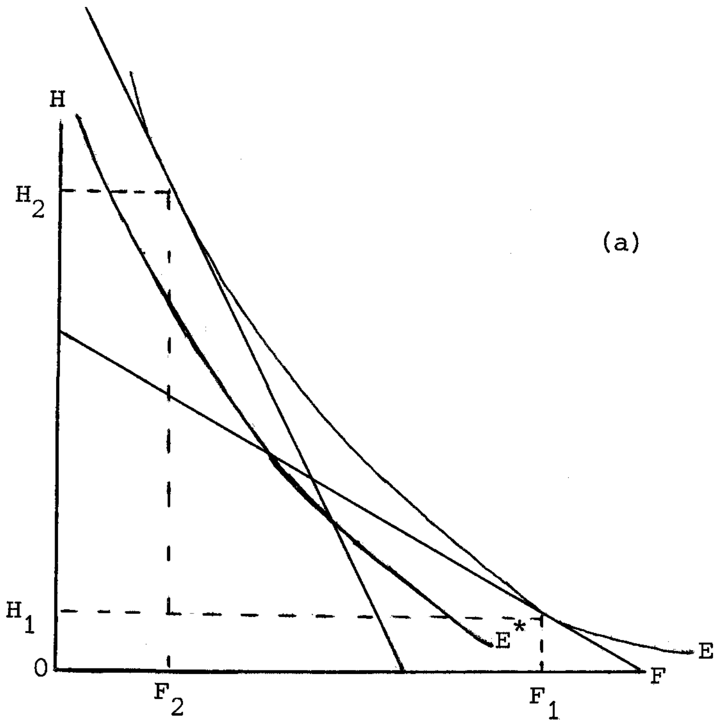
The classical, Marshallian definition of the short and long run is, of course, the period during which the firms' capital stock is fixed, and the period during which it is variable. However, in the evaluation of energy elasticities, capital is not the only input which is deemed to be held constant for analytical purposes, and this inevitably influences the interpretation of what measured elasticities actually represent. This is shown below.

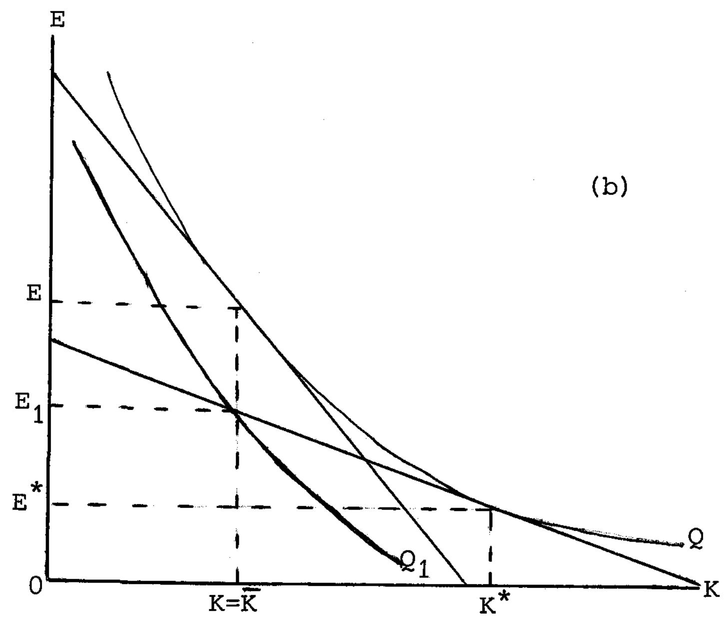
Figure 1 represents in panel (a) the choice between two fuel types, H and F, providing a constant output (input) of energy, E. Given initial fuel prices and assuming equilibrium we have a fuel mix of H_1 and F_1. Panel (b) depicts the energy-capital choice for a given output level, Q. Assuming initial equilibrium in fuel and factor mixes, factor proportions in this case are E (=E in panel (a)) and $K = \overline{K}$. Now allow the price of F to rise. This induces interfuel substitution, with H input increasing from H_1 to H_2 and F input declining from F_1 to F_2, for a constant aggregate energy output E.

The increased price of F means that the relative price of energy has also risen with respect to capital. The new equilibrium factor mix would be E*K* but this is infeasible due to the fixity of the capital stock $K = \overline{K}$. Given this change in prices the firm will initially reduce aggregate energy input to E_1, so that partial adjustment occurs through a lower output level Q_1. Once capital ceases to be fixed the equilibrium factor mix is feasible at a higher capital input K* and a lower energy input E* - shown also in panel (a). Note that the increased price of F has a twofold effect on the demand for F, firstly through interfuel substitution and secondly through factor substitution as a lower input of energy is demanded.[4]

The above analysis reinforces the point that measured demand elasticities may in fact measure different things. If a measure of the responsiveness of a fuel to a change in its price is required then a simple partial price elasticity of the type $\partial \ln E_H / \partial \ln p_{EH}$ is insufficient, since it will represent only interfuel substitution. The full price elasticity will take into account the influence of the changed fuel price, p_{EH}, on total energy demand, E. The full elasticity will therefore be greater than the partial elasticity. Obviously for forecasting purposes, the full price elasticity is the most relevant. Similarly if long run projections of energy or fuel demand are required then the influence of the path of capital accumulation must be included.

Figure 1





3. A DYNAMIC MODEL FOR ENERGY DEMAND BY U.K. INDUSTRY:

The discussion in Section 2 emphasised the fact that the demand for energy is a dynamic process; it depends on both the rate at which the existing stock of equipment is used, and on changes in the stock. Hence a model which captures the essence of the inter-temporal influence of short run capital fixity and long run capital accumulation on the demand for energy seems the most appropriate. In the DFW model the cost of adjustment is explicitly incorporated. By solving for the conventional factor requirements function an objective functional is derived, which minimises the discounted value of (short run) variable and fixed costs. Then, through the specification of a functional form for the normalised restricted cost function, demands for variable inputs and accumulation equations for the quasi-fixed inputs are derived which depend on variable input prices, output, and the stock of quasi-fixed inputs.

A problem with the DFW methodology is that the labour demand schedule is derived as the difference between total variable cost and energy and materials costs. This yields an estimation form which contains several interactive terms in capital stock and output, and hence introduces a high degree of correlation between the explanatory variables. It is possible to avoid this problem through a simple change in the structure of the objective functional.

The DFW model assumes that firms minimise the present value of costs, i.e.

$$\min L = \int_0^{\infty} e^{-rt} \{G(\underline{w},K,\dot{K},Q,t) + u^1 K\} dt \qquad (1)$$

where $G(.)$ is the restricted variable cost function, incorporating the short run cost minimisation solution, and u^1K is fixed cost, defined as the product of user cost of capital, u^1, and capital in place, K.

A profit maximising alternative to (1) is

$$\max J = \int_0^{\infty} e^{-rt}\{\pi(\underline{p}^1,K,\dot{K},Q,t) - u^1K\}dt \qquad (2)$$

i.e. firms maximise the difference between variable profits, $\pi(.)$ and fixed costs u^1K. In turn $\pi(.)$ is defined over prices, $\underline{p}^1$, capital-in-place, K, the rate of change of capital stock, $\dot{K}$, output, Q, and time, t. DFW normalise (1) by taking labour price from the input price vector, $\underline{w}$. Instead we normalise (2) by removing output price from the price vector $\underline{p}^1$. The result is an objective functional

$$\max J^* = \int_0^{\infty} e^{-rt}\{\pi^*(\underline{p},K,\dot{K},Q,t) - uK\}dt \qquad (3)$$

where $\pi^*(.)$ is now a normalised restricted profit function (Lau, 1976). Maximisation of (3) proceeds by choosing the time path of the control variable, $\dot{K}$, conditional on the state variable level, K, and output Q, at time t. Solving (3) and evaluating at the steady-state, $K = K^*$ and $dK/dt = \dot{K} = 0$, gives

$$\pi^*_K(\underline{p},K^*) = -[r\pi^*_{\dot{K}}(\underline{p},K^*) + u] \qquad (4)$$

where as usual subscripts refer to derivatives. Equation (4) says that at the steady-state the marginal benefit (in terms of profit) of changing the capital stock should equal the marginal cost (in terms of profit foregone; in this case adjustment plus user cost). Following DFW (p. 235) we make use of Treadway's (1971, 1974) result, that changes in the capital stock can be generated from (4) as a solution to the linear differential system

$$\dot{K} = \lambda \ (K^{*} - K) \tag{5}$$

where λ satisfies the condition

$$-\pi^{*}_{\dot{K}\dot{K}}\lambda^{2} - r\pi^{*}_{\dot{K}\dot{K}}\lambda + (\pi^{*}_{KK} + r\pi^{*}_{K\dot{K}}) = 0 \tag{6}$$

and provides a solution for λ of

$$\lambda = -\frac{1}{2}\left[r - \left(r^{2} + \frac{4(\pi^{*}_{KK} + \pi^{*}_{K\dot{K}})}{\pi^{*}_{\dot{K}\dot{K}}}\right)^{\frac{1}{2}}\right] \tag{7}$$

Mortensen (1973) has shown that under these conditions the steady-state capital demand equations are long run demand equations generated from static profit maximising behaviour. This means that it is possible to distinguish between short and long run demand elasticities, since the latter now depend upon the path of capital accumulation. The diagrammatic treatment of Section 2 indicated how important a feature this is for any model attempting the accurate identification of energy demand elasticities. In order to derive expressions for variable input demand and for capital accumulation it is necessary to assume a specific functional form for $\pi^{*}(.)$. To avoid placing unnecessary <u>a priori</u> restrictions on the technical parameters, we take a quadratic expansion of $\pi^{*}(.)$ evaluated at first and second partial derivative values. This gives the form

$$\pi^{*} = v_{o} + \sum_{i} v_{i}p_{i} + v_{K}K + v_{Q}Q + v_{T}t + \tfrac{1}{2}\sum_{i}\sum_{j} v_{ij}p_{i}p_{j} + \Sigma v_{ik}p_{i}K + \sum_{i} v_{i\dot{k}}p_{i}\dot{K} + \sum_{i} v_{iQ}p_{i}Q + \sum_{i} v_{iT}p_{i}t + \tfrac{1}{2}(v_{KK}K^{2} + v_{\dot{K}\dot{K}}\dot{K}^{2} + v_{QQ}Q^{2}) + v_{K\dot{K}}K\dot{K} + v_{KQ}KQ + v_{\dot{K}T}\dot{K}t + v_{\dot{K}Q}\dot{K}Q + v_{\dot{K}}\dot{K} \tag{8}$$

where $i,j = K,L,E$; $v_{ij} = v_{ji}$, $i \neq j$. Applying the derivative property to (8) to derive the demand for variable factors, evaluating the profit function at the steady-state, $\dot{K} = 0$, assuming that the time derivative of capital stock can be approximated by $\Delta K = K_t - K_{t-1}$ and that output produced in period t is produced by capital-in-place in K_{t-1} we have variable factor demand equations[5]

$$E = v_E + v_{EE}p_E + v_{EL}p_L + v_{EK}K_{t-1} + v_{Et}t + V_{EQ}Q$$
$$L = V_L + V_{LL}p_L + v_{EL}p_E + v_{LK}K_{t-1} + v_{Lt}t + v_{LQ}Q \qquad (10)$$

Imposing the implicit steady-state restrictions we have the steady-state capital stock, K^*, from (4)

$$K^* = -1/V_{KK}[v_K + v_{EK}p_E + v_{LK}p_L + V_{QK}Q + v_{tK}t + u] \qquad (11)$$

and substituting this into (5) gives the optimal path of capital accumulation

$$\Delta K = -\lambda[1/v_{KK}(v_K + v_{EK}p_E + v_{LK}p_L + v_{QK}Q + v_{tK}t + u) - K_{t-1}] \qquad (12)$$

where λ is as defined in (7) and is recognisable as the amount by which the in-place capital stock is adjusted, during the period of production, toward its optimal level. As in stock-adjustment type models a value of λ close to zero indicates sluggish adjustment and a value close to unity suggests a rapid response.

3:1 INTER-FUEL MODEL :- Equations (10) and (12) represent our estimation model for factor demand. However we also estimated an inter-fuel model to examine the demand elasticities, both own and cross-price, that exist between fuels. These incorporate the influence of changes in total energy demand - the full price elasticity - and the influence of changes in the capital stock - the long run full price elasticity. To do this we took a translog approximation to the cost function H($\underline{p}$, K, Q, t) where $\underline{p}$ is a vector of fuel prices. This gives

$$\ln C = \beta_o + \sum_h \beta_h \ln p_{Eh} + 1/2 \sum_h \sum_f \beta_{hf} \ln p_{Eh} \ln p_{Ef} + \sum_h \beta_{hk} \ln p_{Eh} \ln K +$$

$$\sum_h \beta_{hQ} \ln p_{Eh} \ln Q + \sum_h \beta_{ht} \ln p_{Eh} t \qquad (13)$$

where h and f are fuel types and p_{Eh}, p_{Ef} represent the prices of coal, gas, electricity and petroleum. Using Shephard's Lemma

$$\partial \ln C/\partial \ln p_{Eh} = S_{Eh} = \beta_h + \beta_{hf} \ln p_{Ef} + \beta_{hk} \ln K + \beta_{hQ} \ln Q + \beta_{ht} t \qquad (14)$$

and S_{Eh} represents the share of fuel type h in total energy costs. (14) was estimated under the usual adding-up, homogeneity and symmetry restrictions

$$\sum_h \beta_h = 1, \quad \sum_h \beta_{hf} = \sum_f \beta_{hf} = 0, \quad \beta_{hf} = \beta_{fh}, \; h \neq f.$$

We are now in a position to derive from this system of equations a number of demand elasticities which correspond to the concepts illustrated in Section 2. For example short run partial own and cross-price elasticities for fuels can be expressed as[6]

$$\varepsilon_{hh} = \left[\frac{\beta_{hh} + S_h(S_h - 1)}{S_h^2}\right] S_h , \quad \varepsilon_{hf} = \left[\frac{\beta_{hf} + S_h S_f}{S_h S_f}\right] S_f \qquad (15)$$

Full short run elasticities will allow for the impact of changed aggregate energy demand on individual fuel demand, i.e.

$$\varepsilon^*_{hh} = \frac{p_h}{E_h}\left[\frac{\partial E_h}{\partial p_{Eh}}\Big|_{\bar{E}} + \frac{\partial E_h}{\partial E} \frac{\partial E}{\partial p_E} \frac{\partial p_E}{\partial p_{Eh}}\right] \qquad (16)$$

Denoting ε_{EE} as the own price elasticity of demand for aggregate energy, (15) can be written as

$$\varepsilon^*_{hh} = \varepsilon_{hh} + \varepsilon_{EE}S_h \quad , \quad \varepsilon^*_{hf} = \varepsilon_{hf} + \varepsilon_{EE}S_f \tag{17}$$

Finally the long run equivalents to the above can be derived when the capital stock is free to vary

$$E_{hh} = \varepsilon^*_{hh} + \varepsilon_{KE}[\beta_{hK} + v_{EK}\frac{K}{E}S_h] \tag{18}$$

where ε_{KE} represents the elasticity of capital with respect to the price of energy. Hence (18) incorporates the effects of inter-fuel <u>and</u> inter-factor substitution.

Aggregate elasticities may be defined in a similar manner. Short and long run own-price elasticities for energy are

$$\varepsilon_{EE} = \frac{P_E}{E}\left[\frac{\partial E}{\partial p_E}\Big|_{\bar{K}}\right] \text{ and } E_{EE} = \frac{P_E}{E}\left[\frac{\partial E}{\partial p_E}\Big|_{\bar{K}} + \frac{\partial E}{\partial K}\frac{\partial K}{\partial p_E}\right] \tag{19}$$

which in the above model corresponds to

$$\varepsilon_{EE} = \frac{P_E}{E}v_{EE} \quad , \quad E_{EE} = \frac{P_E}{E}\left[v_{EE} - \frac{v^2_{EK}}{v_{KK}}\right] \tag{20}$$

4. RESULTS:

We estimated system (14) and equations (10) and (12), subject to the appropriate restrictions, from aggregate U.K. manufacturing data for the period 1948-81. The definition and construction of variables and sources of data are contained in an appendix at the end of the paper. Both the aggregate and inter-fuel models were estimated using full-information maximum likelihood techniques, in order to take account of possible contemporaneous correlation of disturbances, and to remove the arbitrary nature of satisfying the adding-up restriction through deletion of the residual estimating equation (Barten, 1969). Table 1 presents the results. Several features emerge.

(i) The influence of technical change has been to encourage the use of electricity and gas as fuels at the expense of coal and petroleum. This is broadly confirmed by Department of Energy statistics, which indicate that over the sample period coal consumption fell by approximately 80% whereas gas and electricity usage increased significantly. Petroleum consumption rose rapidly through the 1960s and early 1970s, but had fallen to almost half the 1973 level by 1981.

(ii) Significant cross-price relationships exist between petroleum and gas, electricity and gas, electricity and coal, and coal and gas. Similarly all fuels are responsive to changes in their own price.

(iii) There are significant economies in the use of gas as a fuel, i.e. as the level of output increases the share of gas in total fuel expenditure falls. This is consistent with a range of increasing thermal efficiency which has been observed in several industrial applications.

(iv) Increases in capital-in-place imply increases in the use of electricity and petroleum, and reductions in the use of coal and gas. However this must be treated with caution because of the time-trended nature of the fuel and capital stock data.

(v) The adjustment of capital stock toward its optimal level is slow. Approximately 16% of the differential between beginning-of-year and optimal capital stock is eradicated after one year. A value of $\lambda = 0.16$ implies that eight years after a change in energy prices one quarter of the final adjustment is still to come. Hence although U.K. industry may have fully adjusted to the initial 1973/74 shock, it appears that the full effects of 1978/79 have yet to be felt.

(vi) Aggregate energy demand is responsive to changes in its own price. There is some (limited) support for energy-labour substitutability.

Generally speaking the performance of the aggregate model is disappointing. The insignificance of several of the capital accumulation equation terms limits the extent to which we can add to the energy-capital debate. In addition the serial correlation problems so common to this type of system-wide model are present. DFW and BMW do not report DW statistics. However in the closely related study by Berndt and Morrison (1981) it is clear that serial correlation is present in several of the estimating equations. To the extent that such problems are caused by mis-specification and/or omitted variables it seems likely that the statistical performance of the model would improve with a disaggregation of the labour variable into its quasi-fixed (high-skill) and variable (unskilled) components. Unfortunately the labour data for the sample period are unavailable. These problems, however, should be borne in mind when interpreting the following elasticities.

Table 2 presents elasticity estimates, derived from the formulae presented earlier and based on the parameter estimates contained in Table 1. We find that in the short run, coal, gas and petroleum are negatively related to their own price but, not surprisingly, demand is inelastic. A 1% increase in the price of coal will, ceteris paribus, reduce consumption of coal in manufacturing by nearly 0.2%. Similarly 1% increases in the prices of gas and petroleum induce cuts in consumption of 0.69% and 0.29% respectively. Hence in the short run industry is somewhat responsive to shifts in own fuel prices.

In addition there are significant cross price relationships between petroleum and gas, electricity and gas, coal and gas, and electricity and coal. In particular a 1% rise in the price of gas yields a 0.1% increase in demand for petroleum, a 0.25% increase in demand for electricity and a 0.47% increase in demand for coal. Note also that an increase in the price of coal leads to a decrease in the demand for electricity. This complementary relationship may suggest problems with our electricity price variable. Several writers have emphasised the need for a marginal as well as average explanatory price variable for electricity demand to account for the multi-tariff schedules that industrial (and domestic) consumers face.[7]

Table 2 also shows estimates of long run own price elasticities. As expected, these are greater than the short run equivalents, and in the case of petroleum and gas suggest considerable elasticity of demand once sufficient time has elapsed for capital stock to be changed. Also shown is an estimate of the long run own price elasticity of demand for energy. Again this is greater than the short run, but note that the difference between the two is not statistically significant because of the insignificance of the v_{EK} and v_{KK} terms. Taken at face value a 1% increase in the price of energy results in an approximately 0.7% decrease in energy consumption.

Some of the results presented above have an intuitive interpretation. In the short run, substitution of energy by non-energy inputs suggests that manufacturing industry has adopted a technically more efficient use of a given stock of energy. This means that the technical efficiency of energy use has been brought closer to its thermodynamic limits. In the short run this can be done by a variety of conservation measures such as waste recycling, a more effective use of temperature and thermostat controls, and by other changes in the use of the stock of resources. In the long run such substitution will affect not only the <u>level</u> of energy resource use, of course, but also the <u>types</u> of resources and their associated conversion technologies.

It has been argued that substitution arising from a higher energy price is likeliest in response to a greater use of labour and (excluded) material inputs rather than in response to greater capital intensity.[8] If firms increase the materials-intensity of their operations through buildings insulation and measures designed to increase the technical efficiency of energy conversion then this will affect the labour market and explain some degree of the energy-labour substitution. Such job-creating effects of higher energy prices are likely to affect different segments of the labour market at different times. For example, it seems likely that the energy-related occupations will be first affected, and only later will unskilled labour feel any benefit.

The relatively low values of cross elasticities reflect the fact that in the short run most of any reduction in consumption for a given increase in the price of energy results from changes in organisational and infrastructural activities, rather than from shifts toward capital or labour intensive techniques. Such activities will include the technically more effective use of lighting and temperature controls and a more energy-efficient programming of production activity.

The relative size of own price elasticities reported in Table 2 generally confirm casual observation. Thus gas is seen as the most flexible fuel in the short run and its demand is elastic in the long run, though the estimate may be biased upwards as the result of a number of factors. For instance, we were unable to normalise for quality changes in gas production even though industrial consumers would, rightly, have perceived a significant improvement in the efficiency of natural over town gas, which would induce substitution as a result. In addition it is clear that since the introduction of natural gas consumers have expected its future price to be low, (and until recently these expectations were undoubtedly fulfilled), which would again induce substitution.

In similar vein a significant degree of substitutability between petroleum and gas and between gas and coal is observable in several industrial applications; and electricity is normally regarded as the least substitutable of fuels in the short and long run. In cases where lighting and appliances are concerned this is practically impossible without major modifications to the stock of capital.

Interestingly, several of the reported elasticities closely approximate earlier estimates. For example Wigley and Vernon (1982) find gas and petroleum to be price elastic in their estimation of a multinomial logit model, with magnitudes of the order -1.34 and -1.62 respectively. They report an extremely high solid fuel elasticity which appears biased upward by its low value in total fuel expenditure, whereas our long run estimate is heavily weighted downward by the negative influence of changes in capital stock on the demand for coal. Hence, whereas Wigley and Vernon's estimate is probably too high, ours is probably inaccurate as well. Pindyck (1979) reports an aggregate long run own price elasticity for the U.K. of -0.84. This again corresponds closely to ours of -0.7 (though the distinction between short and long run is statistically insignificant). Finally Nordhaus (1976) finds a long run elasticity of -0.88 using a geometric lag, and -0.73 to -0.95 using polynomial lags. So despite the fact that the present study has adopted a different methodology for the examination of energy demand elasticity it appears that there are several areas where there is a correspondence. This conclusion is made subject to the statistical reservations mentioned earlier.

5. POLICY IMPLICATIONS AND CONCLUDING REMARKS:

Reliable information concerning the responsiveness of energy demand to changes in prices is important for two reasons. First, it gives an indication of the degree to which energy policy is likely to be successful in meeting the specified objectives of government through the methods of pricing and demand management. Secondly it indicates the effect that changes in energy prices have on production. The results presented in this paper suggest that manufacturing industry in the U.K. is significantly responsive to the allocative signals of energy prices, and particularly so in the areas of domestically produced petroleum and gas. This makes the efficient pricing of these resources particularly important. It also implies that in several cases manufacturing industry is able to alter its fuel-mix substantially, which would mitigate to some extent the impact of any future price explosion on production. Moreover it appears that the effects of the past energy price shocks have yet to be fully realised. This paper has analysed the pattern of energy demand by manufacturing industry in the U.K. using a substantially different methodology from previous studies. Subject to several statistical reservations it seems significant that it is able to confirm most of the available information concerning the importance of price.

FOOTNOTES

1. An exception to this is the study by Barnett and Morse (1969) which emphasises the role of natural resources and the importance of substitutability in the production process.

2. See, for example, Dasgupta and Heal (1974) and Solow and Wan (1976).

3. Briefly, Berndt and Wood (1979) attempt to reconcile the evidence by grouping inputs into subfunctions. For instance by aggregating $K^* = f(K,E)$ and $L^* = h(L,M)$ they analyse the behaviour of K and E as the price of capital changes. It is possible for K and E to be gross substitutes (an increase in the price of capital increases the demand for energy) but net complements (the decrease in the price of capital lowers the cost of "utilised" capital K^* which is substituted for L^*). Hence the expansion effect may increase the demand for energy as the price of capital falls. An econometric examination of K-E relationships would merely reveal which is dominant, the gross substitution effect or the expansion effect. They conclude that the question is unresolved despite engineering evidence suggesting K-E substitutability.

4. The degree to which energy subtypes are substitutes will vary considerably in practice. In certain applications (particularly transportation) a single fuel may be the only feasible source of energy. In other cases there may be a large number of fuel-mixes which can yield a given energy input (output), however measured. Similarly the movement between fuels may or may not require changes to the existing capital stock. We have made the conventional assumption of a convex isoquant for fuel substitution in industry, but this is better interpreted not at a plant level but as an aggregate over a series of plants, all of which switch at different efficiencies. This diagrammatic analysis is therefore a simplification of an extremely complex technological, as well as economic, process.

5. These equations closely resemble those derived by DFW. However, because it is now possible to use the derivative property on $\pi(.)$ the labour demand schedule in (11) contains fewer terms, is easier to estimate, and is statistically more acceptable.

6. See Pindyck (1979) pp. 51-52.

7. See, for example, Taylor (1975). This emphasises a problem with taking a system-wide approach to fuel demand. Whilst there are gains in stochastic specification through the allowance for interdependent equation error terms, the cost is the restricted ability to model the specific features of demand for individual fuels. This trade-off is at the centre

of the single-equation - system-wide debate and is not limited to this study.

8. See LeBel (1982) pp. 296-297.

TABLE 1: PARAMETER VALUES FOR FUEL AND ENERGY MODELS*

ENERGY MODEL:	FUEL MODEL:	
V_{EE} = 0.2396 (0.1175)	β_{pc} = 0.0254 (0.0167)	DW_p = 1.1278
V_{EL} = 0.1346 (0.0802)	β_{gc} = 0.0523 (0.0089)	DW_g = 1.0668
V_{EK} =−0.0837 (0.3335)	β_{ec} = −0.2278 (0.0350)	DW_c = 1.2548
V_{EQ} = 0.4350 (0.1261)	β_{cK} = −0.2366 (0.0752)	
V_{ET} = 0.0049 (0.0225)	β_{cQ} = 0.0696 (0.0465)	
V_{LK} =−0.4215 (0.2046)	β_{cT} = −0.0097 (0.0034)	
V_{LQ} = 0.4948 (0.1193)	β_{pg} = −0.0613 (0.0168)	
V_{KQ} = 2.2467 (5.2411)	β_{pe} = −0.0619 (0.0448)	
V_{TK} = 0.4333 (0.0327)	β_{pK} = 0.5933 (0.1397)	
V_{KK} = 0.0151 (0.0327)	β_{pQ} = 0.1298 (0.0816)	
β = 0.1593 (0.0762)	β_{pT} = −0.0212 (0.0059)	
DW_E = 0.8056	β_{ge} = −0.0194 (0.0094)	
DW_L = 0.8369	β_{gK} = −0.3745 (0.0936)	
DW_K = 2.0624	β_{gQ} = −0.2097 (0.0554)	
	β_{gT} = 0.0234 (0.0029)	
	β_{eT} = 0.0075 (0.0021)	
	β_{eQ} = 0.0103 (0.0320)	
	β_{eK} = 0.0178 (0.0049)	

* Standard errors in parentheses.

TABLE 2: ELASTICITIES FOR FUEL AND ENERGY MODELS

FUEL MODEL:	FULL OWN-AND CROSS-PRICE ELASTICITIES OF DEMAND
$\varepsilon^*_{cc} = -0.1982^{**}$	$E_{cc} = 0.7006^{**}$
$\varepsilon^*_{gg} = -0.6932^{**}$	$E_{gg} = -1.4839^{**}$
$\varepsilon^*_{pp} = -0.2916^{**}$	$E_{pp} = -1.5132^{**}$
$\varepsilon^*_{ee} = 0.0951^{**}$	$E_{ee} = 0.1051^{*}$
$\varepsilon^*_{pe} = 0.2723$	
$\varepsilon^*_{pg} = 0.1014^{**}$	
$\varepsilon^*_{pc} = 0.6085$	
$\varepsilon^*_{eg} = 0.2543^{**}$	
$\varepsilon^*_{ec} = -0.3523^{**}$	
$\varepsilon^*_{gc} = 0.4687^{**}$	

ENERGY MODEL	
$\varepsilon^*_{EE} = -0.2336^{**}$	$E_{EE} = -0.6888$
$\varepsilon^*_{LE} = 0.2036$	
$\varepsilon^*_{KE} = -0.2611$	

* Significant at 90% level; ** Significant at 99% level.

Asymptotic standard errors for significance tests were estimated using Kmenta's (1971) approximation for non-linear coefficients. All elasticities were evaluated at mean values of variables.

DATA APPENDIX

All the data used in this study were taken from U.K. Government publications. Fuel consumption (on a heat supplied basis) and prices by category were taken from successive issues of the U.K. Digest of Energy Statistics, the Ministry of Power Statistical Digest, and for the earlier years, Stone and Wigley (1968). The user cost of capital variable is the static expectations, non-corporate tax equivalent of Hall and Jorgenson's (1967) derivation, calculated from the fundamental relationship between the price of new capital good and the discounted value of all future services derived from it. This is

$$u = q(r + \sigma)$$

where r is the rate of interest, σ the rate of replacement and q the price of capital equipment. Here q is taken as the implicit deflator in current and constant net capital expenditure data published in the NIE Blue Books. The rate of replacement is taken as a weighted average from Griffin's (1976) analysis of the useful lives of assets in sectors of U.K. industry. The rate of interest was taken to be bank base lending rate published in the IMF's Financial Statistics. Output data was taken from successive issues of Economic Trends, and employment data from the British Labour Statistics Historical Abstract and the Department of Employment Gazette. Gross capital stock at 1975 replacement cost were taken from the NIE Blue Books, and for earlier years were linked to data published in Armstrong (1979). All empirical work was conducted for U.K. manufacturing industry and did not include the iron and steel industry, since the published energy price indices are inapplicable to this sector.

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