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# Energy Use and Technological Progress

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## 1. TEST FOR ENERGY AS AN OMITTED VARIABLE

Domar [3] has shown that if we begin with a Cobb-Douglas production function relating gross output to inputs of capital, labor, raw materials and energy:

$$(1) \quad Q = AK^aL^bM^cE^d$$

and construct a value added index V and define it as a function of capital and labor only, then

$$(2) \quad V = A^1K^{a^1}L^{b^1}$$

where $a^1 = 1/(1\text{-}c\text{-}d)$ and $b^1 = 1/(1\text{-}c\text{-}d)$. Thus raw materials and energy are given zero weights, and their former weights are assigned to capital and labor in proportion to their former weights. Thus the weights assigned to capital and labor are overstated and productivity growth is similarly overstated.

A complementary approach to this problem is that of omitted variables. Suppose that energy interacts with capital and labor in such a way that increasing energy input increases the productivity of capital and labor. Then subtracting energy from gross output and from inputs will not eradicate its effect on value added. Thus regressing value added on capital and labor only will result in biased estimates of the weights on capital and labor.

The reason that intermediate inputs are excluded from output is the danger of double counting since the output of one firm or industry can be the input of another. However, this is less true of energy than for other intermediate inputs, especially if we confine ourselves to the manufacturing sector. While manufacturing firms do generate and sell some electricity (the most important energy input), it is a relatively small fraction of total energy used. We will therefore ignore the double counting problem and use electrical energy used as a proxy for all energy consumed by manufacturing industries.

Our first test is to introduce energy in the form of electrical energy used into the value added production function and observe if there is an improvement in the estimation. To do this we collected data on value added in manufacturing [5,9, 10], capital stock in constant dollars [13], labor in manhours [5,9,10], and electricity consumed in manufacturing [9, 10], for the years 1929-1963. The results of this experiment are reported in Table 1.

TABLE 1

TEST FOR ELECTRICITY AS OMITTED VARIABLE
VALUE ADDED IN MANUFACTURING, ALL MFG, 1929-1963

| Regression | Time | Capital | Labor | Electricity | $R^2$ | DW |
|---|---|---|---|---|---|---|
| (1) | 0.030<br>(4.05) | -0.353<br>(1.61) | 1.19<br>(22.5) | | .95 | 2.03 |
| (2) | 0.027<br>(4.98) | -0.41<br>(2.60) | 0.71<br>(7.43) | 0.69<br>(5.42) | .97 | 2.52 |
| (3) | 0.014<br>(1.95) | 0.33*<br>(1.95) | 0.87<br>(5.75) | | .95 | 1.69 |

All regressions are run in first differences. Variables are measured in natural logs, t scores in parentheses.

*In equation (3) capital is adjusted by the Christianson-Jorgenson utilization index [2].

As the table shows, the introduction of energy does not improve the estimation (2) over the original estimate (1). In fact the best estimate is regression (3) in Table 1 where capital is adjusted for utilization by the Christianson-Jorgenson index of electricity actually used divided by the maximum amount of energy that would be consumed if the capital equipment were operated 24 hours a day, 365 days a year [2]. It would seem then that electricity is better used as a utilization adjustment, due to its assumed complementarity with capital, rather than as a separate input into the value added production function.

We can construct a similar test for cross-section data for the year 1962. The dependent variable is value added across two-digit industries in manufacturing [4]. The independent variables are manhours [9], gross capital stock [7], and electrical energy consumed [9]. The regression results are (t scores in parentheses):

(3) $\ln V = 3.08 + .45 \ln L + .26 \ln K + .04 \ln E$
$(3.70)\ (3.61)\ \ (1.24)\ \ (0.26)$
$R^2 = .80$

($3^1$) $\ln V = 2.98 + .45 \ln L + .30 \ln K$
$(4.12)\ (3.73)\ \ (3.22)$
$R^2 = .80$

The coefficient on energy is not significantly different from zero in equation (3). Omitting energy from the equation and reestimating yields ($3^1$). The t scores are improved while $R^2$ does not decline. It would appear that omitting electricity as anything but a utilization index is the correct choice.

## 2. TECHNOLOGICAL PROGRESS AND ENERGY

The results of the previous section indicate that energy is not an omitted variable in the production function. However, energy may nevertheless be a necessary ingredient in explaining productivity growth or technical progress where output per unit of capital and labor input increases. There are two plausible hypotheses concerning technical progress and energy use. The first is, as stated by L. G. Brookes, "Once slack has been taken up, the obvious way to increase output per man is to put more power at each man's elbow" [1; p. 84]. While Brookes does not preclude non-obvious ways to increase productivity, the implication is that increasing energy use is the sole or primary method of increasing productivity. The opposing hypothesis would argue that technical progress can be energy saving as well as energy using and more closely related to such things as increasing quality of the labor force, learning by doing, reduction of barriers to efficient use of resources, and other forces. One way to test these hypotheses jointly is to regress productivity growth on energy and a time trend. The time trend will collect the influences of omitted variables. If Brookes is right, the coefficient on energy will be significantly positive while the coefficient on time will not be significantly different from zero. If the alternative hypothesis is correct both coefficients could be significant but the time trend must be significant. In order to test these hypotheses, we collected data on total factor productivity, the usual measure of technical progress, as computed by Kendrick (PRODY) [11], energy use in constant 1967 dollars (ENERGY) [11] and in BTU's [11], for the years 1929-1970. The estimated equations in first differences to reduce autocorrelation are

(4) $\ln PRODY = 0.011\ TIME + 0.313 \ln ENERGY$
$(2.61)\ \ (4.00)$
$R^2 = 0.30,\ DW = 1.68.$

($4^1$) $\ln PRODY = 0.015\ TIME + 0.195 \ln BTU$
$(3.50)\ \ (3.24)$
$R^2 = 0.22,\ DW = 1.81.$

As equations (4) and ($4^1$) show, energy is significantly associated with productivity growth, but there is also a significant time trend indicating that other variables are also causing productivity to increase. Unfortunately good data on these omitted variables is difficult to find for the time period in question. Thus their influence will have to remain summarized in the time trend until better data becomes available.

One alternative approach is to use cross-section data on rates of productivity growth (1948-66) for various two-digit manufacturing industries [6]. The independent variables are cumulated real investment in plant (CIP) [9,10], cumulated real investment in equipment (CIE) [9,10], cumulated real output (CVAM) [9,10] (all of these are proxies for learning by doing), variability of output (VAR) [6], education of the workforce (EDUC) [6], ratio of research and development to sales (RD) [6], yearly hours worked (HOURS) [6], concentration ratio (CONCEN) [6], rate of growth of the concentration ratio (CONGRO) [6], percent of the workforce unionized (UNION) [6], and the rate of growth of energy use (EGROWTH) [9,10]. The results are reported in Table 2.

TABLE 2

DEPENDENT VARIABLE: PRODUCTIVITY GROWTH ACROSS U.S. TWO-DIGIT MANUFACTURING INDUSTRIES

| Regression: Independent Variable | (1) Coefficient | (1) t score | (2) Coefficient | (2) t score |
|---|---|---|---|---|
| CIP | -3.00E-5 | -0.15 | 4.00E-5 | 0.22 |
| CIE | 1.10E-4 | 1.34 | 5.00E-5 | 0.83 |
| CVAM | -1.00E-5 | -1.66 | | |
| VAR | 8.81E-3 | 0.04 | | |
| EDUC | 2.32E-1 | 0.70 | 1.88E-1 | 0.71 |
| RD | -4.62E-2 | -0.31 | 5.95E-3 | 0.06 |
| HOURS | 2.70E-0 | 1.30 | | |
| CONCEN | -2.34E-3 | -0.14 | | |
| CONGRO | 1.73E-1 | -0.61 | | |
| UNION | -5.03E-2 | -1.91 | -4.92E-2 | -2.47 |
| EGROWTH | 2.29E-1 | 1.34 | 1.00E-1 | 0.79 |
| | $R^2 = .49$ | | $R^2 = .31$ | |

All data in natural logarithms, N=20.

In the first regression using all the variables, the EGROWTH coefficient is not significantly different from zero. In fact the only significant variable is UNION which is negatively related to productivity growth.

In the second regression a number of questionable variables were dropped due to lack of significance or incorrect signs. Those variables with strong *a priori* arguments for retention were retained, including EGROWTH. However, the results are almost identical. EGROWTH is not significantly associated with productivity growth across industries in the postwar period. It would appear that while energy use is positively associated with technical progress, it is not a prerequisite for such progress.

A third approach to the question of the importance of energy growth for technological progress is to examine the ratio of gross national product to energy consumption. This would measure the productivity of energy itself. This ratio is reported for selected years from 1900-1973 below. GNP is measured in constant 1967 dollars [11] while energy use is measured in quadrillion BTU's [8,11,12].

TABLE 3

INDEX OF GNP TO ENERGY USE IN BTU's
(1900=100)
SELECTED YEARS

| | |
|---|---|
| 1973 | 109.2 |
| 1970 | 106.0 |
| 1960 | 107.7 |
| 1950 | 102.9 |
| 1940 | 93.7 |
| 1930 | 81.2 |
| 1920 | 69.7 |
| 1910 | 79.9 |
| 1900 | 100.0 |

Examination of Table 3 reveals that energy productivity has increased slightly from 1900 but more dramatically from 1920 probably because of electrification of industry. Therefore if past experience is a guide, we can expect increasing energy productivity in the future, especially with the added incentive of rising real energy prices.

A related approach to the same question is the energy elasticity, $(\Delta E/E)/(\Delta GNP/GNP)$, which shows the percentage increase in energy use from a one percent increase in GNP. We use the same data, GNP in constant dollars and energy use in BTU's from 1900 to 1973 to estimate the following equation, estimated in first differences to reduce autocorrelation:

$$\ln BTU = 0.80 \ln GNP \quad (5)$$
$$\text{standard error } (0.10)$$
$$\text{t score } (8.07)$$
$$R^2 = .48$$
$$DW = 2.48.$$

As equation (5) shows the energy elasticity is positive but significantly below unity at the 5 percent significance level. Thus a one percent increase in GNP will require only a .8 percent increase in energy consumption. This calculation does not adjust for fuel mix or relative fuel efficiencies. However, we are interested in total energy use, not the fuel mix.

One final question we can ask is if there has been a recent change in the energy elasticity. Various experiments with recent years did not show any significant changes in the 0.8 estimate of energy elasticity.

In conclusion, the evidence seems to be consistent with the hypotheses that energy is not an omitted variable in the value added production function, that energy use is associated with but not a prerequisite for productivity growth, that technological progress can be energy saving as well as energy using, and that increasing output measured as real GNP can be achieved with a less than proportionate increase in energy use.

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