ENERGY CONSUMPTION AS AN INDICATOR OF LONGEVITY

Gains in longevity over the past 25 years have energy-dependent and independent components.

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PREFACE

This report is one in a series by the authors describing their work on the relationship between health and energy. The study was carried out at IIASA in 1976-1977 as part of the joint UNEP/IIASA project *The Comparison of Energy Options: A Methodological Study*. Using cross-sectional as well as longitudinal data, the series examines the role of economic development in improving health. The national data used here extended over the period 1900 to 1975 and covered 99 percent of the world population. The results of this research are descriptive, but may be used in a predictive manner for energy, education, and health policy decisions.

This report describes the relationship between health, measured by longevity and infant mortality, and industrial development, measured by per capita commercial energy consumption.

SUMMARY

This study is a "first cut" at analyzing the relationship between commercial energy consumption and health. As measures of the latter, we have used both infant mortality and longevity data from birth of 150 countries. Both show strong relationships to energy describing logistic functions with an upper plateau at 2000 kg coal equivalent beyond which no further improvement occurs. When the regression of longevity on energy consumption is examined over previous decades, a shift is observed such that the energy requirements for any given level of longevity or infant mortality are shown to be declining. Using 1950 data for energy consumption, approximately half of the subsequent improvements in health could be predicted. The residual is ascribed to a poorly defined "time effect" which is non-economic in character and which has improved health measures among all countries regardless of level of development.

Energy Consumption as an Indicator of Longevity

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"It is better to be rich and healthy than poor and sick"

Graffito, University of California, School of Public Health, Berkeley.

INTRODUCTION

Almost two hundred years ago, Malthus suggested that there existed an intimate relationship between economic activity and population growth. In spite of a long history of investigation, the existence of such a relationship remains controversial, some authors concluding that economic activity does indeed influence population size, others concluding the opposite [1].

The difficulty lies in the estimation of economic activity. A universally satisfactory measure of economic activity does not exist. In its absence, gross national product (GNP) adjusted for population size has most commonly been used as such a measure, but with certain disadvantages. For instance, only those goods and services that are traded in the market place become part of the national products, excluding activities such as the work mothers provide for their families. International comparisons suffer from the need for establishing common units as a measure of GNP. Furthermore, longitudinal measures of GNP fail to convey improvements in the quality or changes in the cost of production. For example, computers currently available at low price perform functions that could not have been carried out on the much more expensive computers of a few decades ago.

Studies of mortality differentials within countries avoid some but not all of the problems identified above by using income as a measure of economic condition. Such studies also encounter the difficulty that vital statistics records do not link with income. Occupational status has been used as a proxy for income, but is rarely available, often relates poorly to income, and can only be used for the analysis of adult health. Until recently comparative studies have generally been limited to those few developed countries that routinely collected vital statistics. Such studies do show strong relationships between socio-economic status and mortality [2].

One of the necessary characteristics of modern economic development is the augmentation of work performed by man's muscle and that of his domesticated animals by energy derived from other sources. As early as 1926 energy was seen as the driving force of the economy [3]. Without entering the controversy regarding net energy analysis [4], one may hold that per capita energy consumption serves as a useful index of development and, in international comparisons, has a number of advantages over GNP. Energy is measured in constant physical units and requires no arbitrary adjustments, e.g., for inflation. Also, commercial energy consumption is more likely to be accurately reflected in national statistics in contrast to the reporting of goods and services which is often incomplete.

Considerable attention has recently been devoted to understanding the relationship between energy consumption and GNP within different societies [5]. Cross-sectional studies demonstrate at least a threefold difference in mean energy use per unit of GNP, the extremes being partly explainable on the basis of differences in industrial mix, transportation requirements, domestic use, and weather. Longitudinal changes within countries also occur. In the US, energy requirements per dollar of GNP rose until the 1920s and have gradually fallen since, apparently stabilizing in recent decades [6]. Nevertheless, for the 130 countries studied herein, energy consumption and GNP were highly correlated (r=0.93).

In this study, we use commercial energy consumption as an index of economic development for the purpose of exploring the relationship between industrialization and mortality among 130 countries for which data are available. Analyses are both cross-sectional and longitudinal, covering the period from 1950 to 1975. From this analysis we conclude that economic development has a measurable and beneficial effect upon longevity but that other factors also make a significant contribution. It appears that energy analysis deserves further study as a means of understanding causes of human mortality.

PRELIMINARY ANALYSIS

We chose two measures of mortality for study: infant mortality and longevity from birth. The latter is a composite measure of mortality at all ages whereas the former is defined as the mortality during the first year of life. Infant mortality is examined separately because it is a major determinant of longevity from birth and because it is considered a sensitive indicator of changing health patterns. One disadvantage in international comparisons is that the definition of infant mortality varies slightly among countries. For example, still births are excluded from infant mortality in some countries but not in others.

We obtained estimates of population size, GNP, infant mortality, longevity from birth [7][1], and energy consumption per capita [8] for 154 countries. However, we limited the analysis to the 130 countries that had complete data. These comprised 97 percent of the world population. Infant mortality estimates for the years 1950, 1960, and 1970 were available for 47 countries covering 69 percent of the world population. Longevity from birth data for 1950, 1960, and 1970 was available for 42 of these countries [9,10][2].

For further analysis, we divided the group of 47 countries into 3 subgroups: Eastern European (those having centrally planned economies), developed (highly industrialized in 1950), and less developed (the remainder). A list of these countries follows (those for which longevity was not available are marked with an asterisk):

Developed: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Federal Republic of Germany, Iceland, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, United Kingdom, United States.

Less Developed: Argentina, Chile, People's Republic of China, Costa Rica, Cyprus*, El Salvador, Egypt, Equador, Guatemala, Hong Kong*, India, Mauritius, Mexico, Panama, Philippines*, Portugal, Sri Lanka, Uruguay*, Venezuela*.

Eastern Europe: Bulgaria, Czechoslovakia, German Democratic Republic, Hungary, Poland, Romania, USSR, Yugoslavia.

In attempting to relate mortality to energy we explored various transformations of per capita energy consumption. The logarithm improved the linear correlation with both infant mortality and longevity. Since economic benefits of industrialization are not equally available to all members of a nation, we adjusted per capita energy consumption for income maldistribution. We calculated an estimate of median energy consumption based on the Gini index [11]. The correlation between mortality and this estimate was essentially identical to the correlation with the unadjusted per capita energy consumption for the same samples.

Assuming that differences in age distribution among countries account for some variation in energy consumption, we carried out an adjustment in which those members of the population presumably not engaged in productive work, i.e., those below age 15

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[1] Data were taken from [7] with the mention of statistical outlines Kuwait, Libya, Qatar, and United Arab Countries.

[2] Data for the People's Republic of China were abstracted from [10].

and those above age 65, were removed. This adjustment also did not reduce the unexplained variance in mortality and therefore was disregarded.

Since the variable energy requirements per unit of economic output varies among countries of similar economic development, we attempted another transformation in which energy consumption was divided by GNP in order to adjust for these differences. Neither this new variable nor its logarithm improved the correlation between energy and mortality.

Although mortality data were fitted well by a linear, or log-linear, function to energy, both historical and biological considerations support the use of nonlinear functions. Examination of historical infant mortality data from both the US and the United Kingdom clearly suggests a logistic function with an early plateau, followed by a rapid decline with industrialization in the late 19th and early 20th centuries, followed by a distinct slowing as infant mortality falls below 20 deaths per 1000 live births (20/1000). Furthermore, logic dictates that some minimum number of infants will inevitably die due to genetic disease and complications of necessarily complex medical intervention, i.e., infant mortality will never become zero (or negative) as might be implied by a linear relationship. Similar arguments support a logistic function with an upward slope for longevity.

In the following analysis we used a regression equation of the form:

$$y = \alpha + \beta \exp(-\gamma x) + e \quad , \tag{1}$$

where y stands for infant mortality, x for per capita energy consumption, e is an error term, and α,β,γ are parameters estimated from the data. When plotted against log x, this function displays an early and a late plateau. The use of this model is supported by logical arguments, such as the energy saturation model, as well as by the data (see Figure 1). Historical precedence also exists. Such an equation was first used in life table studies by Gompertz in 1825 and modified to the above form by Makeham in 1867. The regression equation for longevity is:

$$y = \frac{1}{\alpha + \beta \exp(-\gamma x)} + e \quad , \tag{2}$$

where y stands for longevity from birth and the remaining terms are as in Equation (1).

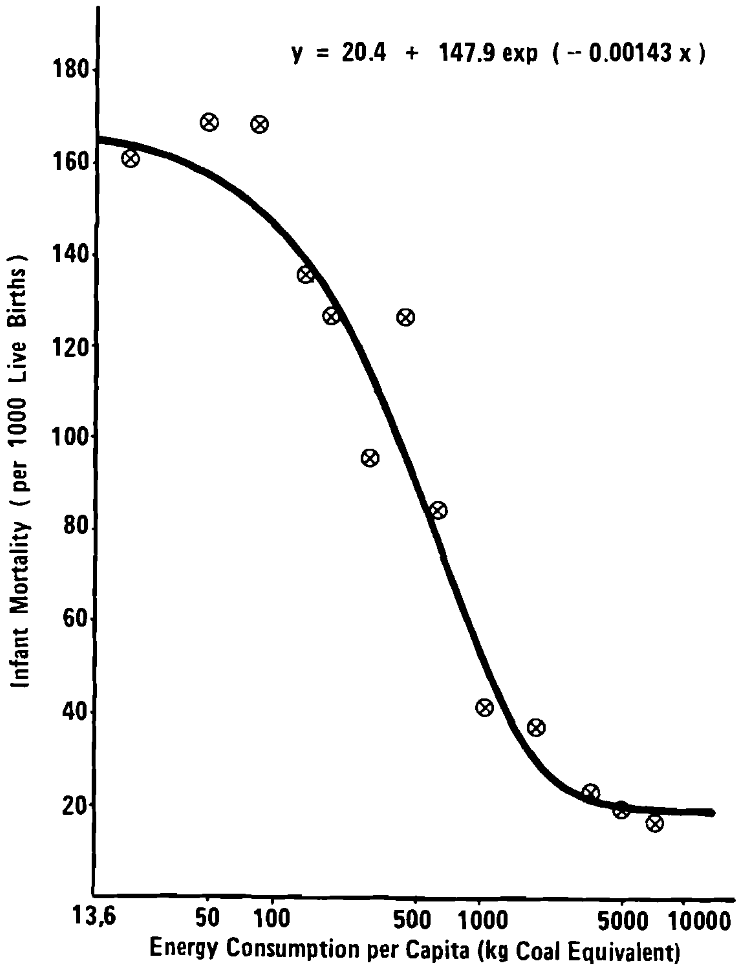

Figure 1. Relationship between energy consumption and infant mortality for 130 countries (1975 data).

ANALYSIS OF INFANT MORTALITY

Figure 1 shows the fitted regression equation of the 1975 infant mortality data on per capita energy consumption (in logarithmic scale) for 130 countries[3]. The data points shown are the averages of successive groups of 10 countries ranked in the order of increasing energy consumption. The sharp decline

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[3]An iterative computer algorithm was used to derive the fitted regression equations. The standard error of estimate (SE) for this equation is 30.8. Thus 77 percent of the original variance was "explained". The SEs for the equations in Figure 2 are 27.7, 21.4, and 17.7 for the years 1950, 1960, and 1970, respectively. Thus 79, 78, and 74 percent of the variances were "explained", respectively. For longevity, the SE for the equation in Figure 4 is 5.6, and for Figure 5 the SEs are 5.4, 4.2, and 3.5 for the years 1950, 1960, and 1970, respectively. The percentages of variance "explained" were 81, 79, 74, and 76 percent, respectively.

Table 1. Infant mortality for selected groups of countries (1950, 1960, 1970) per 1000 live births

	Developed (N=20)	Less Developed (N=19)	Eastern Europe (N=8)	Total (N=47)
For 1950	41.1±16.1	98.0±30.7	98.3±23.0	73.8±36.9
For 1960	26.2± 8.6	75.4±28.2	51.3±21.3	50.3±30.7
For 1970	17.6± 4.9	64.0±28.3	33.3±13.2	39.0±28.5
Decline 1950 to 1970	23.5±13.4	34.0±20.5	65.0±13.5	34.8±21.8
Predicted decline associated with energy	13.4±13.1	15.1± 9.9	20.4±15.3	15.5±12.8

in infant mortality appears at annual consumption levels of about 100 kilogram of coal equivalent (kgce) and continues to 4000 kgce where no significant benefit in infant mortality is observed to accrue with increased energy consumption.

Data for the years 1950, 1960, and 1970 are summarized in Tables 1 and 2. The regression equations for these years are

Table 2. Per capita energy consumption for selected groups of countries (1950, 1960, 1970) in kg of coal equivalent

	Developed (N=20)	Less Developed (N=19)	Eastern Europe (N=8)	Total (N=47)
For 1950	2327±1720	304±251	1502±1114	1368±1531
For 1960	3028±1765	506±437	2653±1678	1945±1807
For 1970	4813±2147	732±623	4103±1769	3042±2514

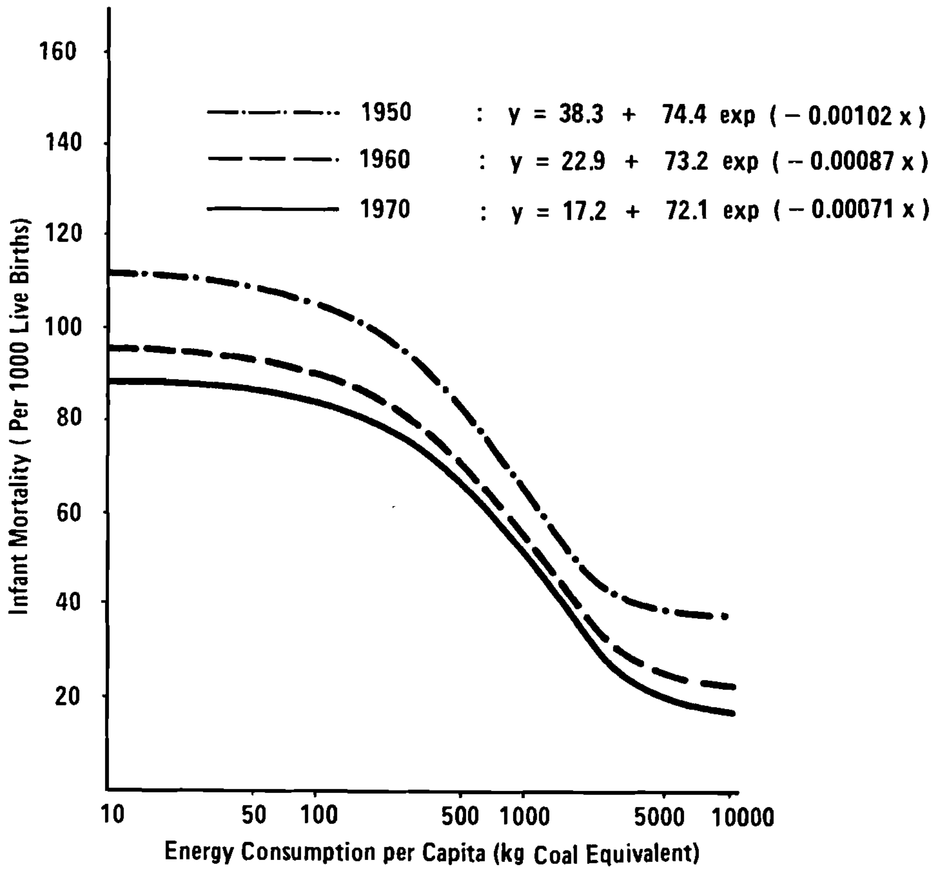

Figure 2. Relationship between energy consumption and infant mortality for 47 countries (1950, 1960, 1970 data).

illustrated in Figure 2. The shapes of the curves are similar. Their deflections occur at about the same energy levels and they are essentially parallel. The 1960 curve lies at an infant mortality level that is approximately 15/1000 lower than the 1950 level at all energy levels, and the 1970 curve is about 20/1000 lower than the 1950 level. However, the upper plateau of the 1970 curve (88/1000) is much lower than that of the 1975 curve (166/1000). This is due to the fact that the 1970 sample of 47 countries is dominated by developed countries with low infant mortality, while the 1975 sample of 130 countries is dominated by developing countries with high infant mortality.

We thought it useful to ascertain the effectiveness of the cross-sectional equation (Figure 2) for predicting declines in infant mortality as energy consumption increased over time. For each country, we used the 1950 regression equation to calculate the predicted infant mortality at the energy consumption for both 1950 and 1970. We called the difference "predicted decline". Table 1 and Figure 3 show the actual and predicted declines in infant mortality. The predicted portion of the

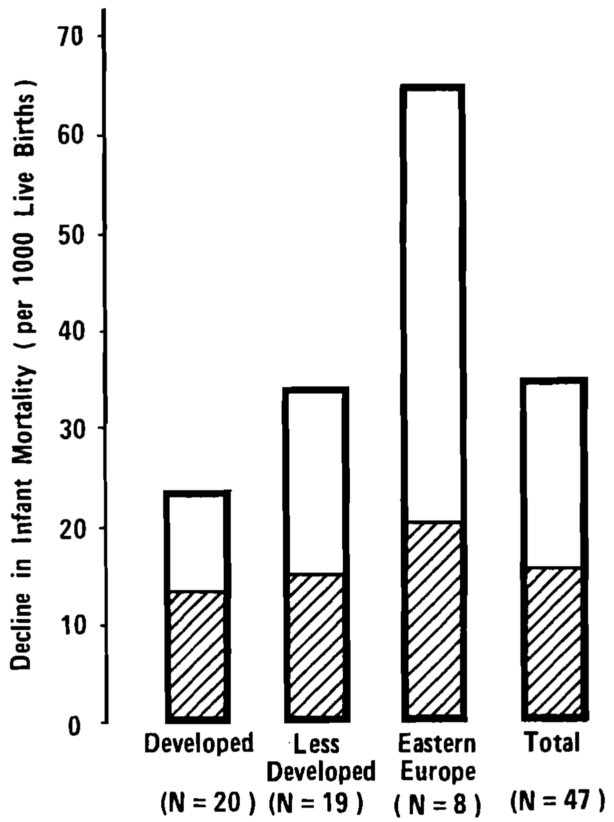

Figure 3. Average decline in infant mortality (1950 to 1970) for selected groups of countries and predicted decline associated with energy (shaded).

infant mortality decline is assumed to be "energy-dependent", whereas the remainder is considered "energy-independent". The energy-independent portion is due partly to a world-wide downward shift in infant mortality and partly to individual country variation. Almost half (0.45) of the total decline for the 47 countries can be "explained" on the basis of increased energy consumption and associated industrialization. Eastern European countries experienced the largest drop in infant mortality, both energy-dependent and energy-independent, while developed countries changed the least in both categories. It is interesting to note that, while the cross-sectional equation "explains" almost 80 percent of the *variation* among countries, it "explains" less than half of the actual *decline* from 1950 to 1970.

ANALYSIS OF LONGEVITY

Since longevity from birth is a statistic highly sensitive to infant mortality, it could be anticipated that the former shows a relationship to energy consumption similar to but the reciprocal of the latter. Figure 4 shows this anticipated regression equation of longevity on energy consumption for the 1975 data for 130 countries.

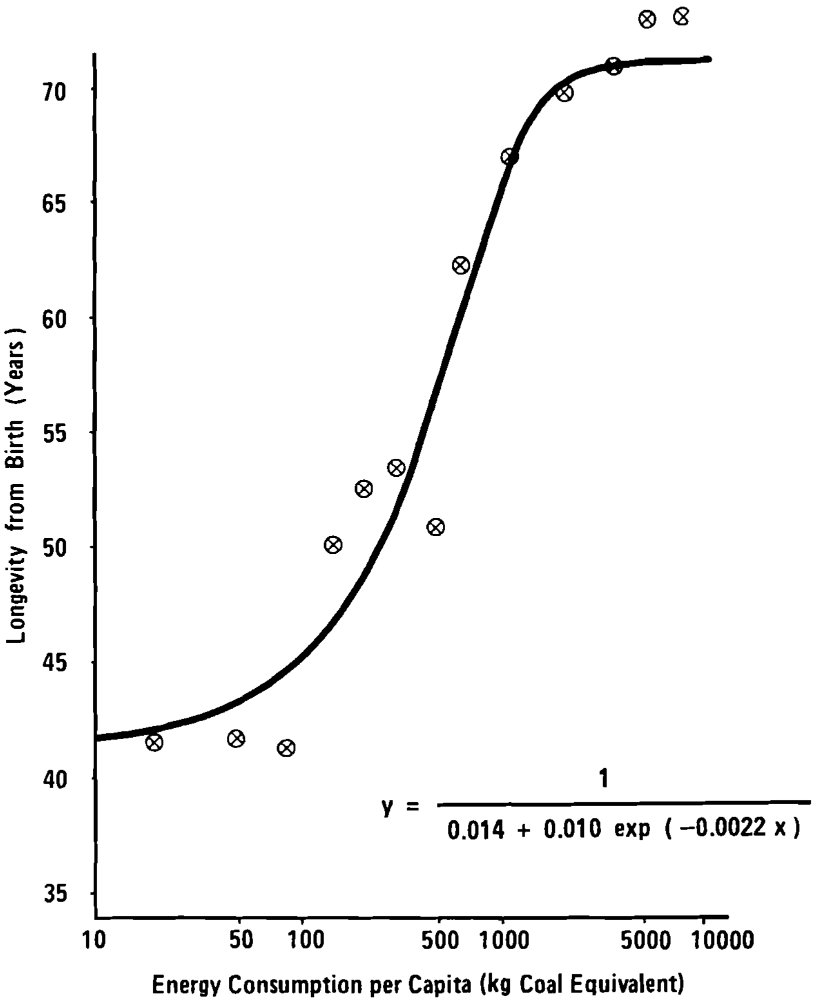

Figure 4. Relationship between energy consumption and longevity for 130 countries (1975) data.

Figure 5 shows the curves for the smaller sample of 42 countries for 1950, 1060, and 1970. Improvements in longevity from birth have occurred in countries at all levels of energy consumption, but unlike in the case of infant mortality, the gain has been greatest in these countries at the lowest level of development. Approximately ten years were gained over the study period at the lower end of energy consumption and five years at the upper end. The point at which longevity leaves the lower plateau is approximately the same as that associated with declining infant mortality rates (about 100 kgce); however, increases in longevity reach an upper plateau at about 2000 kgce per capita, considerably lower than the 4000 kgce at which infant mortality reaches its plateau.

The gains in longevity over the study period can also be examined in Table 3 and Figure 6. Unlike the infant mortality experience, where the greatest declines were achieved by Eastern European countries, longevity gains were greatest in the less developed countries (10.8 years), and the energy-dependent portion (5.0 years) was also greatest for this group of countries.

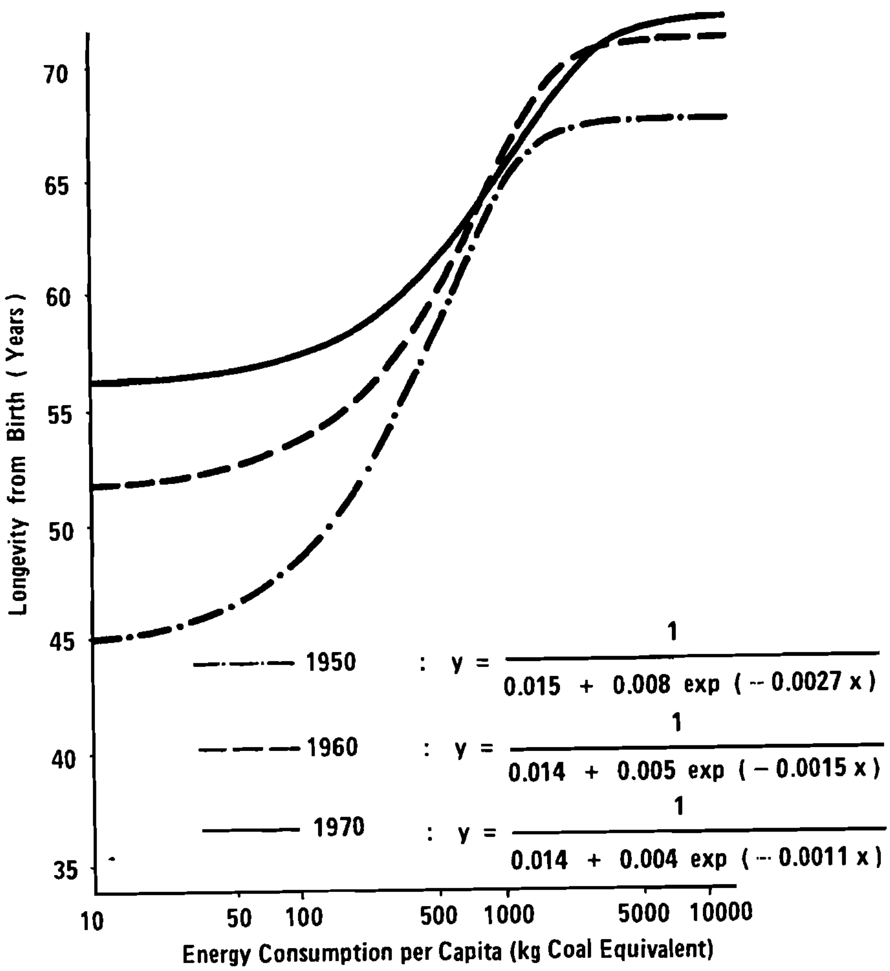

Figure 5. Relationship between energy consumption and longevity for 42 countries (1950, 1960, 1970 data).

CONCLUSIONS AND DISCUSSION

Our interpretation of the data suggests that economic development as measured by commercial energy consumption has a powerful effect on mortality, but that other secular factors that may not be directly related to industrialization, at least as reflected by energy consumption, operate in the same direction.

These conclusions are consistent with those of Preston [12]. Using per capita GNP as an index of economic development, he estimated that 16 percent of the increase in longevity between 1938 and 1963 is attributed to increases in per capita GNP per se. His methodology, like ours, made use of a logistic regression equation. We have not attempted to identify the mechanisms mediating either energy-dependent or -independent factors but offer some observations for constructing and testing hypotheses

Table 3. Longevity from birth for selected groups of countries (1950, 1960, 1970) in years.

	Developed (N=20)	Less Developed (N=14)	Eastern Europe (N=8)	Total (N=42)
For 1950	67.3±3.0	50.7±6.5	62.6±2.2	60.8±9.1
For 1960	70.8±1.7	56.6±7.0	67.8±2.2	65.5±7.7
For 1970	72.3±1.4	61.5±6.4	69.9±1.3	68.2±6.3
Increase 1950 to 1970	5.0±2.6	10.8±3.8	7.3±1.9	7.4±3.9
Predicted Increase associated with energy	1.4±2.8	5.0±3.1	3.1±3.7	3.1±3.5

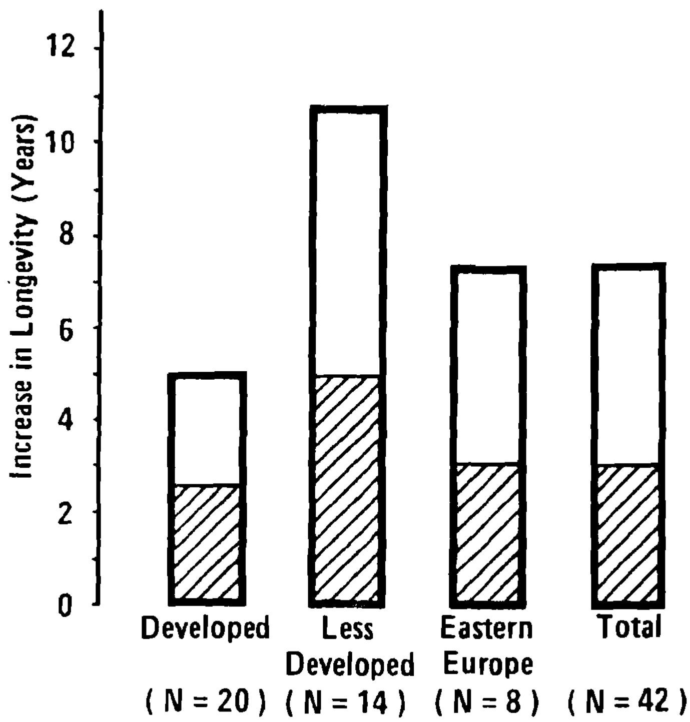

Figure 6. Average increase in longevity (1950 to 1970) for selected groups of countries and predicted increase associated with energy (shaded).

regarding these mechanisms. The energy-dependent factor appears to have the following characteristics:

(1) Its effect is "S" shaped, having lower and upper thresholds as do many biological phenomena.

(2) It does not necessarily operate simultaneously or with equal force on all age groups. Since, as energy consumption increases, longevity reaches a plateau prior to infant mortality we infer that the reduction in mortality of older age groups stabilizes earlier than infant death rates.

With the caveat that our study period (since 1950) has been very limited and that observations based on this experience may not be valid for other historical or future time periods, we have formulated four phases of the relationship between energy consumption and mortality. These phases are implied by the logistic model used here to fit the data.

Phase I "Minimum Energy."

High death rates exist at all ages. Infant mortality rates are above 150/1000, and longevity is less than 45 years. Annual energy consumption is under 100 kgce per capita. Presently, there are 30 countries (8 percent of the world population) in this phase, of which Afghanistan, Yemen, and Ethiopia are examples.

Phase II "Moderate Energy."

Death rates are declining at all ages with rapidly increasing longevity. The average infant mortality is estimated to fall from 150 to 30/1000 and longevity to rise from 45 to 70 years. Annual energy requirements increase from 100 to 2000 kgce per capita. In this phase, an increase of 100 kgce per capita is estimated to reduce infant mortality at an average rate of 6.3/1000 and to increase longevity by an average of 1.3 years. Seventy-six countries (two thirds of the world) are currently in this phase. These include India, China, and most of South America.

Phase III "Moderately High Energy."

Infant mortality rates continue to fall (from 30 to 20/1000), but longevity stabilizes at or close to 70 years and becomes insensitive to further increases in energy consumption. Energy requirements rise from 200 kgce to 4000 kgce. The gain in infant mortality due to an increase of 100 kgce is now 0.5/1000. Greece, Hungary, and Romania are among the 17 countries (8 percent of the world) in this phase.

Phase IV "High Energy".

Mortality rates continue to decline slowly at all ages but are no longer responsive to further energy growth. Infant mortality falls to or near 20/1000, and longevity remains at or near 70 years. Energy requirements exceed 4000 kgce. The United States, Canada, Oceania, and Western Europe (19 percent of the world population) are all in this phase.

Within this framework, it becomes possible to explain the observation that Eastern Europe achieved the greatest gains in infant mortality from 1950 to 1970, whereas the greatest gains in longevity were achieved by the less developed countries. Eastern Europe was leaving Phase II and progressing through Phase III where significant longevity gains no longer occur. Less developed countries were progressing through Phase II where *both* longevity and infant mortality improve. That so little (less than one third) of Eastern Europe's decline in infant mortality was predicted to be energy-dependent may be explained by the rapid development of energy-intensive heavy industries in the planned economies, resulting in higher energy consumption levels than those seen in market economies with similar death rates [13]. During the 20 year study period, the lagging infant mortality levels quickly "caught up" with gains in industrialization. This hypothesis requires further confirmation.

Economists and demographers have investigated a number of mechanisms thought to underlie the energy-dependent effect. These include urbanization, medical care, nutrition, and, in the case of infant mortality, birth weight and family size [14]. Strong interactions among these and other factors are likely to occur and they apparently do not operate in a linear fashion.

If energy utilization had become more efficient over the study period, declining mortality per a given level of energy consumption could be explained, negating the energy-independent theory. Evidence from longitudinal national data on energy requirements per unit output show no consistent trend, increasing in some countries and decreasing in others[4]. For that reason, we have rejected that explanation.

Energy-independent factors account for approximately half of the recent mortality decline. Their major characteristics are that they affect all nations more or less equally regardless of their levels of development, and their effects increase with time. Other observations suggest that this time-dependent, energy-independent phenomenon has been operating through long periods of recent history. Increasing longevity can be demonstrated over at least the past 300 years in selected European

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[4] See Figure 1, p. 1002 in [5].

populations[5]. In some, such as Italy and the USSR, the decline of mortality began late in the 19th century; in these the decline in mortality was more rapid than in those where it had begun earlier [15,16]. The experience of a very rapid decline in infant mortality in Eastern European countries seen in our data is still another example of the remarkable improvements in health seen in countries of recent industrialization. This observation suggests that a minimum industrial base is necessary before low death rates are achieved. Nations are then quickly able to capitalize on the accumulated health advantages of industrialization.

Although improvements in medical technology are frequently given credit for this phenomenon, evidence for such is lacking. Studies directed to the issue have failed to find a relationship between medical expenditures and health [17,18]. Furthermore, since medical care requires resources and is therefore economic in nature, one would expect that if medical care were a significant component of the "energy-independent" effect there would be a gradient from the least affluent to the most, i.e., energy-dependent. Yet, as noted in this study, improvements in death rates were independent of the level of development.

At this stage of our knowledge, we are aware of no adequate explanation of the energy-independent factors.

The 1975 world consumption of energy is 8.4 trillion kg of coal equivalent, with a mean per capita consumption of 2032 kgce. The distribution among countries is highly skewed. Seventy-three percent of the world's population live in countries that are in Phase I and II, i.e. below 2000 kgce. The mean energy consumption of these countries is 526 kgce. In order to bring their energy consumption to Phase III (2000 kgce) consonant with a life expectancy of 70 years and an infant mortality of no more than 30, an increase in energy consumption of approximately 50 percent would be necessary. To bring all of the world's population to Phase IV would require more than a doubling of the current world energy production. These statements should not be interpreted as implying that energy production alone is sufficient to bring about such desirable change, or that increased energy production may not create other health and environmental problems. Nor are they meant to imply that health goals are the only priorities of decision makers: economics, environment, conservation, national security, and so forth, also require consideration. However, those sectors will rarely be able to generate quantitative criteria for planning, nor will there be the same degree of consensus as for health goals.

The use of logistic curves to describe demographic parameters is not new. R. Pearl pursued the use of this mathematical formulation with which to describe population growth and fitted

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[5]See Tables II.5, p. 24 and V.2, p. 111 in [14].

such curves with some precision to historical census data of the US and other countries [19]. His theory, as recently reviewed by B. Viel [20], fell into some disrepute as these populations outgrew projections based on the Pearl model. We interpret our data as indicating that the logistic curve is appropriate for cross-sectional studies but that a single logistic curve may be inappropriate for longitudinal studies since, with a rapidly changing environment, the parameters of the curve may change. Pearl was aware of this, but may not have been aware of how rapidly such changes can occur.

We conclude that commercial energy consumption is a useful tool for demographic studies. We wish to make it clear that we do not consider energy consumption to bear a direct causal relationship to health but rather view energy consumption as a proxy for industrial development. We are currently pursuing an analysis of those factors which may mediate this relationship.

We also conclude that energy analysis is useful in resolving the dispute regarding the Malthusian theory of the role of economic factors in demography. Economic factors strongly influence at least one demographic variable, mortality, but other noneconomic variables play an equally important role.

REFERENCES

[1] Loschky, D., Economic Change, Mortality and Malthusian Theory, *Population Studies*, 30, (1976), 439-452.

[2] Antonovsky, A., *Millbank Memorial Fund Quarterly*, 45, 31 (1967).

[3] Soddy, F., *Wealth, Virtual Wealth and Debt*, Allen and Unwin, London, 1926.

[4] Heuttner, D., Net Energy Analysis and Economic Assessment, *Science*, 192, 4235, (1976), 101-104.

[5] See e.g. Schipper, L., and A. Lichtenberg, Efficient Energy Use and Well Being: The Swedish Example, *Science*, 194, 4269, (1976), 1001-1013.

[6] Schurr, S. and B. Netschert, *Energy and the American Economy, 1850-1975*, Johns Hopkins Baltimore,1960.

[7] *1975 World Population Data Sheet*, Population Reference Bureau Inc., Washington, D.C., March 1975.

[8] *World Energy Supplies, 1950-1974*, ST/ESA/STAT/SER. J/19, United Nations, New York, 1976.

[9] *Demographic Year Book*, United Nations, New York, various issues from 1950 to 1976.

[10] Salaff, J., Mortality Decline in the People's Republic of China and the United States, *Population Studies*, 27, 1551 (1973).

[11] Taylor, C. and M. Hudson, *World Handbook of Political and Social Indicators*, Yale University Press, New Haven, 1972, p. 211.

[12] Preston, S.H., *Mortality Patterns in National Populations*, Academic Press, New York, 1976, p. 75.

[13] Mesarovic, M. and E. Pestel, *Mankind at the Turning Point*, Hutchinson, London, 1975, p. 138.

[14] *Determinants and Consequences of Population Trends*, Vol. I, ST/SOA/SER. A/50, United Nations, New York, 1973, pp. 121-140.

[15] Dublin, L., A. Lotka, and M. Spiegelman, *Length of Life*, Ronald, New York, 1949.

[16] Keyfitz, N. and W. Flieger, *World Population and Analysis of Vital Data*, University of Chicago, Chicago, Ill. 1968.

[17] Fuchs, V., M. Perlman, ed., *The Economics of Health and Medical Care*, McMillan, London, 1974, p. 174.

[18] McKeown, T., R. Record and R. Turner, *Population Studies*, 29, 391 (1975).

[19] Pearl, R., *The Biology of Population Growth*, Alfred Knopf, New York, 1925.

[20] Viel, B., *The Demographic Explosion: The Latin American Experience*, Irvington, New York, 1976, pp. 73-82.