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HEALTH AND ECONOMIC DEVELOPMENT II: LONGEVITY

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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 consumption. The study was carried out at IIASA in 1976/77 and was 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 1900-1975 and covered 99% of the world population. The results of this research are descriptive, but may be used in a prospective manner for energy, education and health policy decisions.

This Research Memorandum studies the relationship between longevity on the one hand and nutritional, medical care, social, and economic indicators on the other.

SUMMARY

Previous reports (PP-78-6, PP-78-7, RM-78-41) describe initial studies of the relationship between energy consumption, economic development, and health. In the previous report (*Health and Economic Development I: Infant Mortality*), we presented data on infant mortality as it is influenced by development. Here, we use longevity from birth as the dependent variable. Unlike infant mortality, which represents death rates within a single age group, namely 0 to 1, longevity from birth is an aggregate of death rates at all ages. From both cross-sectional and longitudinal analyses which include a large number of independent variables, we conclude that longevity is strongly influenced by development. Both per capita energy consumption and literacy show strong interactions with longevity, but approximately half of the improvements in the death rates that have occurred since 1950 remain unexplained.

Health and Economic Development II: Longevity

INTRODUCTION

A remarkable 20th century phenomenon is the dramatic worldwide increase in human longevity. Remarkable also is our lack of understanding of the factors underlying the decline in death rates, which have in many countries doubled life expectancy since the turn of the century. Efforts to unravel this enigma have largely been directed to individual diseases and their pathophysiology, the implicit model suggesting that death is the final outcome only of some specific pathologic process. That model has had some limited success, particularly in the understanding and prevention of certain infectious diseases, but leaves open the larger question of why death rates as a whole have declined.

Another approach, one that has received less attention, is the examination of death rates in relationship to the social and economic environment in which they occur. Economic development has a powerful depressant effect on mortality, yet this relationship has excited little research interest. The casual observation, often uncritically accepted, is that increased longevity is the result of improvements in medical care, nutrition, and sanitation: While that explanation is plausible, it lacks proof.

In a previous paper [1] a study was made of the relationship of economic development to infant mortality with a view toward examination of those interlinking variables that may be explanatory. In this paper a similar analysis is carried out, with longevity from birth as a measure of health.

As a measure of economic development, we have chosen to use annual per capita commercial energy consumption in kilograms of coal equivalent (kgce). The advantage is that this index provides a constant physical unit, comparable over time and among countries. Per capita GNP is often used as a measure of economic development. This quantity has the defect of requiring arbitrary adjustments when used among nations with different currencies or for longitudinal studies where adjustments for inflation or deflation are necessary. Other defects inherent in the use of GNP as a measure of economic activity have been reviewed elsewhere [2].

Longevity from birth is a statistic calculated for a given year from age-specific mortality rates for that year. A common misunderstanding of longevity is that children born in that year will experience those mortality rates throughout the subsequent years of their lives, an assumption almost certain to be in error. Longevity is, nevertheless, a very useful measure of mortality, since it is an aggregate of current death rates.

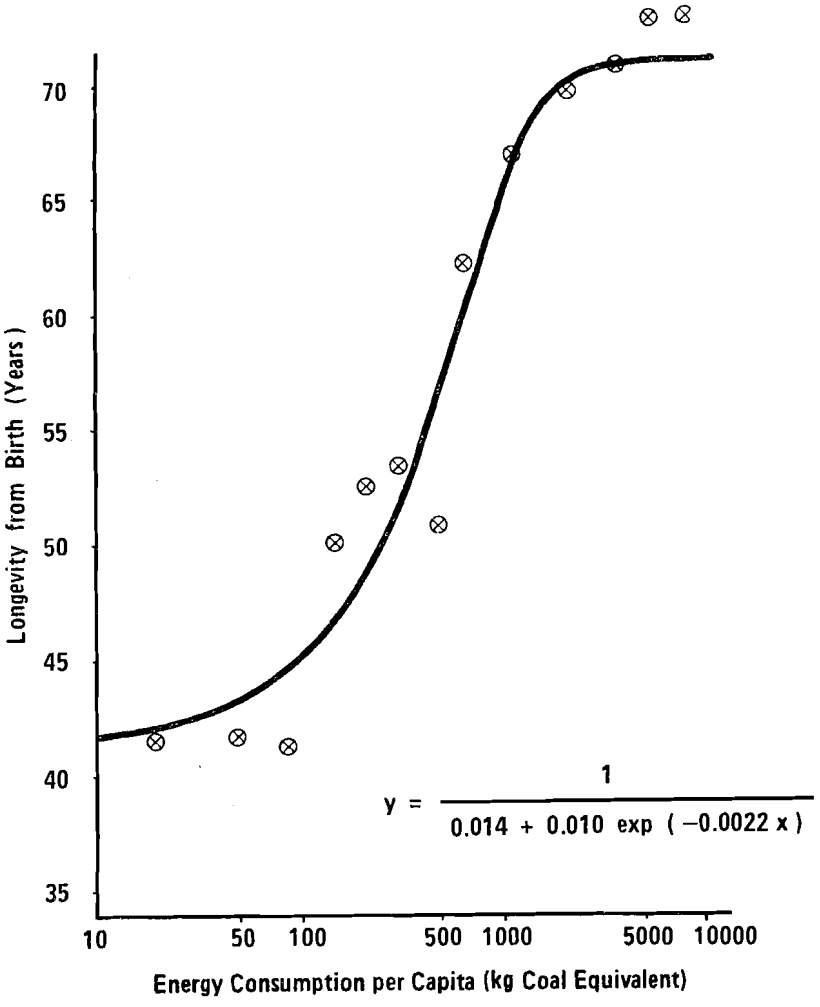

Figure 1. Relationship between energy consumption and longevity for 130 countries (1975) data.

We have described elsewhere [3] the regression of longevity on energy consumption for the years 1950, 1960, and 1970 using a logistic curve of the form $y = 1/(a + be^{cx})$ as presented in Figure 1. We interpreted the results as demonstrating distinct phases in economic development as it affects mortality, namely, an annual per capita consumption of 0 to 99 kgce (Phase I), 100 to 1999 kgce (Phase II), 2000 to 3999 kgce (Phase III), and more than 4000 kgce (Phase IV). Longevity is relatively insensitive to increasing energy consumption throughout the first and fourth phases, but rises sharply through Phase II. In this paper we further divide Phase II into two categories so as to examine the "take-off" phase of economic development in more detail: Phase IIa, from 100 to 399 kgce, and IIb, from 400 to 1999 kgce.

The 29 countries in Phase I, containing 9 percent of the world's population, are characterized by illiteracy, inadequate, monotonous, and uncertain diet, and high rates of infant mortality and fertility. The primary economic activity is subsistence farming. There is little use of money, and energy inputs are largely from human muscle. Ethiopia, Nepal, and much of Africa below the Sahara are examples.

Phase II contains 63 percent of the world's population. Per capita GNP has begun to rise. The portion of the labor force engaged in agriculture begins to fall. Urbanization commences. Infant mortality starts to fall and longevity increases by approximately 28 years. India, China, and much of Latin America are examples. In Phase III all these trends continue although only small gains in longevity occur. In Phase IV the development process is mature. Literacy is now virtually universal, and health benefits plateau in spite of progressive industrialization.

We have carried out both cross-sectional and longitudinal studies on 150 countries, which contain more than 99 percent of the world's population. It was our intent to examine those gross variables for which data are now generally available for most countries to test whether equations could be derived that would permit linking longevity to economic development.

The variables examined, the shorthand notations used in text and tables, and their sources are as follow:

INFMORT	= infant mortality per 1000 live births [4]
LONGBI	= longevity from birth in years [4]
FERTILITY	= annual births per woman aged 15 to 45, calculated from statistics available in [4]
BIRTH RT	= live births per 1000 population [4]
DEATH RT	= deaths per 1000 population [4]
GNP	= per capita GNP in dollars [5]
ENERGY	= per capita annual commercial energy consumption in kilograms of coal equivalent (kgce) [6]
% LABAG	= percent of labor force employed in agriculture [7]
% GTH	= percent of total population living in cities of more than 100,000, calculated from statistics in [8]
% LITERACY	= percent of persons over age 15 able to read and write [9,10]
ENROLM	= percent of eligible population enrolled in school [7]
TOTCALS	= per capita total daily calories [11]
CARBCALS	= per capita daily calories from carbohydrate [11]
FATCALS	= per capita daily calories from fat [11]
PROTCALS	= per capita daily calories from animal and vegetable protein [11]
APRCALS	= per capita daily calories from animal protein [11]
POP/MD	= number of persons per physician [8]
POP/BED	= number of persons per hospital bed [8]
GINI	= an index of distribution of income [7]
% HALF	= smallest percent of population receiving half of total income [7]
% CHRISTIAN	= percent of population who are Christian [7]
% MOSLEM	= percent of population who are Moslem [7].

DATA ANALYSIS

We obtained 1975 values of the above-mentioned variables, whenever possible, for 150 countries. While information on population and vital statistics was available for each country, other data were incomplete. For instance, GINI and % HALF were available for only 71 countries; however, 116 countries had complete data on the variables used in most of the data analysis.

Results based on these data constitute our cross-sectional analysis. Statistical averages (weighted by population) were obtained using complete data on each variable. These averages are presented in Table 1 by development phase. Standardized scores, i.e. (phase mean - grand mean)/total standard deviation, are shown in Figure 2. The signs of these scores were adjusted so that they were all positive for the developed phases.

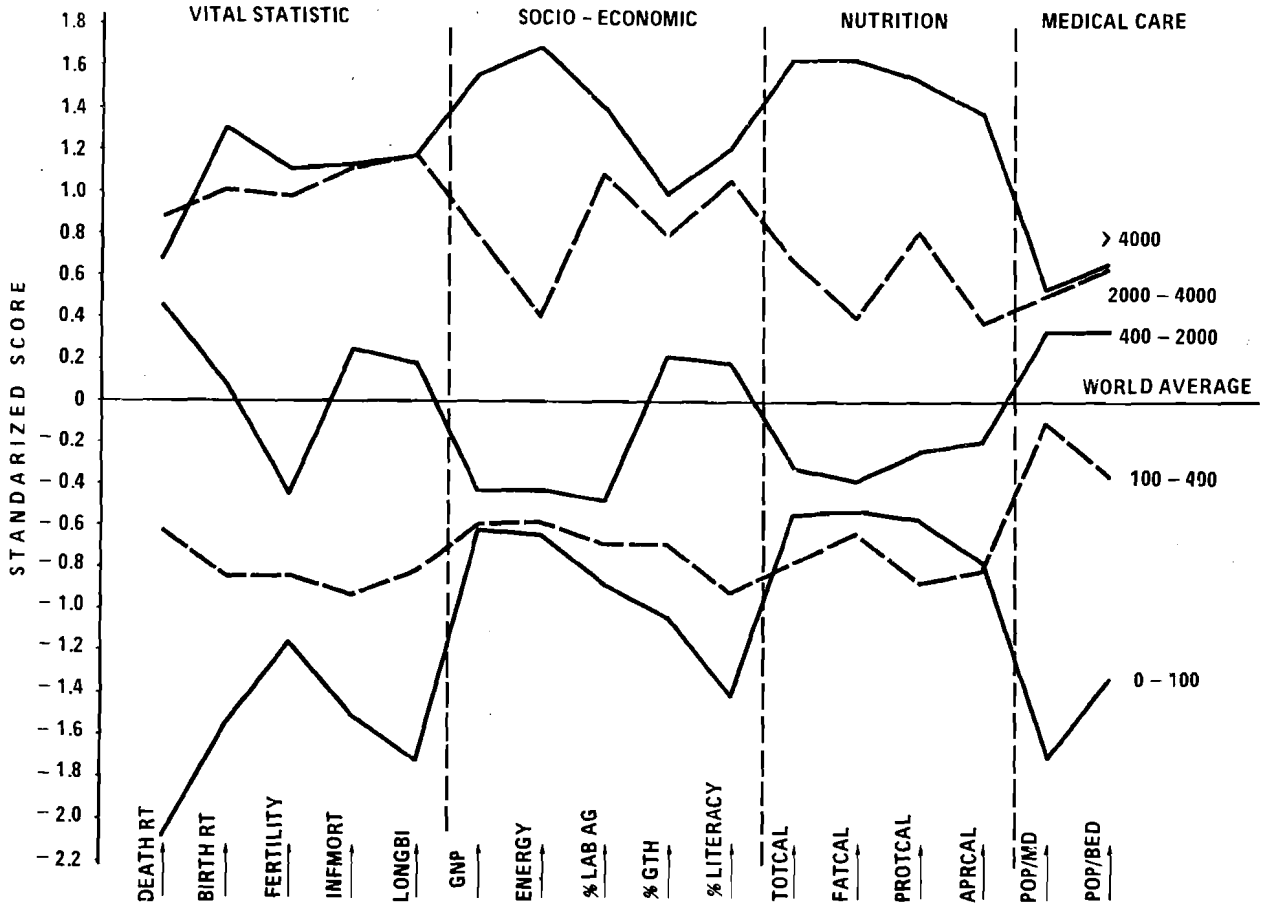

Figure: 2 Standardized scores for 16 variables, by annual per capita energy consumption (kgce), 150 countries.

Table 1. Means of selected variables, by development phase (1975 data)

Variables	I <100 kgce (N=29)	IIa 100-400 kgce (N=34)	IIb 400-1000 kgce (N=41)	III 2000-4000 kgce (N=16)	IV >4000 kgce (N=21)	Total (N=150)
TOTAL POPULATION*	365	1113	1337	296	798	3954
DEATH RATE	23.0	15.8	10.5	8.5	9.4	12.76
BIRTH RATE	47.4	41.5	30.9	20.0	16.5	31.7
FERTILITY	222	202	176	85	77	148
INFMORT	158.6	128.6	67.0	21.0	20.8	80.0
LONGBI	41.3	50.6	60.9	71.0	71.0	59.0
GNP	120	160	459	2615	3967	1219
ENERGY	51.0	201	700	3277	7209	2022
% LABAG	72.3	68.2	63.7	28.3	21.0	52.6
% GTH	6.7	13.3	30.3	41.5	45.3	26.4
% LITERACY	21.2	36.0	68.2	93.7	98.4	62.9
TOTCALS	2092	1979	2201	2673	3131	2354
CARBCALS	1686	1545	1665	1691	1668	1636
FATCALS	295	257	350	619	1043	480
PROTCALS	220	200	243	314	364	259
APRCALS	36	31	77	123	202	93
POP/MD	28234	8355	2812	745	564	7067
POP/BED	2838	1496	540	121	106	1004

*in millions

Weighted simple correlations were estimated from complete pairs of observations. Weighted multiple regression analysis of longevity on various explanatory variables was based on the 116 countries with complete data. This analysis excluded % LABAG, ENROLM, GINI, and % HALF. The longitudinal analysis is based on a subsample of 42 countries for which information was available in 1950 and 1970.

In the regression and correlation analyses some variables were transformed to their logarithmic values since this improved linear correlation with longevity. Variables so transformed were GNP, ENERGY, POP/MD, and POP/BED. Finally, to further illustrate the degree of linear dependence between longevity and the explanatory variables, we chose to report the proportion of standard deviation (SD) explained, rather than the familiar proportion of variance, since the SD is in the same units as the original measurements. While the proportion of variance explained is the square of the multiple correlation coefficient (r^2), the proportion of SD is $1 - \sqrt{1 - r^2}$. The latter is always less than or equal to the former. For example, if $r = 0.8$, then the proportion of variance explained is 0.64 (64 percent) while the proportion of SD explained is 0.40 (40 percent).

Results will be presented in two sections, cross-sectional and longitudinal.

CROSS-SECTIONAL ANALYSIS

Figure 1 illustrates the relationship between energy consumption and longevity for all 130 countries for which complete data were available in 1975. Each data point shown is the average value for each successive 10 countries. The curve was fitted to a logistic function by an iterative procedure. Although the data could also be fitted to a linear function, a number of considerations ruled out the linear model. As will be described later, there is no significant correlation between energy consumption and longevity for the countries with energy consumption either below 100 kgce or above 2000 kgce, thus giving support to the use of a logistic equation.

Correlation coefficients for selected variables with longevity are shown in Table 2 and will be discussed in groupings as shown there. The table shows correlations for the total sample as well as within energy phase.

Vital Statistics

Correlations between longevity and infant mortality are very high since death rates at all ages tend to be highly correlated. Variations in infant mortality are therefore reflected in similar variations of longevity in the opposite direction. Death rates per 1000 are inversely related to longevity in the

Table 2. Correlations of selected variables with longevity from birth; 150 countries

Variables	I <100 kgce (N=29)	IIa 100-400 kgce (N=34)	IIb 400-1000 kgce (N=41)	III 2000-4000 kgce (N=16)	IV >4000 kgce (N=21)	Total (N=150)
Vital Statistics						
BIRTH RATE	-.72	-.31	-.70	-.79	(-.25)*	-.92
FERTILITY	-	(.07)	-.80	-.69	(.19)	-.92
DEATH RATE	-.99	-.97	-.93	(-.29)	.55	-.91
INFMORT	(-.10)	-.86	-.85	-.92	-.79	-.96
% UNDER 15	-	.26	-.67	-.62	-.44	-.88
Nutrition						
TOTCALS	(.10)	.31	(.17)	(-.04)	(-.16)	.73
% CARB	(.01)	-.38	(-.19)	(-.31)	-.62	-.65
FATCALS	(-.04)	.37	.30	(.16)	.65	.68
PROTCALS	(-.34)	(.15)	.33	(.06)	(-.12)	.75
APRCALS	(-.01)	.42	.57	(.02)	.47	.81
Education						
% LITERACY	.54	.73	.76	.46	-.53	.95
ENROLM	-.46	.30	.62	(-.39)	.31	.63
Medical Care						
POP/MD	(-.04)	-.38	-.82	(-.12)	.72	-.88
POP/BED	-.59	-.36	(-.38)	-.57	(.02)	-.91
Economic						
GNP	(.20)	.29	(.04)	.87	.50	.85
ENERGY	(.32)	.52	.30	-.37	(.07)	.92
Social						
GINI	-	.88	(-.04)	-.92	(.20)	-.39
% HALF	-	.85	(-.05)	-.93	(-.27)	.33
% CHRISTIAN	(.34)	.37	(.19)	(-.14)	.59	.51
% MOSLEM	-.71	(-.23)	-.54	(-.22)	-.57	-.54
Urbanization						
% URBAN	(.23)	(.09)	.45	(.45)	(.22)	.78

*Figures in parentheses are not statistically significant at the 0.5 level.

poorer countries where the populations are relatively young in age distribution. With increasing economic development, death rates fall at younger ages, the mean population age increases, and longevity becomes positively correlated with death rates in these older populations. As predicted by demographic transition theory, poorer countries with high death rates have high birth rates and high fertility in order to maintain their population size, thus explaining the negative correlations with longevity. In Phase IV countries, those correlations become insignificant as birth rates drop to replacement levels.

Nutrition

Of the five nutritional variables tested, all were highly correlated with longevity in the overall sample; however, absolute correlations within energy groups were either low or insignificant. The carbohydrate variable is negatively correlated with longevity since it is calculated as the percent of total calories from carbohydrate, rather than measured in absolute levels as with the other nutritional variables.

Education

Several measures of educational levels in various countries were examined, including dollar investment in education per capita and numbers of scientific publications. As shown in Table 2, the most powerful explanatory variable was literacy, the ability to read and write. The overall correlation coefficient betweeen longevity and literacy was a striking 0.95. Furthermore, correlation was highly significant within each of the energy groupings except Phase IV where literacy approaches 100 percent and no longer serves as a useful discriminatory variable. Correlations for the enrollment variable were weaker and less consistent within energy phases.

Medical Care

The effect of medical care was measured by two variables, the ratios of population to numbers of physicians and to hospital beds. Both ratios fall rapidly with economic development, as seen in Table 1. Correlations are, overall, highly significant, however, within energy phases, correlations are neither strong nor consistently significant. In Phase IV the correlation, 0.72, becomes positive for the ratio of population to physicians; i.e., the smaller the number of physicians, the greater the longevity within those 21 countries. Number of hospital beds does not correlate significantly with longevity in the same group.

Economic

Energy consumption per capita and GNP per capita are both measures of economic development and both correlate highly with longevity. Of the two, correlation of longevity with energy consumption is higher in Phases IIa and IIb, where the greatest increase in life expectancy occurs, whereas GNP becomes more strongly correlated in Phases III and IV.

Social Variables

Two measures of the distribution of wealth within countries were examined to explore whether an equitable distribution might have a beneficial effect upon longevity. Neither GINI index nor % HALF confirmed this expectation, both showing weak correlations.

Urbanization

We examined a number of measures of urbanization, using various criteria of urban conglomeration. We also examined the index of urbanization provided to the United Nations by each government. Percent of population in cities of over 100,000, the measure most highly correlated with longevity, increases from 6.7 percent in Phase I to 45.3 percent in Phase IV (Table 1). Although the overall correlation is 0.78, correlation within energy phases is not significant except in IIb.

Other Variables

Religion, through its injunctions on food, sanitary practices, and values, might be expected to have significant effects on longevity. Correlations for percent Christian and percent Moslem were moderately strong, but because no significant correlations appeared within groups, it was concluded that these variables offered little in the way of explanation, and they were dropped from further analyses.

Multiple Regression

In order to evaluate the relative contribution of our independent variables to longevity, we grouped them into six sets, selecting those variables that had demonstrated highest correlations. They are: nutrition (five variables as in Table 2); medical (POP/MD, POP/BED); literacy; energy consumption; degree of urbanization (% GTH); and literacy and energy combined. Variables showing weak correlations were excluded. Multiple regressions were carried out between longevity and each set of variables, as were partial correlations with the remaining variables. Variables with partial correlation greater than 0.5 are

Table 3. Percent of standard deviation in longevity among nations by removing certain variables

Variables	IIa .100-400 kgce (SD=3.7)	IIb 400 2000 kgce (SD=7.0)	III 2000-4000 kgce (SD=2.2)	IV >4000 kgce (SD=1.2)	Total (SD=11.4)
Nutritional (NUTS)	10% LIT*	22% MD,LIT	0% BEDS LIT GNP	35%	53% MD,BEDS LIT,GNP EN
Medical (MD,BEDS)	12% LIT	41%	10% GNP,EN	37%	67%
Literacy (LIT)	30% NUTS	29% MD,GNP	3% BEDS	14% MD,NUTS	67% GNP,EN
Energy (EN)	17% LIT	16% NUTS,MD LIT	0% BEDS GNP	0% MD,LIT NUTS	65% LIT
Urban (GTH)	0% LIT,EN	8% NUTS,MD LIT	6% BEDS GNP	0% MD,NUTS GNP	37% NUTS,MD BEDS,LIT GNP,EN
Literacy and Energy	35%	34% MD,GNP	3% GNP BEDS	13% MD,NUTS	73%

*Variables noted in this manner are those which retain significance at the 0.5 level after removal of the indicated variables in the first column on the left.

indicated in Table 3. This analysis was performed for the total sample as well as for each energy phase except Phase I, where the data were insufficient.

For the total sample, three of the grouped variables are able to explain approximately two thirds or more of standard deviation in longevity: medical, literacy, and energy consumption. Literacy and energy each retain significance after removal of the other, but the two together explain only slightly more of the standard deviation of longevity than does either alone.

The medical variables are not only very powerful in reducing standard deviation in the overall sample (67 percent) but are also consistent within energy phases. In the IIb group of nations, where longevity is rapidly increasing, medical care explains 41 percent of standard deviation, and no other set of independent variables has a larger partial correlation after the medical care effect is removed.

Urbanization is a very weak variable in this analysis, both in the total sample and in individual energy phases where urbanization is almost useless in explaining variability.

In summary, all of the variables examined demonstrated some relationship with longevity, but with the exception of literacy, energy, and medical care, the relationships were neither strong nor consistent enough to be persuasive of a causal relationship to longevity. We therefore undertook further studies in order to determine whether these variables have predictive power.

LONGITUDINAL ANALYSIS

We collected data, where available, for the years 1950, 1960, and 1970. The relationship of energy consumption and longevity for these years are shown in Figure 3. The sample size, 42, is considerably smaller than for the cross-sectional analysis because of absence of data for earlier decades. Since this smaller group with complete longitudinal data consists of more developed countries, the estimates shown for 1970 in Figure 4 and 1975 in Figure 1 differ somewhat.

Although all three curves demonstrate a similar influence of economic development on longevity, there is evidence of a time-related effect that is not connected with energy consumption. This effect is associated with an increase in longevity of approximately 12 years at the lowest levels of energy consumption and is least noticeable at approximately 1000 kgce equivalent. This factor also appears to have produced a greater effect between 1950 to 1960 than between 1960 to 1970.

Comparisons were made of certain variables for those countries for which data were available for 1950 and 1970. Statistical means are shown in Table 4. Total caloric consumption increased by 7 percent, accompanied by a shift from a high carbo-

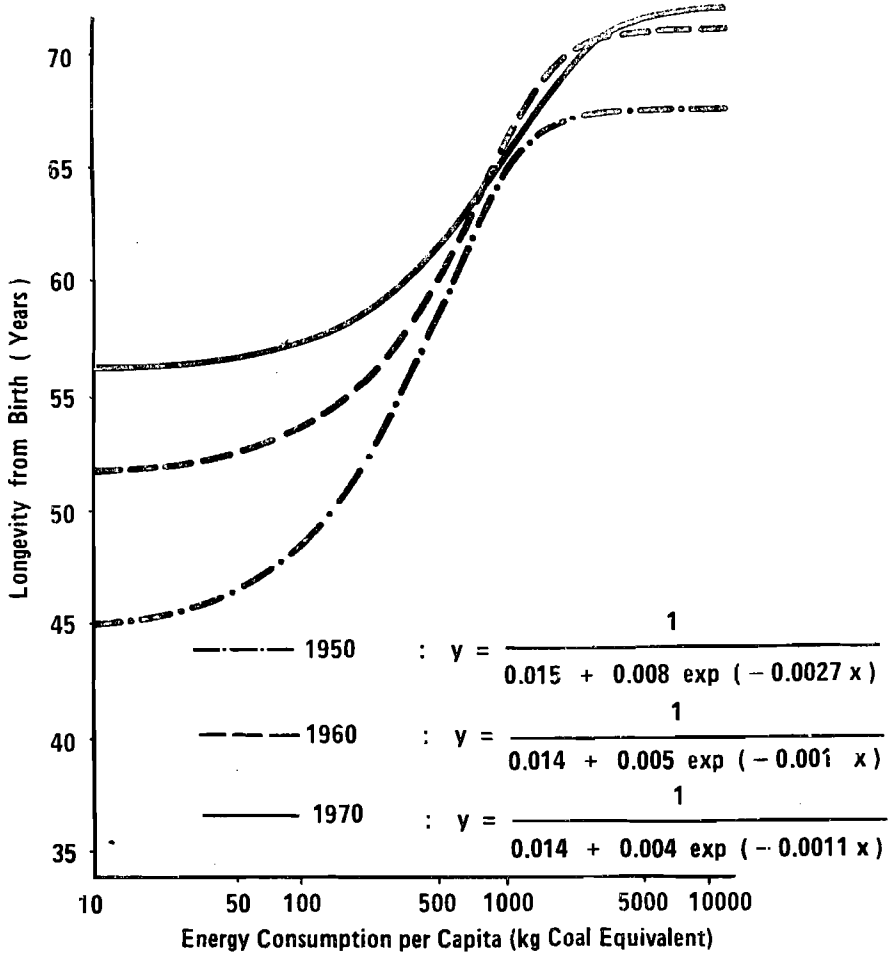

Figure 3. Relationship between energy consumption and longevity for 42 countries (1950-1960-1970 data).

hydrate, low fat diet (12.3 percent) to a high fat diet (34.2 percent). Total dietary protein remained relatively constant but daily calories from animal sources increased by 22 percent. Energy consumption, literacy, availability of medical care, and urbanization also increased.

Correlations with longevity for each of these variables are presented in Table 5. Correlations in each of the two years, 1950 and 1970, are high, except for urbanization. Table 5 also shows correlations of *differences* in longevity, with *differences* in each of the variables, 1950 to 1970. The nutritional and medical variables, with the exception of fat calories, were not significantly related to longevity. Increases in longevity were significantly correlated with increases in both energy and literacy.

Table 4. Statistical means of selected variables

Variables	1950	1970	% Change
LONGEVITY	51.3	63.1	+ 23
INFANT MORTALITY	111.6	57.8	- 48
% LITERACY	62.3	76.4	+ 23
ENERGY	1276	2648	+ 108
TOTCALS	2706	2890	+ 7
FATCALS	333	989	+ 197
APRCALS	144	176	+ 22
CARBCALS	2058	1575	- 23
PROTCALS	315	326	+ 3
POP/MD	1751	1225	- 30
POP/BED	358	226	- 37
% URBANIZATION	25	36	+ 44

Table 5. Correlation coefficients with selected variables

	Longevity (1950)	Longevity (1970)	Difference 1950-1970
% LITERACY	.98	.96	.77
ENERGY	.90	.94	.45
FATCALS	.71	.75	-.32
PRTCALS	.70	.65	.30
APRCALS	.66	.75	-.24
TOTCALS	.76	.73	.31
POP/BED	-.89	-.92	.24
POP/MD	-.81	-.71	-.06
% GTH	.51	.33	.08

Having identified literacy and energy consumption as the major factors correlated with longevity, we attempted to quantify the component of longevity gain from 1950 to 1970 associated with these variables. To that end, we produced an equation based on 1950 data with which to predict longevity (with a standard deviation of 3.7 years):

$$\text{Longevity} = 29.4 + 0.302\ (\text{literacy}) + 2.448 \log\ (\text{energy}) \quad .$$

The weighted mean increases in literacy and log energy for the 42 countries in this analysis were 14.1 percent and 0.508 units, respectively. Applying the equation to these changes, the effects on increased longevity associated with literacy and energy are predicted to be 4.3 and 1.2 years, respectively. These effects amount to 47 percent of the observed mean longevity increase of 11.8 years. The unexplained portion, 6.3 years, we attributed to a "time effect" which will be discussed below.

DISCUSSION AND SUMMARY

As shown in Figure 2, all of the variables that we studied are closely associated with the process of economic development. In such a tight web of interrelationships, any one variable could be chosen as an index of development. Longevity itself might serve as such.

We undertook an analysis of those relationships partly in order to test whether energy consumption was sufficiently closely related to longevity to serve as a proxy or index for economic development. In the absence of experimental evidence, we believe that the results of our statistical analysis, both cross-sectional and longitudinal, are consistent with this hypothesis.

We have presented the relationship between commercial energy consumption and longevity as a logistic function. These data could have been fitted to a linear model as well as to a logistic model, but there are two reasons for rejecting a linear model:

- There is no significant correlation between energy consumption and longevity above 2000 kgce. The increase in longevity that has been observed longitudinally in the *developed* countries over past decades can be explained through another mechanism: the time effect, discussed below.
- The linear model fails to pass the test of plausibility. Clearly, longevity cannot reach to infinity but must have both lower and upper boundaries, conditions that are fulfilled by a logistic function.

A second observation regarding the relation between energy consumption and longevity is the shift in the logistic curve with time as seen in Figure 3. This suggested to us that two separate factors operate to reduce death rates and increase longevity. One of these is clearly economic. The other is noneconomic, which we infer from the observation that all countries benefit equally regardless of economic development. That does not imply that the effect of economic development on longevity is decreasing with time, but rather that another factor is operating related to time but independent of economic development. Preston, using GNP as a measure of development, has made similar observations [12].

Another purpose of this study was to examine those interlinking variables thought to underlie the relationship between increased longevity and economic development. The variable most significantly and consistently related to longevity in our analysis is literacy. Furthermore, although literacy must clearly be related to formal education, the two are not the same. Literacy was more highly consistent in its relationship to longevity than was school enrollment, although there may be a lag in the effect of the latter that partially masks its effect on longevity.

How should we interpret the effect of literacy? Is it simply an association without any causal significance? We think not: the correlations are too strong and too consistent. Although there are undoubtedly many subtle interactions between health, economic development, and education, we speculate that the effects on health which flow from education fall into two categories: access to information and a change in values. The former implies access to modern nutritional, medical, and other health materials, and the latter, the abandoning of the detrimental practices associated with traditional cultures. An example of such detrimental practices is quoted by an American obstetrician who has practiced for 20 years in Beirut:

> A custom at childbirth may lead to one of the worst sets of complications imaginable. After delivery, the vagina is packed with rock salt. This causes the vagina to shrink and prevents hemorrhage. But the pack of salt must be removed in 24 hours or so. Otherwise, it can--and does--cause severe atresia and sloughing. The trouble is that, given the unsettled life of desert nomads, a woman may actually forget to have the salt removed as camp is shifted. After several days, it may be too late. The vagina is nearly occluded by a fibrous band of tissue, and the next pregnancy is certain to be difficult and is often fatal to both mother and child [13].

There is a second sense in which the significance of literacy may be interpreted, and that is as a marker for that constellation of values and attitudes to which social scientists refer as "modernism". By this is meant rationalism, active participation in civic and national affairs, social, physical, and intellectual mobility, and freedom from traditional mores. In analyzing six Middle Eastern cultures, D. Lerner finds that the

variable most highly correlated with these qualities is literacy, and that "Literacy is the basic personal skill that underlies the whole modernizing sequence" [14].

Many variables are closely related to economic development. These include GNP, urbanization, and percent of labor force in industry, as well as literacy and longevity. Only the last two reach a maximum at the same point of development, namely, when energy consumption reaches 2000 kgce.

The availability of medical care, as reflected in our crude measure of numbers of doctors and hospital beds, shows a very strong relationship both to economic development and to longevity. Whereas this relationship is strong in the cross-sectional analysis, it is insignificant in the longitudinal analysis (Table 4). We are reluctant, for two additional reasons, to accept medical care as playing a strong role in the reduction of death rates that has been observed in association with economic development. They are the following.

First, reduction in death rates began long before truly effective medical therapy became available [15]. Death rates began falling in some areas of Europe at least one hundred years ago and in most of Europe 50 years ago [16]. The introduction of sulfa drugs began in the 1930s and of antibiotics in the late 1940s, and even more recently outside the developed countries. It seems unlikely in the extreme that the introduction of these drugs became so common throughout the underdeveloped world as to add many years to longevity within two decades. Furthermore, it would be an error to assume that these drugs are universally effective in the treatment and cure of the diarrheas, pneumonias, and other infections that, to a large extent, are responsible for falling death rates. Not are these drugs easily used by unskilled persons. Since the population to physician ratio is of the order of many thousands in less developed countries (Table 1), the burden of proof would seem to rest on those who allege medical care as the cause of this phenomenon.

Second, death rates have fallen at all ages proportionately. It would seem unlikely that medical care has equally affected multiple diseases acting independently at different ages throughout life. Figure 4 illustrates life expectancy at various ages by level of energy consumption. The curves show a proportionate decline at all ages for each level of economic development. It is unlikely that this is the result of medical care.

An alternative explanation of increased longevity is that it is the effect of sanitation and preventive health efforts, such as vaccinations. In view of the fact that the reductions in death rates associated with economic development often reflect the lesser frequency of infectious disease, this seems plausible. Variables that we tested for this effect, percent of homes with piped water or flush toilets, showed no significant relationship to longevity, however (data not shown). Furthermore, the only disease for which worldwide vaccination programs have been undertaken is smallpox, for which death rates in this century have been very low.

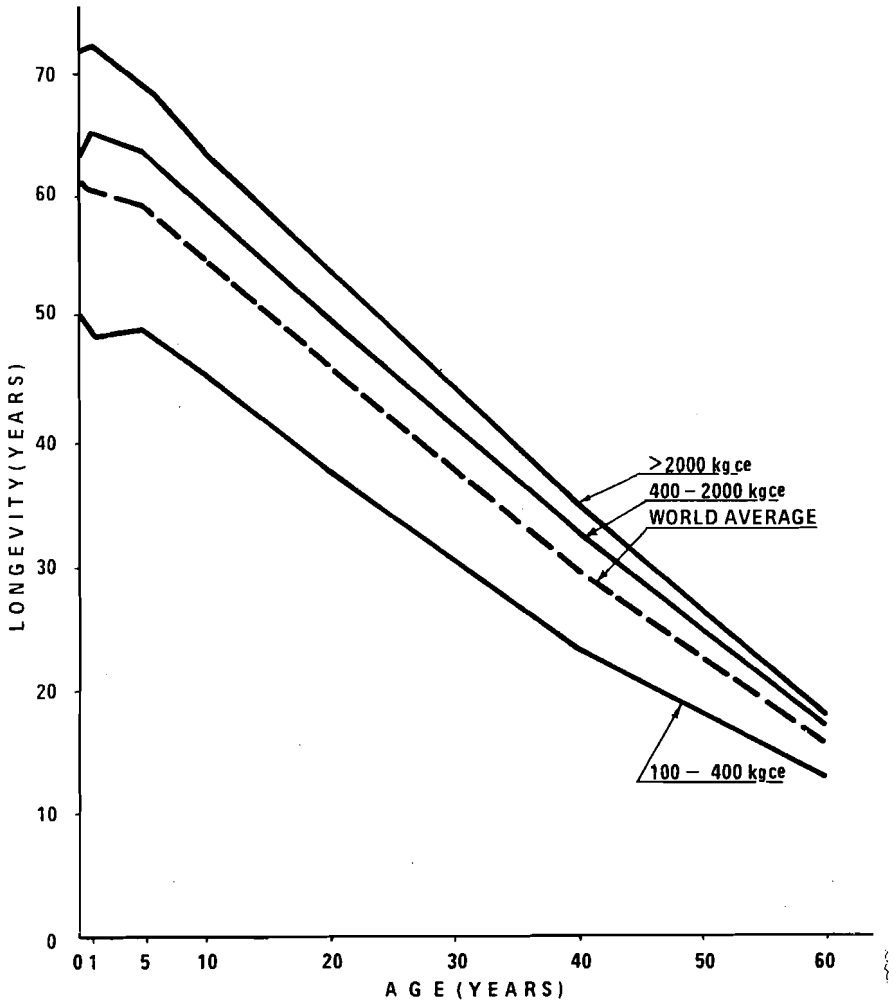

Figure 4. Longevity age for phases of energy consumption, per capita (1975 data).

More perplexing still is the non-economic, time-related factor. Some medical efforts made by international and other organizations could be operating here, but these have, in the global sense, been miniscule and usually directed toward specific diseases or "eradication" programs, such as against malaria. Even the effect of these programs is questioned [17].

A more credible speculation is that the increase in resistance to disease experienced first in the developed nations is now producing some effect in the underdeveloped population of the world. Experiments among mouse colonies into which pathogenic organisms have been introduced in order to study the history of epidemics demonstrate that the numbers of susceptibles in such populations and densities of animals are critical factors [18,19]. Relative virulence of the bacterial organism is of less importance.

In summary, economic development has been shown to add approximately 30 years to life expectancy. This range was observed throughout the period of study. Literacy and energy consumption are strongly associated with increased longevity, and we have suggested that literacy may operate through increasing access to information, or by association with other values, or both. Another factor affecting longevity, unrelated to economic development, has been identified in less developed countries. The cause of this phenomenon is unkown.

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