Energy Demand in the US Manufacturing Sector

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Division Working Paper No. 1987-5
May 1987

Commodity Studies and Projections Division
Economic Analysis and Projections Department
Economics and Research Staff
The World Bank

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SUMMARY

1. The use of energy in the US manufacturing sector has been declining over the last two decades and the rate of decline has accelerated in the post-1973 period--the period of sharply-higher energy prices. There has been much debate over the contribution of various factors to this decline. In this paper we have attempted to disaggregate the total decline in energy use in the US manufacturing sector into three main components. We have found that the increase in energy prices was primarily responsible for the decline. We estimate the contribution of the change in energy prices to be as high as 62%. The contributions of technological change and the changes in output and its mix are estimated to be about 22% and 16%, respectively. To derive these estimates, three sets of energy demand models were specified for the sector to allow estimation of the own-price elasticities of demand for energy, the elasticities of substitution between energy and other factors of production, estimates of technological bias affecting input use and the impact of investment on energy utilization. Estimates were made for the total manufacturing sector as well as its 10 SIC sub-classifications.

2. The first set of models was specified with an appropriate almon lag structure to capture long-run effects of price changes. Model II introduced dynamics by using time-lagged values of the dependent variable as one of the regressors. A novel aspect of our analysis is that Models I and II also incorporated the effects of investment on the demand for energy. This was done through two-stage least squares estimation to reduce simultaneity bias. The predicted value of investment, estimated in the first stage of the two-stage

least squares procedure, was used in models I and II estimated in the second stage. The third specification is the transcendental logarithmic approach to estimating factor demand. The energy demand equation was derived from a three factor constant returns to scale production function, using the principles of duality theory. Technological change, defined as a reduction in cost per unit of output was also introduced in this specification. While all models have been estimated using time series data, the models for the total manufacturing sector have also used pooled cross-section and time-series data.

3. The magnitude of the output elasticity of the demand for energy varies depending upon the model specification. However, for each model, the short-run and long-run estimates are fairly close to one another for each industry sub group. For the total manufacturing sector the short-run output elasticity was estimated to be in the range of 0.6 to 0.75. In general, for the different industry sub-groups, the long-run income elasticity was estimated to be much lower than unity. The only exception to the rule is for the food, drinks and tobacco products industry where the income elasticity estimate is well above unity.

4. Our estimates point to the demand for energy in the US manufacturing sector being fairly price-elastic. Hence, prices will be an important determinant of the demand for energy and in allocating expenditure between factors of production. The short-run, own-price elasticity of demand for energy for the total manufacturing sector is estimated to be as low as -0.21 but with the long-run elasticity as high as -0.75. Among the industry sub-groups, the industries classified as chemical and allied products, non-ferrous primary and fabricated metals, and paper, publishing and printing appear to be least price-elastic--particularly estimates from Models I and II. On the other

hand, energy demand in the iron and steel industry is much more price-elastic. The own-price elasticity of demand for the iron and steel industry from the translog specification is estimated to be -0.98.

5. Our estimates of the elasticity of substitution between energy and other inputs show that substitution takes place between energy and other non-energy inputs, though it is somewhat limited. Our main finding is that energy and labor are strong substitutes within the total US manufacturing sector as well as in all the sub-classifications with the possible exception of the group classified as wood, lumber and furniture. Our results do not confirm decisively the controversial relationship between energy and capital. Within the total US manufacturing sector energy and capital are weak complements. Of the ten industry sub-classifications, energy and capital are seen to be complements in seven sub-groups. This result holds both in the short and the long run. Among the three industry groups where energy and capital are found to be substitutes, the effect is strongest in the iron and steel industry.

6. Our results show that in general there is a negative correlation between the demand for energy and net additions to the stock of capital. The implication of this evidence is that capital retrofitting and capital additions have been energy-saving. An exception to this finding is the food, drinks and tobacco products industry, where energy use per unit of output has grown over the sample period.

7. In order to estimate technological bias as it has affected factor use, technological change has been defined as a reduction in the average cost per unit of output. Our study shows that in general, technological change has been energy-saving, labor-saving and capital-using. This is seen from the estimates for the total US manufacturing sector and most of the subsectors.

Technological bias in favor of energy intensity is seen only in the food, drinks and tobacco products and paper, printing and publishing industries. In every subclassification, with the exception of food, drinks and tobacco, technological change has been biased towards displacing labor. However, technological change has been biased in favor of increasing capital intensity with the exception only of the non-ferrous primary metals group. If these tendencies continue, the share of energy and labor in total cost will decline and the manufacturing sector will become more capital intensive.

8. One of the most disputed issues in the current debate on input substitution has been the controversy over energy-capital substitution. Our results show that while energy and total gross capital have been complements in the short and medium run, energy and <u>net</u> additions to capital stock have been substitutes. This suggests that at least part of the energy saving has been achieved by an increasingly energy-efficient capital stock. The implications of this result are farreaching. If this tendency towards energy-saving investment continues, after a sufficient period of time when the technical coefficients have fully adjusted the energy-efficient content of capital stock will be higher. This would reverse the relationship between energy and capital from being complementary to one of substitution.

9. The results of our study on the elasticities of energy demand, energy-saving technological bias and the energy bias of investment decisions are critical to predicting the prospects for energy demand. The industrial production processes in the major industrial countries have been undergoing substantial structural and technological changes and will be making further changes in response, for example, to energy price shocks. The models specified here have established the groundwork for an examination of these issues in the

industrial sectors of other major industrial and newly-industrializing countries. Perhaps the main limitation of our study is that it has not introduced material inputs into the specification. This is largely a data issue which can be overcome.

I. INTRODUCTION *

Background

10. The sharp decline in energy intensity of output since the first oil price increase of 1973-74 distinguishes the industrial countries from the rest of the world. In the United States, the decline (nearly 24% between 1973 and 1985) has been, to a large extent, due to the enormous drop in the energy consumption of the industrial sector which fell by 4.5 quads--from 31.5 quads in 1973 to 27 quads in 1985. In contrast, energy consumption in the transportation and the residential and commercial sectors increased during the same period. As a result, industry's share in total US energy consumption declined from 42.5% in 1973 to 36.5% in 1985 (Table 1).

11. In the US industrial sector (which includes manufacturing, mining, construction and agriculture) not only does manufacturing account for more than 75% of the energy consumed, but it also represents the most energy-intensive sub-sector. Energy intensity in the US manufacturing sector declined moderately during the 1950s and 1960s, however, the fall since the beginning of the 1970s has been dramatic (Table 2). Analysis of the factors leading to the sharp decline in the energy intensity of output must, therefore, start with the manufacturing sector.

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* The authors are very grateful to Ron Duncan for useful comments at various stages of this research and indepth review of the manuscript. The authors have also benefited from discussions with Nadeem ul Haque and members of the Commodity Studies and Projections Division. Comments received from an anonymous reviewer have also been very useful. The usual disclaimer applies.

Table 1: END-USE SHARES IN US ENERGY CONSUMPTION
(%)

	Residential and Commercial	Transportation	Industry	Total Energy Consumption, Quads BTU a/
1973	32.5	25.0	42.5	74.3
1974	32.7	25.0	42.3	72.5
1975	33.9	25.8	40.3	70.6
1976	33.6	25.7	40.7	74.4
1977	33.3	26.0	40.7	76.3
1978	33.4	26.4	40.2	78.1
1979	32.7	25.9	41.4	78.9
1980	33.8	25.9	40.3	75.9
1981	34.1	26.3	39.6	74.0
1982	36.2	26.9	36.9	70.8
1983	36.3	27.1	36.6	70.5
1984	35.7	26.8	37.5	74.1
1985	36.3	27.2	36.5	73.9

Source: US Department of Commerce, Annual Survey of Manufactures; World Bank, EPDCS.

a/ Quads = 10^{15} BTUs.

12. In the period prior to the early 1970s, the decline in manufacturing energy intensity was probably due to the introduction of new technologies that permitted the production of a given volume of product with smaller quantities of capital, labor, energy and materials. Throughout this period, there was also a shift in the source of energy from inefficient burning of coal to the more efficient combination of oil and gas.

13. The energy-efficiency improvements in all manufacturing activities, notably the more energy-intensive ones, have been remarkable. Improvements,

Table 2: ENERGY INTENSITY IN THE US MANUFACTURING SECTOR

	Value Added (Billions 1972 dollars)	Energy Consumption (Trillion BTUs)	Energy Intensity (BTU/dollar of Value Added)
1955	209.5	8,664	41,360
1960	231.3	9,029	39,040
1965	295.0	11,010	37,320
1970	332.1	12,709	38,270
1973	380.4	13,962	36,700
1975	346.6	12,085	34,870
1979	441.8	12,867	29,120
1980	419.4	11,563	27,570
1982	418.5	10,750	25,680

Source: US Department of Commerce, Annual Survey of Manufactures; World Bank, EPDCS.

usually in excess of 25%, have also been accompanied by reduced use of oil and natural gas. Altogether, the decline in the post-1973 manufacturing energy-intensity may be traced to four factors: firstly, the considerable investment in the more energy-efficient manufacturing process; secondly, rapid retro-fitting of existing plants with energy-efficient equipment; thirdly, better housekeeping, requiring little capital expenditure; and, fourthly, the structural shift from energy-intensive to less energy-intensive manufacturing, especially since the second oil price increase of 1979/80. Despite the considerable decline in energy prices since the early 1980s, it is expected that the energy-saving momentum of new investment will continue in the future not only because energy prices are still considerably higher than those prevailing in the early 1970s, but also on account of the anticipated increase in energy prices later in the 1990s.

14. The main purpose of this study is to estimate the sensitivity of the demand for energy to changes in the relative price of energy and to changes in US manufacturing industry output. It also aims to estimate the substitution elasticities between energy and other factors of production and to determine the direction of the bias of factor utilization in the technology of the production process. The analysis is carried out for the US manufacturing sector in total and for its 10 sub-sectors. The paper also presents a simple approach to decomposing the total change in energy demand into income or output effects, price effects and technological change effects.

15. In the earliest Cobb Douglas specifications of production functions, gross physical output was presented as a function of labor and capital, usually without reference to natural resources. Natural resources were first included in econometric studies of production in the area of agricultural economics. One of the earliest studies to include natural resources as a factor of production in the manufacturing sector was undertaken by Berndt and Jorgenson (1973). This work was followed by other studies that were designed to estimate the elasticity of substitution between natural resources and labor and capital, for example, Berndt and Wood (1975), and Halversen and Ford (1978). Similar studies to estimate substitution responses between energy, labor and capital were conducted by Pindyck (1979b) and Griffen and Gregory (1976) using pooled international data. With the exception of the study conducted by Griffen and Gregory, these studies came to the conclusion that labor and energy are substitutes; the issue of whether energy and capital are substitutes or complements remains controversial. Perhaps, resolution of the controversy lies in making a clear distinction between the long run and the

short run. In the short run, it seems that energy and capital are complementary, while in the long run they could be substitutes.

16. The estimate of the price elasticity of the demand for energy for the industrial sector is also an area of continuing dispute. To cite an example, Halversen and Ford (1978) obtained long-term price elasticity estimates for the United States within the range -0.66 to -2.56; while Berndt and Wood (1975) found the price elasticity to be -0.49.

17. Although literature in theoretical form exists on the subject of technological change, empirical work on the topic is scarce. Earlier models assumed technological change to be exogenous and disembodied. Berndt and Wood (1975) and Wills (1979) in their econometric presentation of induced technological change assumed constant returns to scale and Hicks' neutral technological change. Moroney and Trapani (1979) in two different models presented technological change as price-induced and non-neutral in one model and imposed Hicks' neutral technical change in the other. In estimating technological bias, Jorgenson and Fraumeni (1981) maintained that though the bias in technical change is independent of relative price movements, the rate of growth in productivity is a function of the input mix in a multi-factor production function and is responsive to relative price changes. This report has been updated (Jorgenson, 1982) by five years of data and by defining energy sources for the US manufacturing sector that exclude feedstocks and metallurigical coal. The basic conclusion of the aforestated studies on technological bias in the US manufacturing sector is that, with the exception of a few manufacturing subgroups, technological progress bias has been energy-using.

18. This study goes a step further than the -abovementioned papers in dealing with the demand for energy in the manufacturing sector. It presents three different specifications for the estimation of energy demand functions. This approach facilitates comparisons between various approaches and provides estimates that reduce, though slightly, the controversy in the literature on the response of energy demand to its relative price change and the complementarity-substitution relationship between energy and capital. While the study by Jorgensen (1982) uses data up to 1979, this study extends the time period to 1981. 1/ This extension of the sample period is particularly relevant, for it includes the period of the sharp increase in the price of oil in 1979 and the subsequent instability in energy prices following the price shock. Another distinguishing feature of the study is that an investment function is introduced.

1/ The US Department of Commerce discontinued the collection of data on fuels consumed after 1981.

II. THEORETICAL MODELS

19. This section develops three approaches to estimation of the energy demand function. The first two approaches differ only in the dynamic specification.

20. In the first two models, where the impact of investment on the secular decline in energy demand is estimated, the investment function is taken as a proxy for technological change. Obviously, technological change is a much broader phenomenon than changes which occur via new investment; other changes may take place which improve the productivity of all factors proportionally (Hicks-Neutral) or disproportionately such that the factor mix is altered (technological bias). This broader concept of technological change is applied in Model III; here, technological change is defined as the change in the cost of production per unit of output. Such technological change may be partly price-induced and partly exogenous or autonomous. However, there is no attempt made to account for the factors influencing the extent and nature of technical change.

21. To simplify matters, it is assumed that the labor and capital markets are perfectly competitive; that is to say, the prices of the factors are equal to the value of their marginal products and returns to factors equalize after full adjustment has taken place. Any differentials in wage rates and prices of capital services across the manufacturing sector subgroups are assumed to be due to differences in skills and other qualities of factors.

Model I

The demand for energy as a function of income (output) and prices is represented in the following logarithmic form:

$$\left(\log X_E\right)_y = \alpha_y + \alpha_1 \log Z_y + \lambda_{EE} \log P_{Ey} + \varepsilon_t \qquad (1)$$

where

$(X_E)_y$	=	demand for energy by the y^{th} sector;
Z_y	=	output of the y^{th} industry;
P_{Ey}	=	price of energy (deflated) in the y^{th} sector;
α_1 and λ_{EE}	=	are output and price elasticities, respectively.
ε_t	=	error term

Model II

22. This model uses the lagged values of the dependent variable as one of the regressors. The model takes the following form:

$$\left(\log X_E\right)_y = \alpha_y + \alpha_1 \log Z_y + \lambda_{EE} \log P_{Ey} + \alpha_0 \log\left(X_{E-1}\right)_y + \varepsilon_t \qquad (2)$$

In this model the long-run elasticities are computed by dividing each coefficient by one minus the coefficient of the lagged dependent variable. Both models can be extended by including the prices of labor, capital and other factors of production.

23. As one of the intentions of the study was to estimate the effects of net capital investments on the demand for energy, a variable was included that

represents net investment. A negative coefficient on this variable would imply that capital additions are energy-saving. Since incorporating this variable directly in the model may give rise to simultaneity bias, a two-stage least squares simultaneous equation estimating technique was used to eliminate this bias. In the first stage of the two-stage estimation process the investment function (I), which is the instrumental variable, was defined in the following way:

$$I = \gamma(\overset{*}{K}_t - K_{t-1}) \tag{3}$$

$$= \gamma\left(\alpha \frac{Z}{(i+\delta-\pi^*)} - K_{t-1}\right) \tag{4}$$

where

$\overset{*}{K}$ = desired capital stock

r = the real rate of interest

π^* = the expected rate of inflation

i = $r + \pi^*$ (the nominal interest rate)

δ = the depreciation rate

γ = the speed of adjustment.

α = the steady state capital/output ratio.

and $$\pi^*_t = \pi^*_{t-1} + b(\pi_{t-1} - \pi^*_{t-1}) \tag{5}$$

This specification assumes that the expected rate of inflation in period t is equal to the expected rate of inflation in time t-1 plus a fraction of the difference between the actual and expected rates of inflation in time t-1. The fraction is determined by the speed of adjustment b in equation (5).

24. The predicted value of (I) estimated from equation (4) in log form is used in the energy demand equation in the second stage of the two-stage least squares estimation process. The effect of investments on energy demand has also been estimated directly in a few cases by excluding the price of capital services from the equations. The results are much the same as those estimated in the two stage process. Since, we are interested only in the energy demand equation, the estimated investment equation is not reported.

25. While the long-run elasticities can be computed directly from Model II, it is necessary to incorporate an appropriate lag structure in Model I to capture long-run effects. The simple approach adopted to deal with lagged responses, i.e. Koyck or geometric lag, has been adopted in Model II. Because of its flexibility in terms of building in an appropriate dynamic adjustment path, the Polynominal distributed lag approach has been used in Model I.

26. After incorporating the lag structure in Model I and introducing the investment function and prices of other inputs in both models, equations (1) and (2) can be rewritten as follows:

$$\log(X_E)_y = \alpha_y + \alpha_1 \log Z_y + \lambda_{EE} \sum_{\Delta=1}^{n} \alpha_2 \log P_{Ey(t-\Delta+1)}$$

$$+ \lambda_{EK} \sum_{\Delta_1=1}^{n} \alpha_3 \log P_{Ky(t-\Delta_1+1)} + \lambda_{EL} \sum_{\Delta=1}^{n} \alpha_4 \log P_L (t-\Delta_2+1)$$

$$+ \beta^*(I)_y + \varepsilon_t \qquad (6)$$

$$\log(X_E)_y = \alpha_y + \alpha_1 \log Z_y + \lambda_{EE} \log P_{Ey} + \lambda_{EK} \log P_{Ky} +$$

$$+ \lambda_{EL} \log P_{Ly} + \beta^{*}(I)_y + \alpha_0 \log(X_{E-1})_y + \varepsilon_t \qquad (7)$$

where

$(I)_y$ is the endogenously-determined, investment function, P_K and P_L are the prices of capital and labor, respectively, β^{*} is the co-efficient of investment, and α_2, α_3 and α_4 are the weights in the lag structures $\sum\alpha_2 = 1$, $\sum\alpha_3 =1$ and $\sum\alpha_4 =1$.

27. Equations (6) and (7) have been used for estimation purposes. In equation (6) α_1 , λ_{EE}, λ_{EK} and λ_{EL} represent the long-run elasticities, while, $\lambda_{EE}\alpha_2$, $\lambda_{EK}\alpha_3$ and $\lambda_{EL}\alpha_4$ are the short-run elasticities. In equation (7), α_1, λ_{EE}, λ_{EK} and λ_{EL} are the short-run elasticities, while $\lambda_{EE}/1-\alpha_0$, $\lambda_{EK}/1-\alpha_0$ and $\lambda_{EL}/1-\alpha_0$ are the long-run elasticities. The only essential difference between the two equations is in the structure of the lag.

Model III

The transcendental logarithmic approach provides a relatively more informative functional form than the simple logarithmic approach of Models I and II. The derivation of the translog factor demand function is as follows. Assume a K, L, E, twice-differentiable, constant returns to scale production function as follows.

$$Z = f(K, L, E) \qquad (8)$$

28. If output could be defined as gross output in physical units, technological change could be defined as a variable in the production function. As

the value of output is used as a proxy for output and since the changes in the value of output are equal to the sum of the changes in input share values, the residual value of output that is conventionally associated with technological changes is zero. In the formulation adopted here, therefore, technological change is defined as a reduction in the cost per unit of the value of output produced and, hence, is an argument in the cost function and the derived factor demand function.

29. The dual of the production function is the following twice differentiable cost function: (The principles of duality applied here were developed by Samuelson 1947, Shephard 1953, Uzawa 1964, and Diewert 1974.)

$$C = C(Z, P_K, P_L, P_E, T) \tag{9 a}$$

Where T is a measure of technology. This function follows the neoclassical regularity conditions. By applying the duality theorem, the unit cost function is independent of the level of output of the yth firm and is written as follows:

$$C = ZC\ (P_K, P_L, P_E, T) \tag{9 b}$$

30. The translog functional form imposes no a priori restrictions on the elasticities of substitution between the factors.1/ The translog cost function of the three input model (originally proposed by Christensen, Jorgenson, and Lau 1971) with technological change is as shown in equation (10). It is assumed that the cost function is concave and linearly homogeneous in prices. It is a function of Z and the factor prices and tends to infinity as Z tends to infinity.

$$\begin{aligned} \log C = {} & \log\alpha_0 + \log Z + \lambda_K \log P_K + \lambda_L \log P_L + \lambda_E \log P_E + \lambda_T \cdot T \\ & + \frac{1}{2}\lambda_{KK}(\log P_K)^2 + \lambda_{KL}\log P_K \log P_L + \lambda_{KE}\log P_K \log P_E + \lambda_{KT}\log P_K \cdot T \\ & + \frac{1}{2}\lambda_{LL}(\log P_L)^2 + \lambda_{LE}\log P_L \log P_E + \lambda_{LT}\log P_L \cdot T \\ & + \frac{1}{2}\lambda_{EE}(\log P_E)^2 + \lambda_{ET}\log P_E \cdot T \end{aligned} \tag{10}$$

The general form of the translog cost function is as follows:

$$\log C = \alpha_0 + \log Z + \sum_i \lambda_i \log P_i + \frac{1}{2} \sum_i \sum_j \lambda_{ij} \log P_i \log P_j$$

where: α_0, α_1, λ_i, and λ_{ij} are technologically-determined parameters.

1/ The translog cost function is not the only specification that is flexible; Generalized Leontief (Diewert 1971) and the Generalized Cobb-Douglas (Diewert 1973) are also sufficiently flexible in this respect.

31. For a given level of output and factor prices, the demand for energy and other factors that minimize production costs is derived by the use of Shephard's Lemma (Shephard 1970). It follows that at the point of minimum cost the demand for the i^{th} factor by the y^{th} industry is given as $X_i = \frac{\partial(C)}{\partial P_i}$. Differentiating the translog function presented in equation (10) with respect to the price of the factor input gives the equilibrium share of the i^{th} factor. The general form of the share equation is

$$S_i = \alpha_i + \sum_i \lambda_{ij} \log P_i + \lambda_i^* T \qquad (11)$$

where i, j = K, L and E

The share equations for each of the three inputs are derived in the following way.

$$\frac{\partial \log C}{\partial \log P_E} = S_E = \frac{P_E \cdot E}{\phi} = \lambda_E + \lambda_{KE} \log P_K + \lambda_{LE} \log P_E$$

$$+ \lambda_{EE} \log P_E + \lambda_{ET}^* \cdot T \qquad (12)$$

$$\frac{\partial \log C}{\partial \log P_K} = S_K = \frac{P_K \cdot K}{\phi} = \lambda_K + \lambda_{EK} \log P_E + \lambda_{LE} \log P_E + \lambda_{KK} \log P_K$$

$$+ \lambda_{KT}^* \cdot T \qquad (13)$$

$$\frac{\partial \log C}{\partial \log P_L} = S_L = \frac{P_L \cdot L}{\phi} = \lambda_L + \lambda_{KL} \log P_K + \lambda_{EL} \log P_E + \lambda_{LL} \log P_L$$

$$+ \lambda^{*}_{LT} \cdot T \tag{14}$$

Where S_E, S_K, and S_L are the share equations and ϕ equals total cost. The sign on λ^* shows the bias of technological change. $\lambda^* \gtreqless 0$ suggests that technological change is factor-using, factor-neutral or factor saving, respectively (top to bottom). The share equations (12), (13) and (14) are the estimated equations for Model III.

32. The shares can also be seen as the coefficients ω_E , ω_K , and ω_L estimated from the total cost function. The equation that gives the ω_i is represented as follows:

$$\log\phi = \log\alpha + \omega_E \log(P_E . KE) + \omega_K \log(P_K . K) + \omega_L \log(P_L . L) + \varepsilon_t \tag{15}$$

where $\omega_E + \omega_K + \omega_L = 1$

Linear homogeneity in prices imposes the following restrictions on the translog function.

$$\sum_i \lambda_i = 1$$

$$\sum_i \lambda_{ij} = 0$$

$$\lambda_{ij} = \lambda_{ji}$$

33. The system of factor demand equations should also satisfy the slope and the concavity properties of the minimum cost function. This requires that the gradient of the estimated input cost function with respect to input prices

is non-negative and that the Hessian matrix of the minimum cost function based on the parameter estimates be negative semi-definite. These restrictions are translated into the condition that the matrix of Allen partial elasticities of substitution be negative semi-definite.

34. The Allen partial elasticities of substitution between factors of production (Uzawa 1964) within the translog framework are derived in the following way:

$$\sigma_{ii} = \frac{\lambda_{ii} + S_i^2 - S_i}{S_i^2} \qquad i = K, L, E \tag{16}$$

$$\sigma_{ij} = \frac{\lambda_{ij} + S_i S_j}{S_i S_j} \qquad \begin{array}{c} i, j = K, L, E \\ i \neq j \end{array}$$

$$\text{or } \sigma_{ij} = \frac{\lambda_{ij}}{S_i S_j} + 1 \tag{17}$$

35. The σ_{ii} and σ_{ij} are multiplied by the share of the factor in order to arrive at the substitution elasticity estimates as follows (Allen, 1956):

$$\varepsilon_{ij} = \sigma_{ij} S_j \tag{18}$$

$$\varepsilon_{ii} = \sigma_{ii} S_i$$

This estimate of the own-price elasticity has embedded in it a complete set of complementarity and substitutability relationships between the i^{th} input and all other inputs.

III. DATA AND VARIABLES

36. The US manufacturing sector is disaggregated into the following industry groupings:

a. Food, Drinks & Tobacco
b. Textile, Leather & Clothing
c. Wood, Lumber & Furniture
d. Paper & Printing
e. Chemical & Allied Products
f. Petroleum & Coal Products
g. Stone, Clay & Glass
h. Non-Ferrous Primary Metals, Fabrications, Machinery and Transport Equipment
i. Iron & Steel
j. All Others

37. Energy consumption by the US manufacturing sector is represented by purchased fuels only and ignores fuels that are generated in the process of production and subsequently consumed within the plant. Energy consumption is presented in aggregate terms. There is no distinction between various types of fuels. Consumption of all fuels, including electrical energy, is converted into BTU equivalents and aggregated.

38. Due to the insurmountable problem of aggregating heterogeneous physical units of output, not only across industries but also within industries, the analysis uses the total manufacturing value added as a proxy for output. A divisia input price index has been used as a deflator for the nominal value of output (Arrow 1974, Diewert 1976, Werbos 1984).

39. The price of labor services is represented by the real unit cost of labor. The index of energy prices for the manufacturing sector has been taken directly from Department of Energy sources.

40. The price of capital services is computed as quasi rent from the following relationship (Moroney and Trapani, 1981):

$$P_{KS} = \frac{[P_L \cdot L + P_K \cdot K] - P_L \cdot L}{\overline{K}} \tag{19}$$

where

P_{KS} = price of capital services

$P_L \cdot L + P_K \cdot K$ = value added

$P_L \cdot L$ = labor costs

$\overline{K}$ = stock of capital

41. In order to arrive at the stock of capital, a series was constructed assuming a stock figure for 1946 (the value of industrial investment has been recorded since 1947), applying a constant depreciation rate of 5% per year and taking into account the subsequent incremental annual investments. The deflator for capital stock (P_D) is given by the following:

$$P_D = \sum_{t=\tau-n}^{\tau} \frac{[K_t - K_{t-1}]\ ti}{\sum_{\tau-n}^{\tau} [K_t - K_{t-1}]} \tag{20}$$

where

$K_t - K_{t-1}$ = net investment

ti = implicit deflator (the published capital equipment price index)

42. The time period for the study is from 1958 to 1981. The main sources of data include the <u>Annual Survey of Manufactures</u> and the <u>Census of Manufacturers</u>. Both sources are publications of the Department of Commerce, Bureau of Census. Data has also been acquired from the annual statistical publication of the Department of Energy.

IV. RESULTS

43. The results from estimating the three models are presented in Tables 3 and 4. The equations have been estimated for the US manufacturing sector, using both pooled and time series data, and for its ten subsectors. Although the signs of the coefficients are the same for each variable under every specification, the values of the coefficients differ across specifications. The differences seem to be primarily due to the different adjustment mechanisms adopted for the different specifications. Apart from this difference, the pooled estimates (for total manufacturing) are lower than the estimates from pooled data. Pooled time-series cross-section data have only been used in estimating Models I and III. Model I has been estimated with no lag structure on the independent variables when using pooled data. This is effectively the same equation as Model II without the lagged value of the dependent variable. This was done because the results from pooled data--which are dominantly cross-section with few time-series observations--mainly reflect static equilibria, whereas models with lagged dependent variables are dynamic in nature. The dynamic specification of the translog cost share model has not been estimated. Introduction of the adjustment process in terms of shares rather than input levels could result in violation of Le Chateliers principle, i.e., short-run elasticities could be larger than long-run elasticities.

Table 3: ELASTICITY ESTIMATES FROM THE ENERGY DEMAND MODELS FOR THE US MANUFACTURING SECTOR

	Model I			Model II		Model III	
	Time Series			Time Series			
	Short Run	Long Run	Pooled	Short Run	Long Run	Time Series	Pooled
ω_E						0.10	0.10
ω_K						0.15	0.15
ω_L						0.75	0.75
η_Z	0.65	0.67 ~0.75	0.73	0.60 ~0.72	0.72	-	-
ε_{EE}	-0.21	-0.37	-0.65	-0.22	-0.29	-0.60	-0.75
ε_{EK}	-0.10	-0.23 >	-0.29	-0.17	-0.22	-0.26 >	-0.23
ε_{EL}	0.43	0.84	1.20	0.32	0.68	0.84	1.02
β^*	-	-0.25	-0.27	-	-0.32	-	-
λ_i^*	-			-	-	-0.018	-0.017

contd....next page

Table 3 contd...

	Model I		Model II		Model III
	Short Run	Long Run	Short Run	Long Run	
Food, Drinks and Tobacco-Products					
ω_E					0.08
ω_K					0.22
ω_L					0.70
η_Z	1.39	1.39	1.37	1.37	-
ε_{EE}	-0.22	-0.36	-0.21	-0.26	-0.29
ε_{EK}	-0.35	-0.42	-0.25	-0.35	-0.60 >
ε_{EL}	0.25	0.86	0.33	0.79	0.79
β^*	-	0.47	-	0.36 >	-
λ_i^*	-	-	-	-	0.062
Textile, Leather and Clothing					
ω_E					0.05
ω_K					0.12
ω_L					0.83
η_Z	0.50	0.50	0.63	0.78	-
ω_{EE}	-0.27	-0.71	-0.21	-0.66	-0.65 >
ω_{EK}	-0.11	-0.23	-0.20	-0.31	-0.40
ε_{EL}	0.52	0.95	0.44	0.86	1.00
β^* –	-	-0.23 <		-0.19 <	-
λ_i^*	-	-	-	-	-0.032

Table 3 contd....

	Model I		Model II		Model III
	Short Run	Long Run	Short Run	Long Run	
Wood, Lumber and Furniture					
ω_E					0.06
ω_K					0.18
ω_L					0.76
η_Z	0.56	0.56	0.20	0.23	–
ε_{EE}	-0.27	-0.32	-0.29	-0.37	-0.53
ε_{EK}	0.35	0.72	0.68	0.72	0.75
ε_{EL}	-0.23	-0.47	-0.36	-0.36	-0.16
β^*	–	-0.05	–	0.014	–
λ_i^*	–	–	–	–	-0.034
Paper, Publishing and Printing					
ω_E					0.21
ω_K					0.30
ω_L					0.49
η_Z	0.82	0.82	0.61	0.67	–
ε_{EE}	-0.11	-0.19	-0.11	-0.19	-0.31
ε_{EK}	-0.15	-0.26	-0.36	-0.51	-0.52
ε_{EL}	0.30	0.60	0.11	0.40	0.90
β^*	–	-0.10	–	0.29	–
λ_i^*	–	–	–	–	0.045

Table 3 contd....

	Model I Short Run	Model I Long Run	Model II Short Run	Model II Long Run	Model III
Chemicals and Allied Products					
ω_E					0.15
ω_K					0.26
ω_L					0.59
η_Z	0.47	0.47	0.60	0.67	–
ε_{EE}	-0.07	-0.28	-0.06 >	-0.25 >	-0.65
ε_{EK}	-0.22	-0.45	-0.39	-0.56	-0.34
ε_{EL}	0.36	0.69	0.32 >	0.35 >	0.77
β^*	–	-0.08	–	-0.10	–
λ_i^*	–	–	–	–	-0.008
Petroleum and Coal Products					
ω_E					0.24
ω_K					0.44
ω_L					0.32
η_Z	0.49	0.49	0.33	0.57	–
ε_{EE}	-0.35	-0.60	-0.28	-0.49	-0.65
ε_{EK}	-0.40	-0.62	-0.48	-0.64	-0.56
ε_{EL}	0.29	0.50	0.49 >	0.75 >	0.92
β^*	–	-0.33	–	-0.39	
λ_i^*	–	–	–	–	-0.067 >

Table 3 contd....

	Model I		Model II		Model III
	Short Run	Long Run	Short Run	Long Run	
Stone, Clay and Glass					
ω_E					0.15
ω_K					0.23
ω_L					0.62
η_Z	0.82	0.82	0.60	0.65	-
ε_{EE}	-0.15	-0.35	-0.32	-0.37	-0.74
ε_{EK}	0.35	0.89	0.55	0.62	0.65
ε_{EL}	0.20	0.54	0.47	0.49	0.21
β^*	-	-0.048	-	-0.05	-
λ_i^*	-	-	-	-	-0.059
Non Ferrous Primary and Fabricated Metals, and Electronic and Transportation Equipment					
ω_E					0.03
ω_K					0.20
ω_L					0.77
η_Z	0.67	0.67	0.64	0.64	-
ε_{EE}	-0.09	-0.20	-0.21	-0.24	-0.25
ε_{EK}	-0.15	-0.35	-0.17	-0.19	-0.35
ε_{EL}	0.05	0.17	0.11	0.12	0.78
β^*	-	-0.10	-	-0.10	-
λ_i^*	-		-	-	-0.030

Table 3 contd....

	Model I		Model II		Model III
	Short Run	Long Run	Short Run	Long Run	
Iron and Steel					
ω_E					0.20
ω_K					0.17
ω_L					0.63
η_Z	0.72	0.72	0.57	0.68	-
ε_{EE}	-0.31	-0.50	-0.45	-0.57	-0.98
ε_{EK}	0.62	0.87	0.73	0.88	0.42
ε_{EL}	0.36 <	0.80	0.72	0.72	0.74
β^*	-	-0.50	-	-0.51	-
λ_i^*	-	-	-	-	-0.029 >
All Other Industries					
ω_E					0.03
ω_K					0.13
ω_L					0.84
η_Z	0.49	0.49	0.38	0.46	-
ε_{EE}	-0.07 >	-0.26	-0.16	-0.38	-0.60
ε_{EK}	-0.09 <	-0.29	-0.16	-0.32	-0.17
ε_{EL}	0.27	0.36	0.10	0.19	0.72
β^*	-	-0.02 <		-0.08	-
λ_i^*	-	-	-	-	-0.009 >

< = T-Statistics less than 1.0
> = T-Statistics greater than 1.0 but less than 1.3
No sign = T-Statistics greater than 1.3.

Notes: ω_E - share of energy; ω_K - share of capital; ω_L - share of labor; η_Z' - output elasticity; ε_{EE} - energy own-price elasticity; ε_{EK} - energy cross-price elasticity with capital; ε_{EL} - energy cross-price elasticity with labor; β^* - investment elasticity; λ_i^* - technology bias coefficient.

Table 4: ESTIMATED CO-EFFICIENTS OF TECHNOLOGICAL BIAS

	Energy	Labor	Capital
Total Manufacturing Sector	-0.017 (2.14)	-0.065 (3.02)	0.078 (1.72)
Food, Drinks & Tobacco	0.062 (1.92)	0.026 (2.04)	0.096 (1.53)
Textiles, Leather & Clothing	-0.032 (1.29)	-0.015 (1.77)	0.153 (1.49)
Wood, Lumber & Furniture	-0.034 (2.55)	-0.043 (2.30)	0.153 (3.90)
Paper, Printing & Publishing	0.045 (1.40)	-0.034 (2.25)	0.149 (3.78)
Chemicals and Allied Products	-0.008 (3.20)	-0.023 (0.94)	0.074 (2.24)
Petroleum and Coal	-0.067 (1.23)	0.131 (2.02)	0.095 (4.02)
Stone, Clay & Glass	-0.059 (1.74)	-0.015 (2.90)	0.057 (1.20)
Non-Ferrous Primary Metals	-0.030 (1.27)	-0.065 (3.30)	-0.034 (2.20)
Iron and Steel	-0.029 (1.25)	-0.034 (2.33)	0.029 (1.67)
All Other	-0.009 (0.52)	-0.020 (0.96)	0.077 (1.09)

Note: T-Statistics in parenthesis.

V. DISCUSSION OF RESULTS

44. The coefficients of output or income elasticity of the demand for energy (η_Z) are reasonable and have the appropriate signs. The income elasticity for the aggregated industrial sector is estimated to be in the range of 0.65 and 0.75. This coefficient is the average of all the point elasticities along the curve within the range covered by the sample period. Inspection of the income elasticities of demand for each year finds a declining trend in the post-oil price shock period, badly reflecting the declining energy-intensity of output. However, this pattern is disrupted by negative income elasticities in the years immediately after the oil price shocks, i.e., 1974, 1979 and 1981, which probably reflects a short-run overreaction to the price increase. Due to the limitations on the length of the data series, we were unable to test the changes in income elasticity for the subsectors. However, between 1970 and 1981 we find that the energy intensity per unit of output has declined by about 30%. This is consistent with an income elasticity of 0.7 in the latter period, if we assume that the income elasticity of demand for energy in the pre-oil-shock period was close to unity. Based upon the fact that between 1960 and 1973 (the year of the first oil price shock) energy use per unit of real industrial value of output remained more or less constant, this is a reasonable assumption. For this reason also we can interpret the change in the income elasticity as a change in the energy intensity per unit of output, or more generally as a change in the factor mix of output.

45. The own-price elasticity for energy is well below unity under all specifications. Previous studies yielded a range of estimates from about -0.5

to about -2.6. The elasticity estimates from Model II are generally the smallest. This is due to the dynamic nature of the model which has a lag structure designed to smooth out the stochastic changes in price. In the period under study there have been many and substantial changes in energy prices. Moreover, changes have become highly unpredictable, therefore the adjustments in energy demand to price changes are slow.

46. For the total manufacturing sector, energy and capital are seen to be complements while energy and labor are strong substitutes under all specifications. Similar relationships are observed for almost all the subsectors; exceptions are the group subclassified as wood, lumber and furniture where energy and labor are weak complements and energy and capital are substitutes, and the stone, clay and glass manufacturing and iron and steel groups where energy and capital are also seen as substitutes.

47. In the aggregated sector the negative sign of the coefficient used as a proxy for technical change in Models I and II indicates that a unit increase in expenditure on retrofitting the existing capital stock results in reduced energy use by up to 32%. The results from Model III show that technological change has been capital-using, labor-saving and energy-saving; however, the bias towards energy saving is not as great as that towards labor-saving (see Table 4).

48. Since the paper, chemicals, petroleum and coal, and iron and steel subgroups account for a large percentage of energy consumption in the US manufacturing sector, the results for these industries are discussed more thoroughly below.

49. As indicated by the cost shares, the production of paper, publishing and printing is very energy-intensive. The energy share ($\omega_E = 0.21$), however,

does not represent total energy use within the industry because paper and pulp factories generate a large amount of their own energy needs through the use of wood residues. This industry also has a tendency to integrate with wood and lumber industries which provide the raw material. About 50% of total energy used in this industry is believed to be internally generated. The long-run price elasticity of demand for energy in the paper and pulp industries is estimated to be around -0.2 in Models I and II and -0.31 in the translog specification. This coefficient is low relative to some of the other industry groups. Though the industry is capable of generating part of its own fuel requirements, and can substitute away from the use of purchased fuels in response to a price increase, still it apparently does not generate enough fuel such that the price elasticity for purchased energy is high. The self-generation of fuels tends to blur the picture in respect of the nature of technological change, but the positive coefficient of technological bias in respect to energy and the positive elasticity of energy demand with respect to capital expenditure indicate that capital retrofitting has been in the direction of increasing energy consumption. The paper and pulp industry has become more capital-intensive over the years. This is indicated from its increase in capital expenditures in the last ten years of the sample period. The expenditure incurred on new capital has risen from 8% of total revenue in 1970 to about 11% in 1980. Between 1973 and 1981 the industry spent $37.6 billion on energy- efficient, pollution-abatement facilities. This investment could in future years reverse the technological bias from its present energy-using tendency towards energy saving.

50. The low income elasticity of energy demand in the <u>petroleum and coal</u> industries (about 0.5) is somewhat puzzling, as it was thought that this would

be one of the more output-sensitive industries. Perhaps the explanation lies more on the supply side, more specifically in the energy endowment. The recently declining demand for energy and its low income elasticity of demand in the US energy sector may be due to the scarcity of energy resources. The own-price elasticity of demand for energy in the petroleum and coal industries is in the moderate range of estimates from Model III and is slightly high by comparison with other estimates from Models I and II. The high price elasticity of demand for energy could reflect the larger increase in the price of petroleum inputs relative to the price of non-petroleum energy inputs. An elastic demand for petroleum-intensive products would lead to substitution towards the consumption of less petroleum-intensive products, contributing to the decline in the demand for energy inputs. In fact, petroleum industries were used at only 65% capacity in 1981. The low income elasticity and the moderately high price elasticity of demand for purchased energy may also result from the ability of the petroleum and coal industries to vertically integrate with the industries supplying energy inputs, thereby producing its own fuel needs. The negative coefficient of both technological bias and energy demand with respect to capital retrofitting indicates that in the petroleum and coal industry, the direction of change has been towards greater energy efficiency.

51. The <u>chemical</u> industries and their allied product groups are the largest energy users, accounting for about 26% of the total energy use of the industrial sector in 1981. This subgroup is also the largest consumer of premium fuels. The chemical industry is of a dynamic nature in the sense that it can quickly alter its product mix. Therefore, one interpretation of the energy-saving bias in technology and investment is that the industry has been

shifting from the production of chemicals with a larger energy content to higher value pharmaceutics, pesticides and other consumer products (which it is doing, in fact). The lower price elasticity relative to petroleum and coal industries and the negative but low coefficient of the variables representing technological changes can be attributed to the slow adjustment process that the industry is going through. The industry has been contemplating new techniques of production. For instance, the expenditure incurred on research and development by the industry was in the order of $4.7 billion in 1981. The effects of this will be observed only after a lag.

52. In spite of the decline in its demand for energy, iron and steel production is still one of the most energy-intensive industries. In the last decade, the steel industry has gone through a difficult period because of the recession and the weight conservation induced by high energy prices. In an effort to reduce its losses the industry has concentrated its production around the most efficient steel mills. The industry's capital investment is also directed toward the more efficient use of energy in its production process. This explains the relatively large negative coefficient on the investment variable. The technological change coefficient also indicates energy-saving investment. The steel industry is substituting away from the more energy-intensive production processes to less energy-intensive ones such as the use of scrap in electric arc furnaces and mini-mills. Whereas, previously, steel slabs and blooms were reheated before they were rolled into steel products, the US steel industry has been investing increasingly in the more energy-efficient continuous casting process. Its demand for energy is relatively elastic, possibly because of the ability of the industry to alter

its product mix by substituting away from the production of energy-intensive products.

53. Although the consumption of energy by the industries classified as food, drinks and tobacco and textiles, leather and clothing has gone up, their energy-output ratio is still comparatively low. In fact, these are the only two groups of manufacturing industries where the ratio of energy to output has increased. This is partially explained by the high positive coefficient of the income variable--especially in the food industries where the income elasticity is well above unity. Apart from paper products, food, drinks and tobacco products industries are the only other group that shows a technological bias towards energy consumption. This result may be due to the fact that the current level of energy consumption is below the optimal and the industry is adjusting towards the optimal level of consumption by altering its capital structure, or it may be due to the fact that energy-intensive technology is still cheaper to adopt in these groups of industries, i.e., due to the relatively smaller share of energy the costs of making capital stock more energy efficient exceeds the benefits. The estimates for the wood, lumber and furniture industry indicate energy-saving technical and structural changes. The income elasticity may be an underestimation of the actual energy intensity of this group. The data include purchased energy only, while this group also generates a part of its own energy supplies and has the ability to substitute away from the use of purchased fuels in response to a change in price. Indeed, the demand for energy in this group is very responsive to price changes. The energy content of stone, clay and glass manufacturing industries is significant; as is shown by the output coefficient, especially in Model I. The price elasticity of demand for energy for this industry is high in the

translog formulation because of its larger factor share. The output of industries classified as "all other" mostly have low energy content and therefore limited possibilities and interest for altering their product mix to save energy.

54. The key determinants of the changes in energy consumption in the US manufacturing sector during the sample period appear to be: (i) the change in the energy-intensity per unit of output; (ii) changes in the price of energy; and, (iii) technological change. In the following, the aggregate reduction in energy consumption in this sector is explained in terms of these factors. It should be noted that part of the decline attributed to (i) and (iii) could be thought of as being due to the increase in energy prices, as these factors can be partly price-induced.

55. To disaggregate the recent total decline in energy consumption in the US industrial sector into its three main components the demand for energy (X_E) as a function of output (Z), price of energy (P_E) and investment (I) is presented as follows:

$$X_E = X_E\,(Z,\ P_E,\ I) \tag{21}$$

Differentiating with respect to time gives

$$\frac{\partial X_E}{\partial t} = \frac{\partial X_E}{\partial Z}\ \frac{\partial Z}{\partial t} + \frac{\partial X_E}{\partial P_E}\ \frac{\partial P_E}{\partial t} + \frac{\partial X_E}{\partial I}\ \frac{\partial I}{\partial t} \tag{22}$$

where the rates of change, i.e., $\frac{\partial X_E}{\partial t}$, $\frac{\partial Z}{\partial t}$, $\frac{\partial P_E}{\partial t}$ and $\frac{\partial I}{\partial t}$ are expressed in logarithmic form.

By using the following elasticities:

$$\eta_Z = \frac{\partial X_E}{\partial Z} = \frac{\partial(\log X_E)}{\partial(\log Z)} \quad \text{Income elasticity}$$

$$\varepsilon_{EE} = \frac{\partial X_E}{\partial P_E} = \frac{\partial(\log X_E)}{\partial(\log P_E)} \quad \text{Price elasticity} \qquad (23)$$

$$\beta^* = \frac{\partial X_E}{\partial I} = \frac{\partial(\log X_E)}{\partial(\log I)} \quad \text{Investment elasticity}$$

Equation (22) can be rewritten as follows:

$$\partial X_E = \eta_Z \frac{\partial Z}{\partial t} + \varepsilon_{EE} \frac{\partial P_E}{\partial t} + \beta^* \frac{\partial I}{\partial t} \qquad (24)$$

Equation (24) is used to calculate the contribution of each of the three factors.

56. The symbol ∂ represents the partial effect of varying one of the underlying parameters with others held constant. Hence $\frac{\partial X_E}{\partial Z}$ represents the proportionate change in energy demand due to a proportionate change in output with prices and investments held constant; $\frac{\partial X_E}{\partial P_E}$ represents the proportionate change in energy demand due to a proportionate change in prices with output and investments held constant; and $\frac{\partial X_E}{\partial I}$ represents the proportionate change in energy demand due to a proportionate change in investments with output and prices held constant.

57. The calculations are based upon the following estimates. The data and results are <u>approximations</u>.

Variables	Rates of Change % Change Each Year (1974-82)
Manufacturers Real Output	~1.26
Energy Consumption	~-3.0
Unit Cost of Energy (Real)	~10.5
Divisia Energy Price (1974-81)	~17.0
Price of Capital (1974-81)	~11.0
Price of Labor (1974-81)	~8.0
Real Capital Accumulations	~2.6
Energy Intensity per Unit of Output	~-3.5

If we assume a unitary income elasticity in the pre-1973 period, our income elasticity estimate of about 0.7 (ceteris paribus) for the recent period implies an approximate 30% reduction in the income elasticity. As argued earlier, the simplifying assumption of an income elasticity of unity for the pre-oil shock period is not an unrealistic one. It is observed that the energy intensity per unit of real value of output (deflated by the GDP deflator) for the period 1960-73 remained more or less constant; real manufacturing value of output increased by about 58% and total energy consumption increased by over 55%. The energy-output ratio declined at a rate of 3.5% per year in the period 1974-81. As we are calculating the contribution of the change in the output mix to the total decline in energy use, we have substituted the calculated value of the decline in energy intensity for the coefficient of income elasticity.

58. The estimated price elasticities have wide range. In order to estimate an energy price elasticity that is consistent with the income and

investment elasticities, the energy price elasticity was derived from equation (24) after substituting estimates for the other parameters. The value of the price elasticity calculated in this fashion was found to be -0.21. This elasticity falls in the relevant range of our short-run estimated price elasticities.

59. By substituting the elasticity estimates in equation (24) the contribution of each factor towards the decline in total energy use, which averaged about 3% per year, can be estimated. The contribution of the change in energy prices to the total decline in energy consumption--about 62%--is the largest. The decline of energy demand due to technological changes is calculated to be 22%. The change in the energy content per unit of output has also played a significant role in the general decline in energy utilization in the US manufacturing sector. Our estimates show that the decline in the energy intensity per unit of output (substituted for the coefficient of income elasticity) has contributed as much as 16% to the total decline in energy demand. Obviously, part of these savings has been achieved by changing the output mix.

60. Another way of looking at this question is as follows. The decomposition of the change in energy intensity of output can be expressed in terms of its own price elasticity, the elasticity of substitution with other factors, variations in the prices of factors and factor shares, and technological change in the following way.

Assume the following demand-for-energy function:

$$X_i = X_i\left(P_E, P_K, P_L, T\right) \tag{25}$$

By totally differentiating equation (25) with respect to time we get:

$$\frac{\partial X_i}{\partial t} = \frac{\partial X_i}{\partial P_E}\ \frac{\partial P_E}{\partial t} + \frac{\partial X_i}{\partial P_K}\ \frac{\partial P_K}{\partial t} + \frac{\partial X_i}{\partial P_L}\ \frac{\partial P_L}{\partial t} + \frac{\partial X_i}{\partial T} \qquad (26)$$

where the rates of changes, i.e.,
$\frac{\partial X_i}{\partial t}$, $\frac{\partial P_E}{\partial t}$, $\frac{\partial P_K}{\partial t}$ and $\frac{P_L}{\partial t}$ are expressed in logarithmic form.

By using the relations, $\varepsilon_{EE} = \sigma_{ii}\ S_i = \frac{\partial(\log X_i)}{\partial(\log P_E)}$;

$$\varepsilon_{EK} = \sigma_{ij}\ S_j = \frac{\partial(\log X_i)}{\partial(\log P_K)}\ ;\ \sigma_{EL} = \sigma_{ij}\ S_j = \frac{\partial(\log X_i)}{\partial(\log P_L)}$$

and $\frac{\partial X_i}{\partial T} = \frac{\partial(\log X_i)}{\partial T} = \lambda_i^*$

(i = energy, and j = capital and labor)

Equation (26) can be rewritten as follows:

$$\partial X_i = \varepsilon_{EE}\left(\frac{\partial P_E}{\partial t}\right) + \varepsilon_{EK}\left(\frac{\partial P_K}{\partial t}\right) + \varepsilon_{EL}\left(\frac{\partial P_L}{\partial t}\right) + \lambda_i^* \qquad (27)$$

The elasticities used in the decomposition analysis are the values estimated in the translog formulation. By substituting these into equation (27), it becomes:

$$-\!-\ 3.56 \simeq -\ 5.55 - 2.55 + 6.3 - 1.75$$

which can be interpreted to mean that changes in energy prices, the energy-capital complementarity relationship and technological change have contributed towards the decline in the intensity of the factor demand for energy. The substitution relationship between energy and labor has worked in the opposite direction.

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