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PATTERNS OF ENERGY CONSUMPTION AND ECONOMIC GROWTH AND STRUCTURE

by

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Patterns of Energy Consumption and Economic Growth and Structure

Peter E. de Janosi

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In recent years economists and policy makers have become increasingly concerned with the nature of the relationship between economic growth and the utilization of inanimate energy sources -- coal, oil, natural gas, hydroelectricity and nuclear power. There are sound reasons for this interest as the expansion in energy consumption concomitant with economic development has in some countries created serious problems. In selected instances, the growth in industrial production has placed a severe strain on available inexpensive domestic energy supplies which in turn necessitated an increase in imports and in this way contributed to balance of payments difficulties. At times also, energy shortages have been blamed as a cause for failures to meet planned national growth targets.

The analysis presented is designed to provide some information on a number of broad issues relevant to how the growth and structure of an economy affect energy consumption. The primary emphasis of the paper will be limited to the following two specific questions:

1) What are the quantitative responses of energy consumption to changes in national income?

2) What quantifiable economic explanations for these responses can be found?

While the analysis will build on earlier work of others, it is worth noting that much of the past research has been qualitative, or was based on limited statistical analysis and techniques. These limitations have been primarily of two sorts. In some cases only one country's experience was analyzed from a historical point of view without any reference to the observed record of other nations. Research, however, that followed an international comparative approach tended to be restricted to one single year. Both approaches -- the time series and the cross-section -- have provided useful insights into why energy consumption differs in different stages of economic development. Yet, being limited to either historical experience or geographic coverage reduces the generality of the findings and conclusions. Our research is designed to partially overcome these limitations by bridging the cross-section and the time series approach. It is worth noting, however, that this bridge is only one of many possible ones and much further work will be needed to test its particular validity.

The paper will be organized as follows: Part I will review the pertinent literature. In Part II the response of energy consumption to Gross National Product will be estimated for a series of countries for the period 1953-1965. Part III will introduce simple and multiple regression analyses of the inter-country differences in the relationship estimated in the previous section, and Part IV will summarize the major conclusions.

I

In an important study Schurr and Eliasberg investigated the long-term relationship between energy consumption and real GNP in the United States.[1/] They conclude that from about 1880 to 1915 there was a steady rise in energy requirements per unit of GNP. From 1915 through 1955, however, the use of energy per unit of GNP has been declining steadily. As the decline in the latter period was less than the increase in the former, the total 75-year period witnessed a 55 per cent rise in the amount of energy used per unit of GNP.

The decline in the output of energy per unit of GNP is not obvious from an a priori point of view. Indeed, increasing industrialization of the United States since 1915 might have resulted in a relative rise. The primary reasons for the decline according to Schurr and Eliasberg are the following:

(1) Increased efficiency of energy production resulting in dramatic increases in the useful energy output obtained from the raw energy input.

(2) A more rapid increase in electricity than in total energy consumption. Generation of electricity has experienced especially significant technological improvements that have resulted in greater efficiency.

1/ Sam H. Schurr and Vera F. Eliasberg, Energy and Economic Growth in the United States, Resources for the Future, Inc., Washington, D.C. 1962, partially based on S.H. Schurr and B.C. Netschert, Energy in the American Economy, 1850-1975, Baltimore, Johns Hopkins Press, 1960, Chapter 4. See also C.A.R. Wardwell, "Energy Output and Use Related to the GNP," Survey of Current Business, February 1961, Washington, D.C., pp. 28-32.

(3) The decade of the 1910's which marked the turning point in the input of energy per unit of real GNP also marks the turning point in capital and labor productivity.[2/]

(4) Finally, and probably most important, changes in the structural composition of GNP partially explain the decline in relative energy output. Prior to World War I the industrial sector of the economy increased faster relative to total GNP than it did in the following decades. At the same time the services sector, as a share of total GNP, increased faster in recent years. The impact of these structural changes is self-evident; industry is an energy-intensive sector of the economy and the services sector is, of course, less so.

Attempts to view the relationship between energy and economic growth in a broader geographic context have involved cross-section analyses that measure the level of energy consumption of countries at different stages of their economic development. For example, Mason related per capita income and per capita energy consumption in 52 countries for the year 1952. He concluded that "no country can enjoy a high per capita income without becoming an extensive consumer of energy."[3/] Also, Robinson and Daniel not only successfully related per capita income with per capita fuel consumption in 1949 but also related the changes in primary fuel consumption and manufacturing production, 1939-1950, for the principal countries

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2/ Some of the measurements of this point were disputed by E.F. Renshaw, "The Substitution of Inanimate Energy for Animal Power," Journal of Political Economy, June 1963, pp. 284-292. See also R.B. Du Boff, "Comment on E.F. Renshaw, op.cit.," Journal of Political Economy, April 1964, pp.196-197

3/ E.S. Mason, Energy Requirements and Economic Growth, National Planning Association, Washington, 1955.

of Western Europe and North America.[4/]

In addition, a number of other scholars attempted to make broad estimates of the relationship between per capita GNP and per capita energy consumption, though the conclusions they have reached are not always consistent. For instance, Kindleberger suggests that the rate of energy consumption accelerates as development gets beyond $450 per capita income.[5/] At the other end of the scale, Graham states that "as consumption rises above about four tons of coal equivalent per capita the rate of (energy) growth is invariably slow."[6/]

Particularly interesting work relevant to this paper has been done on the possible use of energy consumption as a proxy variable for capital. One of the first to give this possibility some attention was Frankel whose primary objective was to explain productivity differentials in the United States and Great Britain.[7/] He put forward the use of horsepower/worker figures to provide a substitute for the lack of capital data for these comparisons. Similar use of horsepower/worker data were made by J.B. Heath for Anglo-Canadian comparisons of productivity.[8/]

[4/] E.A.G. Robinson and G.H. Daniel, "Need for a New Source of Energy," The World's Requirements for Energy, United Nations, New York, 1956, pp.39-42.

[5/] Charles P. Kindleberger, Economic Development, McGraw-Hill Book Co.,New York 1958, pp. 22-25.

[6/] M.G. Graham, "Factors Affecting the Future Pattern of the World Energy Market, Sixth World Power Conference Proceedings, Melbourne, October 1962.

[7/] Marvin Frankel, "Anglo-American Productivity Differences: Their Magnitude and Some Causes," American Economic Review, May 1955, pp. 99-103.

[8/] J.B. Heath, "British-Canadian Industrial Productivity," Economic Journal, December 1957, pp. 665-686.

Frank, using measures of capital data available for the United States and the United Kingdom, correlated energy consumption and the industrial capital stocks for these two countries.[9/] In both cases he found very high correlation for the years 1880-1948. Oliver, while objecting to some of Frank's conclusions as too ambitious also supports Frank's general findings that "an index of energy can be used as an index of capital."[10/] Warren suggests that for a less developed country "statistics on energy consumption represent, with certain qualifications, a broad gauge of aggregate economic activity in the country."[11/] Finally, Olson experimented with a formulation of a Cobb-Douglas production function that substitutes energy for capital. He concludes that "energy is an index of a certain kind of capital; namely, energy consuming capital of all kinds -- both measuring different ways the productive apparatus of society."[12/]

9/ A.G. Frank, "Industrial Capital Stocks and Energy Consumption", Economic Journal, March 1959, pp. 170-174.

10/ F.R. Oliver "Comment" on A.G. Frank, op.cit., Economic Journal, December 1959, pp. 809-812.

11/ J.C. Warren, Jr., "Energy and Economic Advances," The Philippine Economic Journal, First Semester 1964, pp. 78-87.

12/ Ernest C. Olson, "Factors Affecting International Differences in Production," American Economic Review, May 1948, p. 515.

II

The initial step taken in estimating the relationship between energy consumption and economic development was the selection of the countries on which to base the first part of the study -- the time series analysis. Countries that met the following criteria were selected:

1) Representative of a wide spectrum of stages in economic development;
2) Consistent energy and GNP data available for the period 1953-1965;
3) Characterized primarily by a prevailing market economy. Excluded, therefore, were the Soviet Union, Eastern Europe, and China (Mainland).

Altogether thirty countries met all the criteria adequately. In terms of 1964 per capita Gross Domestic Product they range from $78 in India to $3,002 in the United States. They also differ greatly in terms of economic characteristics such as degree of industrialization, rate of economic growth, and importance of foreign trade sector.

The basic gross national product data and energy data used in the research are respectively published in the United Nations Yearbooks of National Account Statistics, New York, and United Nations, World Energy Supplies, Series J, New York. In all cases GNP data are measured in local currencies, but have been adjusted for price changes. The energy data are measured in millions of metric tons of coal.

We have decided to follow the practice of previous work and define energy consumption as a derived concept. It is obtained by taking a country's production and imports of energy and subtracting from this total exports, additions to inventories and bunkers. As the various energy sources are measured in different units of differing calorific values, it has been found necessary to convert these into a common unit. The standard method of conversion is to express all energy in terms of metric tons of coal equivalent.[13/]

In order to make a quantitative estimate of the response of energy consumption to GNP, an equation in logarithmic form was fitted for each of the thirty countries as follows:

$$\text{Log } E = a + b \log GNP$$

where

E = Energy [illegible]ption in millions of metric tons of coal

GNP = Gross National Product in price adjusted local currencies.

The results of this statistical exercise is shown in Table I. The first conclusion that can be drawn is that the GNP seems to be, without exception, highly correlated with energy consumption. R^2 is in all but two cases above .9; in the two exceptions it is above .8. The t-ratio (b/σ) in all cases is well above the 99% confidence level ranging from a low of 7.5 to a high of 43.4.

[13/] United Nations, World Energy Supplies, Series J, New York.

Even though the statistical reliability of the regression is uniformly high, the striking substantive result is the wide range in the income elasticities. As can be seen from Table I in which countries have been arranged according to their income elasticity, the Philippines has the highest and the United Kingdom the lowest elasticity. At the top of the range the elasticity is four times larger than that at the bottom of the range. The average elasticity is 1.34.

Cursory examination of Table I confirms one finding of some previous studies, namely, that the income elasticity of energy consumptions is in part influenced by a country's stage of economic development. However, such conclusion is confounded by the high ranking of the Scandinavian countries and Switzerland, on the one hand, and the low position of Brazil, Taiwan, and two European less developed countries -- Portugal and Greece. Thus a simple interpretation will not do and in the next section alternative and more complex explanations of the wide disparity of income elasticities will be explored.

TABLE I

Relationship Between Energy Consumption and Gross National Product

Country	b	σ_b	R^2
Philippines	2.0696	.0764	.986
Thailand (a)	1.9341	.1223	.958
India (a)	1.8925	.0974	.972
Finland (a)	1.8739	.0939	.972
Iraq (a)	1.8462	.1777	.908
Italy	1.7666	.0687	.984

TABLE I - continued

Country	b	σ_b	R^2
Israel	.9649	.0776	.933
Japan	.9605	.0300	.990
United States	.9588	.0221	.994
France	.8778	.0637	.945
Belgium	.8155	.0962	[illegible]
Germany	.6612	.0478	.945
United Kingdom	.4780	.0637	.837

(a) Gross Domestic Product at Factor Cost

(b) Expenditure on Gross Domestic Product.

III

As the initial step we explored simple, one variable, "explanations" of the calculated elasticities. The first and most obvious one is based on the hypothesis that the income elasticities of energy consumption are related negatively to the level of economic activity -- a relationship already noted by Graham.[14/] Per capita energy consumption[15/] and per capita Gross Domestic Product[16/] are used as proxy variables for the level of activity.

An alternative hypothesis tested is that income elasticities are related to the industrial structure of the Gross Domestic Product. Schurr and Eliasberg's work related to this hypothesis; namely, that the structural composition of GDP partially explains the nature of energy consumption.[17/] For a measure of this structure we use the share of mining and manufacturing (expected relationship negative) and the contribution of agriculture (expected relationship positive) in the Gross Domestic Product.[18/]

The final hypothesis formulated is that the structure of energy consumption exerts an important influence on the elasticities depending on the efficiency and price of the predominant energy sources. Two measures are employed: the share of coal, and the share of hydroelectricity in total energy consumption.[19/]

14/ Graham, loc.cit.

15/ United Nations, World Energy Supplies, Series J, New York.

16/ United Nations, Yearbook of National Account Statistics, New York 1966.

17/ Schurr and Eliasberg, loc. cit.

18/ Yearbook of National Account Statistics (computed)

19/ World Energy Supplies, op.cit., (computed).

The rationale for selecting the share of coal was that it is a domestic fuel source, where price in most cases is maintained at an artificially high level. This was, however, not always so and coal, historically, was available in practically all industrialized countries and was probably used inefficiently. Thus, the greater the share of coal in total energy consumption, the less energy consumption is added per unit of increased GNP as there is room for increased efficiency of energy utilization. We, therefore, expect it to be inversely related to the elasticities. Hydroelectricity on the other hand while also a domestic fuel source is usually inexpensive wherever it is available, and, therefore, the greater its share in energy consumption the greater we expect the income elasticity to be.[20/]

For all six simple regressions representing these hypotheses, the dependent variable was the calculated income elasticities of energy consumption for 28 or 30[21/] countries as calculated in section II and the independent variables were the appropriate measures based on 1964. (Not all data were available for 1965, the last year of the time period under analysis).

20/ We used the share of coal and hydroelectricity, respectively, as a proxy for relative prices because, contrary to suggestions we have received, such prices are not available on a comparable basis.

21/ Sweden and Switzerland do not publish GDP by industrial origin, and therefore, had to be omitted in some of the calculations.

The first six equations in Table II summarize the statistical results of the regressions. In all cases the parameters had the "correct" sign and all but equation 4 were significant at the .05 level.[22/] Thus, the hypotheses appear to be sensible, but, of course, the important and significant question still remains how much a multivariate analysis can improve on these results.

In view of the fact that the share of hydroelectricity in total energy consumption did not turn out to be significant in the simple regression this variable is omitted from the further analysis. For experimental purposes we combined the remaining five variables (Table II, Equation 7) although the results bore out our expectations that the coefficients would be unstable because of the high intercorrelations among some of the independent variables. There was, however, a sizeable improvement in the correlation coefficient compared to the simple regressions.

In the remaining computations, alternative combinations of variables were used. One of the most interesting findings is that the level of economic activity variables were not statistically significant, except marginally in Equation 9 (X_1) and 10 (X_2). It is also true in these equations that the measure of industrial structure was the share of mining and manufacturing in the GDP (X_5) rather than the share of agriculture,

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22/ A possible explanation as to why the hydro variable performed so poorly is that virtually all of hydro is publicly owned and, more likely than not, uneconomically priced. For an interesting institutional account of such pricing see Judith Tendler, Electric Power in Brazil: Entrepreneurship in the Public Sector, Harvard University Press, Cambridge, 1968.

TABLE II

Relationship between Income Elasticity of Energy Consumption and Selected Measures of Economic Development and Structure.

	$\mu = \alpha_o$	$+10^{-3}\alpha_1 X_1$	$+10^{-3}\alpha_2 X_2$	$+10^{-3}\alpha_3 X_3$	$+10^{-3}\alpha_4 X_4$	$+10^{-2}\alpha_5 X_5$	$+10^{-2}\alpha_6 X_6$	R^2
1)	1.568	-.218 (.090)						.173
2)	1.559		-.091 (.032)					.226
3)	1.585			-8.694 (2.738)				.265
4)	1.292				+7.913 (9.302)			.025
5)	2.084					-2.639 (.871)		.261
6)	.945						+2.254 (.599)	.353
7)	1.228	-.028 (.285)	+.022 (.089)	-8.555 (2.514)		- .220 (1.015)	+2.303 (1.094)	.602
8)	1.126		+.017 (.037)	-8.710 (2.308)			+2.478 (.724)	.602
9)	2.151	-.173 (.087)		-6.537 (2.444)		-1.612 (.814)		.518
10)	2.136		-.052 (.031)	-6.397 (2.513)		-1.734 (.820)		.500
11)	1.121	.044 (.118)		-8.619 (2.281)			+2.474 (.794)	.601

TABLE II - continued

( ) = Standard error of regression coefficient.

X_1 Per Capita Gross Domestic Product (U.S. Dollars)

X_2 Per Capita Energy Consumption (Kgs of coal equivalent)

X_3 Share of Coal in Total Energy Consumption (%)

X_4 Share of Hydroelectricity in Total Energy Consumption(%)

X_5 Share of Mining and Manufacturing in Gross Domestic Product (%)

X_6 Share of Agriculture in Gross Domestic Product (%).

The two variables that appear to maintain the most persistently significant relationship were primarily the share of coal in total energy consumption and the share of agriculture in GDP. In all cases where coefficients were found to be statistically significant, the sign were also consistent with the stated hypothesis, which was that income elasticities of energy are related both to the industrial structures of GDP and to the structures of energy consumption.

IV

The results obtained in our analysis confirm the earlier substantive finding reached in various studies of energy consumption based on the United States experience. We have also found overwhelming evidence in other countries that in fact a similarly strong relationship exists between economic growth and energy consumption, but that this relationship differs widely among countries.

While relative income levels do have some power in explaining the differential response of energy consumption to economic growth, we have also discovered two other significant associations. The first of these consists of measures of the structure of the economy as indicated respectively by the share of agriculture and the share of mining and manufacturing in GDP. The second set of variables that seems to affect the differential response relates to the composition of the sources of energy consumption. That is, the smaller the proportion of one fuel source - coal - in total energy consumption, the more elastic the response of energy consumption to economic

growth. Thus, the response of energy consumption to economic growth is not a simple one, and is also influenced by factors other than the level of income.

In conclusion we must emphasize that the findings presented here are to be interpreted with caution. We are especially concerned about the inadequacies of the currently used index of energy consumption and the possible biases introduced by its use in both developed and underdeveloped countries. In the latter countries an important, but decreasingly so, part of energy consumption is satisfied from non-commercial sources. Because non-commercial energy is not measured in the official statistics, the on-going substitution of commercial for non-commercial energy has probably introduced an upward bias into the calculated elasticities for the less developed countries.[23/] A bias in the other direction centers on the developed countries and is the consequence of the substitution of oil and gas for coal.[24/] (Most developed countries were originally coal based energy economies; the less developed countries usually satisfied thei fuel requirements from oil). The conversion of all fuels into coal equivalents assumes an average relative efficiency of energy sources even though in reality some fuels are very much more efficient, in some applications, as are others. In inter-country comparisons it may make a difference if the substitution of oil and gas (efficient fuels) for coal (relatively inefficient

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23/ N.B. Guyol, India's Energy Balance, 1959, National Council of Applied Econo Research, New Delhi, 1961.

24/ F. Gerard Adams and Peter Miovic, "On Relative Fuel Efficiency and the Outp Elasticity of Energy Consumption in Western Europe," The Journal of Industr Economics, November 1968 and Ralph Turvey and A.R. Nobay, "On Measuring Ene Consumption," Economic Journal, December 1965, pp. 787-793.

fuel) is proceeding at a differential pace. This may account, in part, for the low observed elasticities for such originally coal based countries as the United Kingdom, Germany, Belgium and France.

Regrettably, as yet, no satisfactory answers have been provided to the problems of measurement. In spite of this -- and we do not believe that this is crucial -- we hope that our analysis has taken steps toward answering the basic questions posed at the beginning of the paper and has been successful in offering some new insights [illegible] ion and economic growth and structure.