ENERGY AND LITERACY: AN INDEX OF HEALTH DEVELOPMENT

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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 to 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 1900-1975 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 is the final in the series. It presents an INDEX of health development which is a function of literacy and per-capita commercial energy consumption. The INDEX, together with an additional time component, traces the progress of health measures in this century with a high degree of accuracy.

SUMMARY

In previous reports (PP-78-6 , RM-78-41, and RM-78-42), percent literacy and per capita commercial energy consumption were found to have the strongest association with longevity and infant mortality among a large number of explanatory variables. In this report we derive on a statistical basis a Health Development Index which is linear in literacy and logistic in energy consumption. A country moving from the lowest to the highest points on the INDEX is expected to increase the longevity of its population by 36 years and reduce infant mortality by 150 deaths per 1000 live births. In addition, we found evidence of a "time effect" operating since the turn of the century, independently of economic development. This effect accounts for an increase in longevity of 18 years and a decrease in infant mortality of 100 deaths since 1900.

Energy and Literacy: An Index of Health Development

INTRODUCTION

"Development" is a many splendored thing. Economists think of growth of GNP, industrialists think of increasing production, farmers of improved crops, and sociologists of "modernization" of values and behavior. The public health specialist also has his own criteria for development: improved nutrition and medical care, concern for prevention of disease, and lowered death rates. Each of the above aspects of development relates to the others through a complex web of interactions. The common denominator may be innovation and willingness to change.

In this paper we address ourselves to the following questions: To what extent can improved health be attributed to development? What are the mechanisms underlying this phenomenon? Are the relationships linear? At what rates does health development progress? Is there a consistent pattern to health development? To what extent are factors other than development operating to improve health? We shall present data which suggest that economic development adds 35 years to longevity and reduces infant mortality by 150 deaths per 1000 live births. Study of mechanisms underlying this phenomenon indicate that literacy and commercial energy consumption are together a powerful INDEX of health development with upper and lower boundaries. Through this INDEX literacy is linearly related to health whereas energy consumption bears a logistic relationship. In the 20th century, progress in health development has been proceeding at a rate which suggests a requirement of 120 years to reach 90 percent of its full potential. This rate of development is relatively constant across countries and apparently is not influenced by geography, time, or political institutions.

Finally, our data suggest that an independent "time factor" operating at least since the turn of the century has added 18 years to longevity, independently of the economic development. This time factor is estimated by a logistic function reaching its upper asymptote at about the year 2000.

Measurement of Health

In order to explain the interactions between the general process of development and health development specifically, one must have measures of both. Studies of morbidity are notoriously sensitive to diverse criteria of disease, even within countries. Health and illness do not have sharp cutting points, nor do physicians always agree on their diagnostic criteria. International comparisons are even more difficult in this respect. Since our analysis included time series covering 75 years and almost three generations of physicians, we concluded that mortality rates would be far more suitable than morbidity.

Mortality data are also far more widely available.

Longevity from birth, or life expectancy as it is sometimes called, is an hypothetical statistic that assigns to a child born today age-specific death rates currently experienced and assumes that these risks will remain unchanged throughout the life of this child. It is thus an aggregate measure of current death rates. Our other measure of health is the infant mortality rate, which is defined as the number of deaths within the first year of life per thousand live births.

Measure of Industrial Development

The economist generally chooses GNP as a measure of economic growth. However, there has been a growing recognition of the need to devise an indicator that more effectively measures the degree of progress than is possible with GNP. For example, the US Foreign Assistance Act of 1973 requires that appropriate criteria other than GNP be established to assess progress in developing countries. Also in 1973, the Secretary General of the United Nations recognized the need for a supplement to per capita GNP as a measure of progress in addressing human needs [1].

As a measure of industrial development we have chosen to use per capita commercial energy consumption, which for our purposes has a number of advantages:

- Being measured in constant physical units, kilograms of coal equivalent (kgce), no arbitrary adjustments are necessary for energy consumption in international comparisons or for inflationary tendencies.

- The use of national energy consumption most of which in each country is created by industrial and commercial activities avoids the assumption implicit in the use of GNP that improved health can be purchased.

- In an era of resource scarcity, when there are efforts afoot to "decouple" energy consumption from GNP, information about the relationship of health to energy consumption has its own inherent interest, namely, to what extent can energy consumption be restrained or reduced without affecting health?

Both GNP and energy consumption suffer from a common defect: they fail to reflect improvements in technology over time; the former does not express the improvements in products whose price may not increase, whereas the latter fails to account for the increased thermodynamic efficiency of the conversion of fuels to work which has occurred with time.

The reader should not misunderstand: we use energy consumption as a proxy for industrial development. We are fully aware that energy consumption *per se* does not produce health benefits.

Development and Health

In a previous publication, we presented data on the relationship between energy consumption and health for 150 nations for 1975 [2]. Longevity was fitted well to a logistic function with a "take-off" at about 100 kgce per capita annual consumption, followed by a rapid rise and an upper plateau at 2000 kgce (approximately 2 kW). Less than 9 percent of the world's population is below the 100 kgce level, two-thirds are in the transition phase, and a quarter are above 2000 kgce. A similar but inverse logistic relationship holds for infant mortality.

In longitudinal studies covering a smaller sample of 47 nations over the period 1950-1970, almost half of the improvement in longevity or infant mortality could be "explained" by development as measured by increased energy consumption over this period. The unexplained portion was experienced by all countries regardless of their level of development. Over this period of time there was no reduction in the advantage of the most developed over the least developed countries, which remained at about 35 years of longevity, and 150 infant deaths per thousand live births. In other words, the effect of development remained constant over time, but other factors were also operating to reduce death rates.

In examining interlinking variables and their association with longevity and infant mortality, we identified a persistent and highly significant correlation with literacy [3,4]. The relationship was stronger than for certain nutritional and/or medical variables. Indeed, the partial correlations between our health measures and all of these intermediary variables become nonsignificant once the effects of literacy and energy are removed. Furthermore, literacy showed a stronger correlation with health than other measures of education, such as percent of eligible population enrolled in schools. We interpret literacy, which is defined as the percent of persons above age 15 able to read and write a simple statement, as a measure of the development of "human capital", and as a reflection of the modernization of values [5,6].

In this paper, we present a new index of health development which combines the effect of both energy consumption and literacy. It is standardized to take values over the range 0 to 100. Using this index, we have produced an equation highly predictive of longevity and infant mortality over the years 1900 to 1975. The equation consists of the index plus a component representing a time factor independent of development.

METHODOLOGY AND RESULTS

Data for literacy, longevity, infant mortality, and energy consumption were collected for 115 countries from a variety of sources [7-13]. Countries of a population less than one million in 1975 were excluded. In all, 303 data points complete on all four variables were collected for the period 1900-1973.

Using least squares, we fitted a regression equation of longevity to literacy, energy consumption, and calendar date (years). Based on our previous results, the effect of literacy was taken as linear and that of energy as logistic [2-4]. Because of the effectiveness of literacy as an explanatory variable, we plotted longevity versus time, grouped by literacy levels, as in Figure 1. At any given level of literacy, longevity shows a consistent increase over time until 1970 when this effect appears to be decreasing. This independent additive effect was therefore included in our predictive equation. It is seen that the data points for 1975 lie consistently below a linear fit to the data for each literacy grouping. We also noted that this effect began its upward takeoff around the turn of the century. With these characteristics in mind, we concluded that a logistic function was appropriate for this relationship. An iterative least-square computer subroutine was utilized to estimate the parameters A to H of the equation:

$$\text{longevity} = A \cdot \text{literacy} + \frac{B}{1 + C\, e^{D \cdot \text{energy}}} + \frac{F}{1 + G\, e^{H(\text{year}-1900)}} \quad . \qquad (1)$$

It should be noted that no additive constant is necessary since it is implicit in the second term of this equation.

A Health Development Index (INDEX)

The first two terms in equation (1) were estimated as follows:

$$0.288 \text{ literacy} + \frac{22.78}{1 + 0.4214\, e^{-0.00514 \text{ energy}}} \quad . \qquad (2)$$

We refer to quantity (2) as the "crude index". It is not a measure of health but rather a measure of those factors of development that are most strongly related to health, namely energy consumption and literacy. In order to convert the crude index into a more convenient form with values ranging from 0 to 100, the following transformation was carried out:

$$\text{INDEX} = 100\ (\text{crude index} - 16.015)/35.56 \quad . \qquad (3)$$

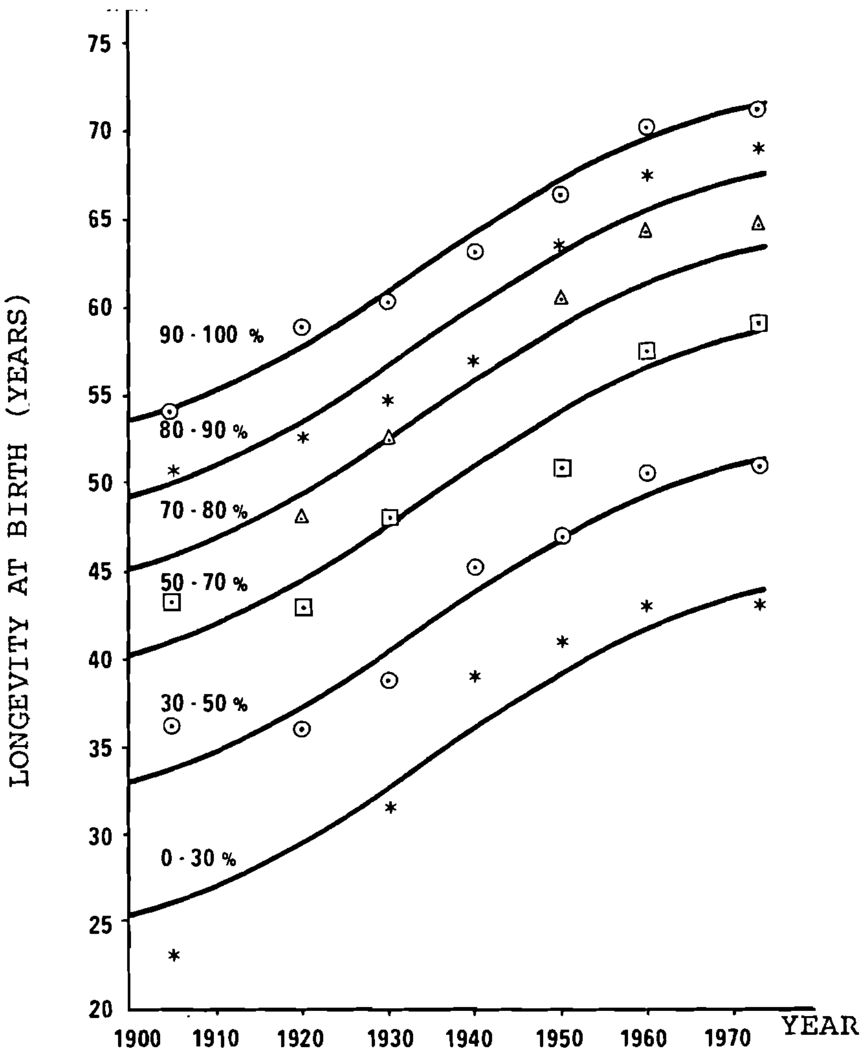

Figure 1. Longevity versus time (years) by percent literacy 115 countries (303 data points).

This INDEX can be used with cross-sectional data, but cannot be used to predict longevity in longitudinal data since it contains no component for the time effect. This is achieved by using the full estimate of equation (1),

$$\text{longevity} = \text{crude index} + \frac{23.37}{1 + 7.893\ e^{-0.0582(\text{year}-1900)}} \cdot \qquad (4)$$

The standard error of estimate for this equation is 3.25 years. Since the original standard deviation for longevity is 11.90, the equation "explains" 73 percent of the standard deviation (or 93 percent of the variance) of longevity.

This equation allowed us to separate longevity for each of the 303 cases into two components: that due to development as estimated by equation (2), and that due to the time effect as estimated by the second function in equation(4).

We examined the validity of these two effects separately. For each of the 303 data points, we compared the INDEX with the longevity residual after removing the time effect (last term of equation (4)). Table 1 and Figure 2 show these data grouped by deciles of the INDEX (the last decile was split into two intervals since it included a large number of data points). The data fit the model well and the variation is fairly uniform throughout (see standard deviation column in Table 1). It is noted that health development is associated with estimated 35.6 years of increased longevity for any given time point[1].

Table 1. Health development index versus longevity (303 data points).

Health Development Index Interval	Mean	Number of cases	Longevity after removing time effect (Mean ± SD)
<10	7.7	14	3.4 ± 2.5
10-19.9	15.5	17	5.7 ± 4.0
20-29.9	25.2	20	8.3 ± 4.0
30-39.9	34.5	17	12.4 ± 4.1
40-49.9	43.9	18	15.4 ± 4.9
50-59.9	54.8	17	19.9 ± 3.2
60-69.9	65.8	17	22.9 ± 4.4
70-79.9	75.4	20	25.9 ± 3.5
80-89.9	84.7	29	30.7 ± 2.9
90-94.9	92.7	22	32.3 ± 3.4
⩾95	98.2	112	34.7 ± 2.5

[1]From equation (2) we attribute 28.8 years to literacy and 6.8 years to energy consumption. Approximately the same quantification of effects was reached in another way by considering a simultaneous equations model

$$\text{longevity} = f_1\ (\text{literacy}, \log \text{energy}),$$
$$\log \text{energy} = f_2\ (\text{literacy}, \log \text{GNP}).$$

Using log GNP as an instrumental variable, we obtained by two-stage least squares from 1973 data the equation

$$\text{longevity} = 34.7 + 0.284 \cdot \text{literacy} + 2.4320 \log \text{energy}.$$

The effect of literacy is thus estimated as 28.4 years and the effect of energy (as energy increases from 10 to 10,000 kgce) to be $3 \cdot 2.4320 = 7.3$ years. This is in close agreement with the estimate presented above as derived from equation (2). (The authors thank Dr. Allan Kelley for suggesting this simultaneous equations model).

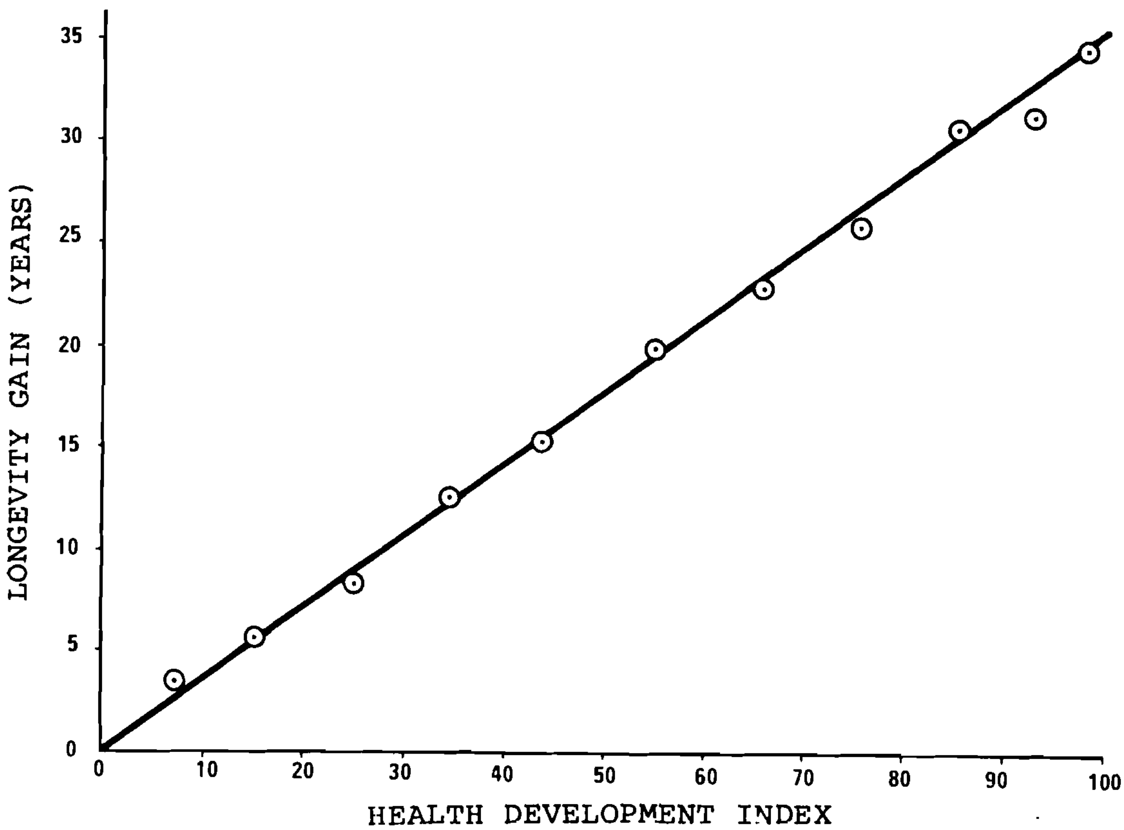

Figure 2. Longevity gain versus health development index (303 data points) 1900-1975.

We also compared the estimated time effect on longevity (last term of equation (4)) with the actual longevity after removing the INDEX effect (equation (2)). Table 2 and Figure 3 show these data grouped by calendar years. Here again the data show an excellent fit to the logistic model and the standard deviation remains rather uniform throughout. The time effect is estimated to have added 18.3 years to longevity from 1900 to 1973 for any fixed level of development.

We carried out an additional analysis. Longevity residuals from equation (4) were calculated for each of the 115 countries for which 1973 data were available. These were then grouped by continent and tested for significance by means of an analysis of variance. (North America, Europe, and Oceania were considered as a single group). The F ratio was 0.83 with 3 and 111 degrees of freedom. There was thus no statistical evidence of a geographical effect on longevity after removing the effect of development. We interpret the uniform applicability of the INDEX throughout the world as lending increased validity to our results.

Rate of Health Development

Several typical examples of countries for which relatively long series of data points were available were plotted against

Table 2. Time effect: Increase in longevity after removing the effect of development.

Year Interval	Year Mean	Number of cases	Longevity after removing development effect (mean ± SD)
<1915	1908.0	15	19.3 ± 3.5
1915-24	1921.3	12	24.0 ± 3.3
1925-34	1930.0	27	25.3 ± 3.6
1935-44	1940.6	24	28.4 ± 3.8
1945-54	1950.0	40	32.1 ± 3.3
1955-61	1960.0	41	35.3 ± 2.7
1962-72	1963.7	29	36.1 ± 2.2
1973	1973.0	115	36.8 ± 3.2

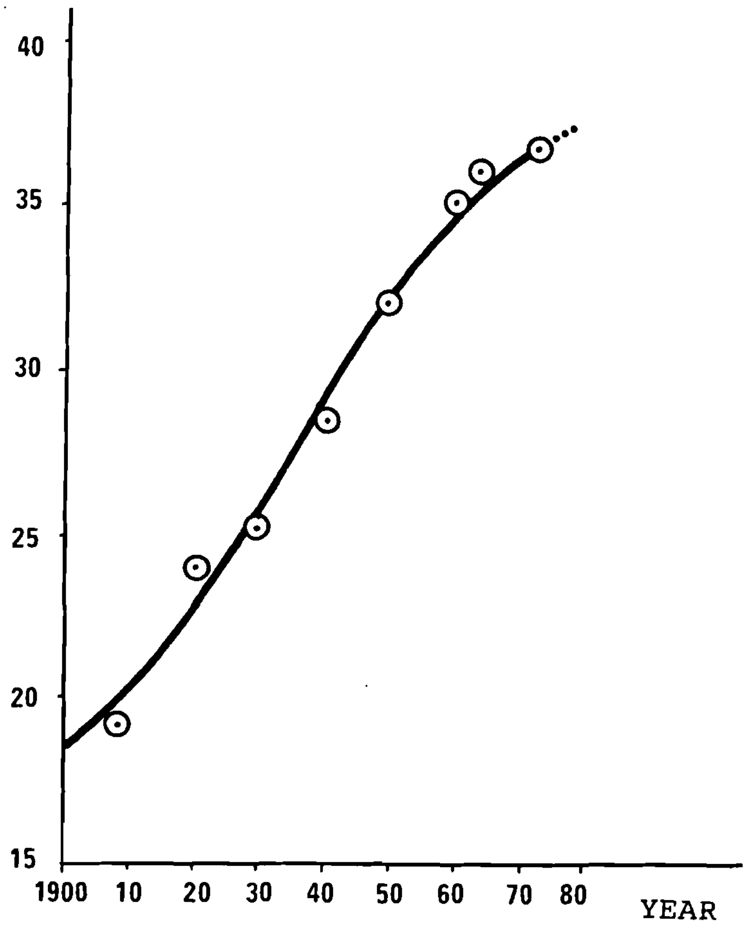

Figure 3. Longevity at zero INDEX versus time (years), (303 data points).

year, as shown in Figure 4. We observed that the rate of increase for the INDEX appeared to be quite consistent over approximately 50 years for which most of these countries had data. This was truly remarkable for certain countries which had undergone considerable political turmoil and/or devastation during this period. It appeared that there was an inherent momentum to growth of health development once it commenced and that this was quite predictable.

We therefore undertook a systematic examination of each of our 303 cases ranked by INDEX values, and estimated from the time series available for each country the number of years it

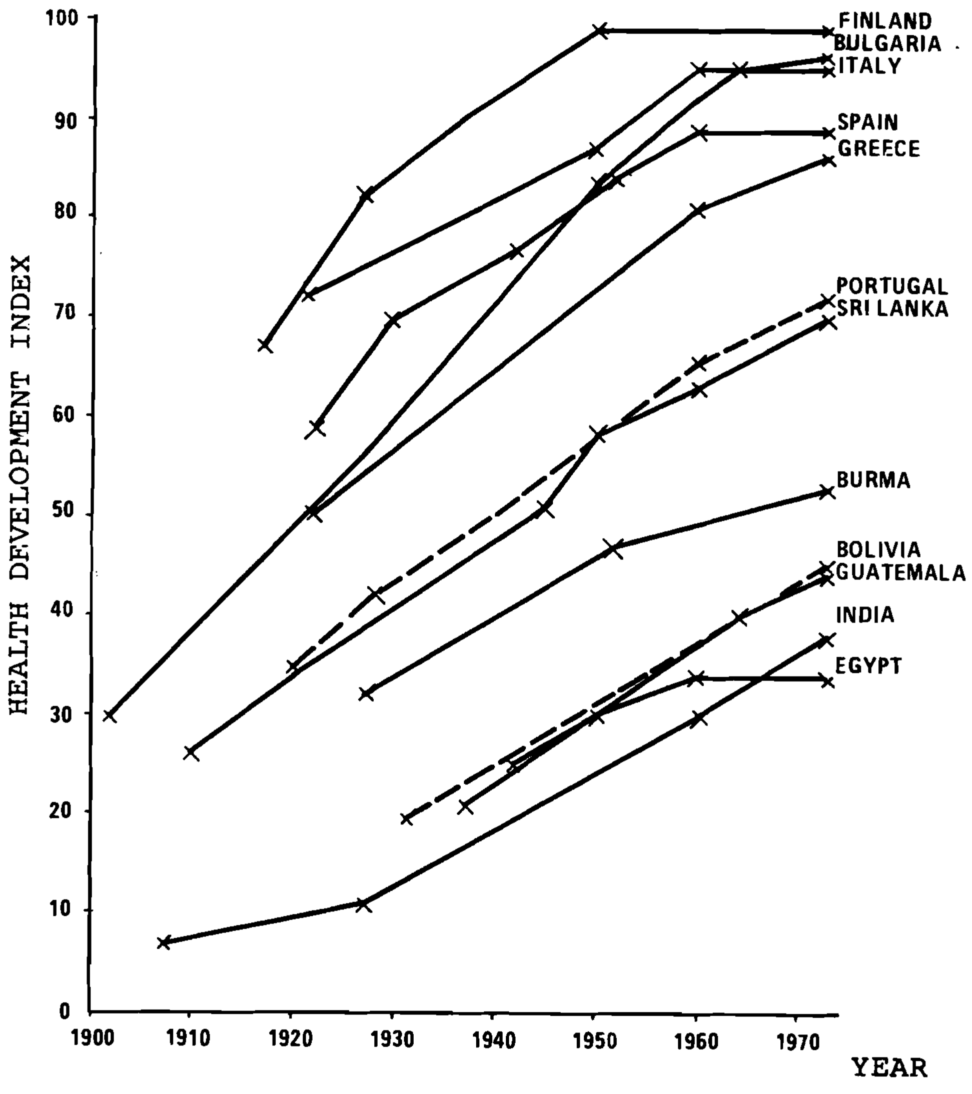

Figure 4. Growth in health development for certain seclected countries, 1900 to 1973.

Table 3. INDEX as a function of time.

INDEX Interval	Transit time (years)* (Mean ± SD)	Cumulative time+
10-19.9	17.0 ± 7.1	17.0
20.29.9	15.7 ± 2.6	32.7
30.39.9	15.7 ± 2.7	48.4
40-49.9	14.2 ± 6.0	62.6
50-59.9	10.7 ± 3.6	73.3
60-69.9	12.0 ± 3.9	85.3
70-79.9	15.0 ± 5.4	100.3
80-89.9	16.8 ± 4.9	117.1

*Time required to move from lower to upper limit of INDEX interval.

+Time required to move from INDEX value of 10 to upper limit of interval.

required to progress from each decile to the next (Table 3). These data also followed a logistic form and thus we fitted to it the curve:

$$\text{INDEX} = \frac{100}{1 + e^{-0.0606(\text{time}-59.3)}} , \qquad (5)$$

where time is measured from the point at which INDEX equals 10. A plot of this curve and the data from Table 3 are shown in Figure 5. The standard error around this curve is 2.14 years. From this curve we estimate the takeover time, i.e. the time required to move from INDEX values of 10 to 90, to be 120 years.

Infant Mortality

Since infant mortality is highly related to longevity we anticipated that the INDEX would be as useful in predicting the former as the latter. A model incorporating a linear function of INDEX and an exponential decline function of time was fitted to our 303 cases. This produced the equation

$$\text{infant mortality} = 150.0 - 1.547\ (\text{INDEX}) + 131.6\ e^{-0.0208\ (\text{year}-1900)} . \qquad (6)$$

The standard error of estimate is 24.6 deaths per thousand

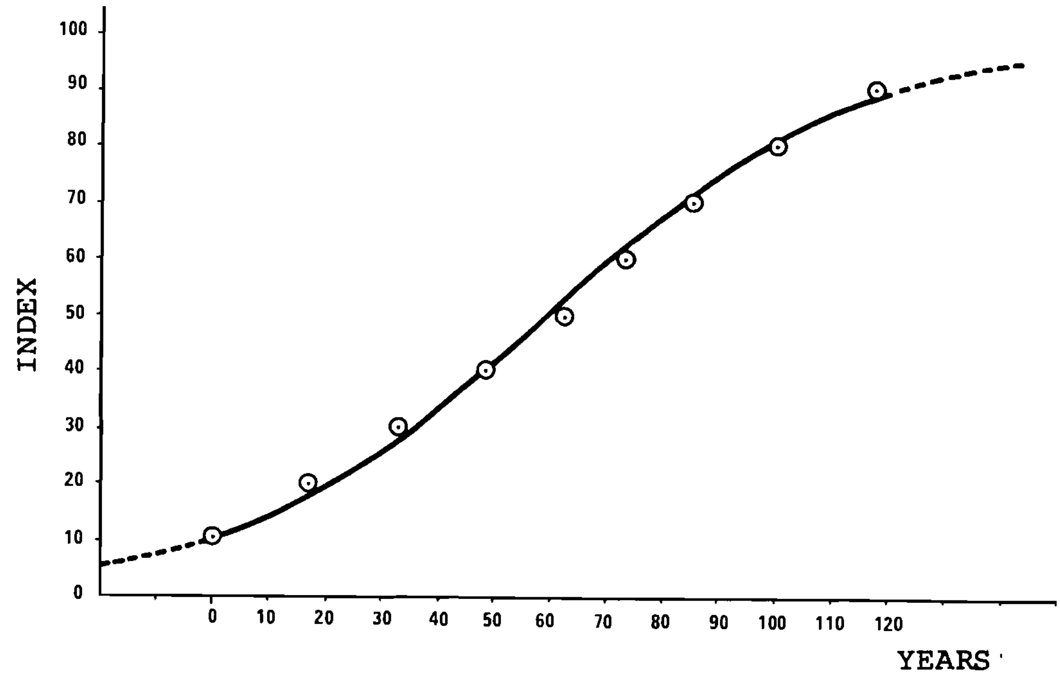

Figure 5. INDEX as a function of time.

live births. Compared to an original standard deviation of 63.6, this equation explains 61 percent of the standard deviation (or 85 percent of the variance) of infant mortality.

Figures 6 and 7 show the development and time effects on infant mortality. The data points shown are calculated in a similar manner to that used for Figures 2 and 3. Development

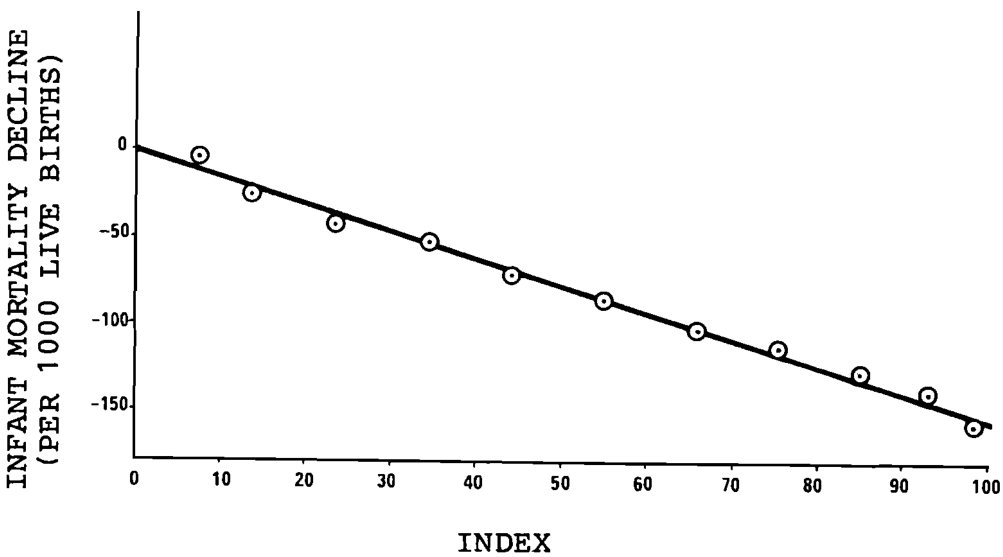

Figure 6. Infant mortality decline versus INDEX, (303 points) 1900 to 1975.

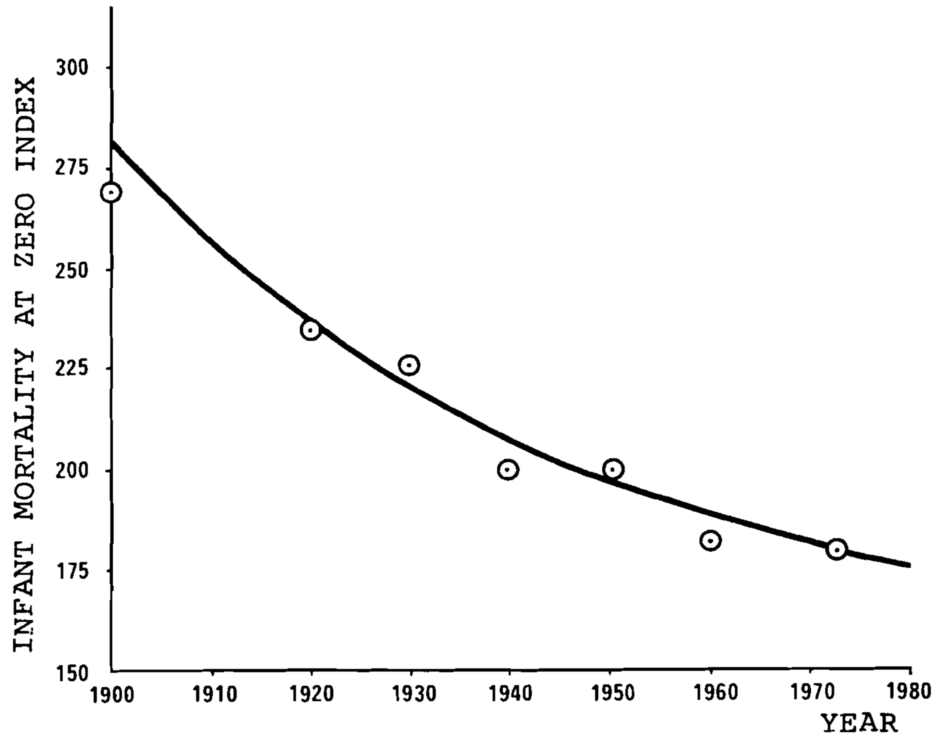

Figure 7. Infant mortality at zero INDEX versus time (year), (303 data points).

is associated with a reduction of 154 in infant mortality. The magnitude of that effect seems to be constant over time. In addition, the time effect is associated with a reduction of almost 100 infant deaths per 100 live births.

DISCUSSION

The relationship between economic development and population has been of interest ever since it became clear to Malthus in 18th century England that both appear to increase simultaneously. Demographic transition theory holds that the former precedes the latter and does so in a certain specified manner. Primitive agrarian societies are viewed as those with high death rates balanced by high birth rates, thus maintaining stable numbers. Increased economic activity is associated with an initial reduction in death rates, but not in birth rates, leading to an increase in numbers. It is widely conjectured that improved nutrition, better sanitation, and the increased availability of medical care are the responsible agents. After some interval, birth rates fall as urbanization increases and the economic advantages of large families disappear. The population then stabilizes at a higher level than in the earlier agrarian phase.

This theory, while explaining much demographic history, is attacked on two grounds. The first is that it does not *exactly* describe all demographic experience, an objection we are not concerned with in this paper. The second objection is that there is evidence that death rates can fall *without* a major reorganization of a peasant economy. In other words, substantial economic improvement may be a sufficient condition for a decline in mortality, but it is not today a necessary condition [14]. It is to the question of the effect of economic development on health that our INDEX has relevance and towards which this discussion is addressed.

In order to satisfy the expressed need for a measure of development other than per capita GNP, the Overseas Development Council has considered combinations of various indicators [15]. They have concluded that three indicators, life expectancy, infant mortality, and literacy, can be used to measure the results of a wide range of policies. Their index is a simple average of these three variables. In so doing, they have used health as a facet of economic development. As early as 1944, others have also used life expectancy as a measure of social progress(16]. In our case we wished to examine the effect of development on health and therefore used life expectancy as a *dependent* variable.

The INDEX we have developed was a weighted average of a linear (literacy) and a non-linear (energy consumption) component. The weights were determined empirically on the basis of a large sample covering a long period of time, 75 years. These two variables, literacy and energy consumption, were selected from a large number of indicators on the basis of their strong statistical association rather than through value judgement.

Although any simplistic equation purporting to explain much of human health and behavior is to be treated with scepticism, we believe that the high degree of precision with which this INDEX predicts longevity and infant mortality deserves careful consideration. We are not the first to recognize the significance of literacy and energy. Rottenberg has written:

> "The critical importance of knowledge in the economy can be perceived if all productive inputs are collapsed into two classes: knowledge and energy. Nothing can be said about the relationship of the two classes because each is an aggregate of diverse things; if they were decomposed some kinds of *knowledge* would be seen to be substitutable for some kinds of energy, and other pairs would be clearly complementary." [17].

We agree with those comments suggesting substitutability of one element for the other, but would add that the two components are not of equal weight. If those two components could be hypothetically isolated, then, on the average, literacy would add 29 years to longevity whereas energy consumption would add only 7 years, a ratio of 4 to 1. The contribution of each of these elements to the INDEX varies considerably from country to country. In Figure 8 we have graphed contours of constant values of the INDEX as well as the experience of some selected countries to illustrate those variations. Liberia, for example, with a relatively low literacy level of 9 percent, but a relatively high energy consumption level of 463 kgce, achieved an INDEX value of 23.9 with a predicted longevity of 45.5 years and actual longevity of 44 years. Seventy percent of this longevity is "due" to energy, in contrast to the mean level for all countries of 20 percent. Sri Lanka, on the other hand, in 1973 achieved a longevity of 68 years with a high level of literacy (76 percent) and a low level of energy consumption (174 kgce). India, with a somewhat higher level of energy consumption but much lower literacy, experienced a much lower longevity, i.e. 50 years. Other examples of diversity in achieving specified INDEX values are illustrated in Figure 8.

The mechanism relating literacy to health is not clearly understood at all and there is no standard body of theory

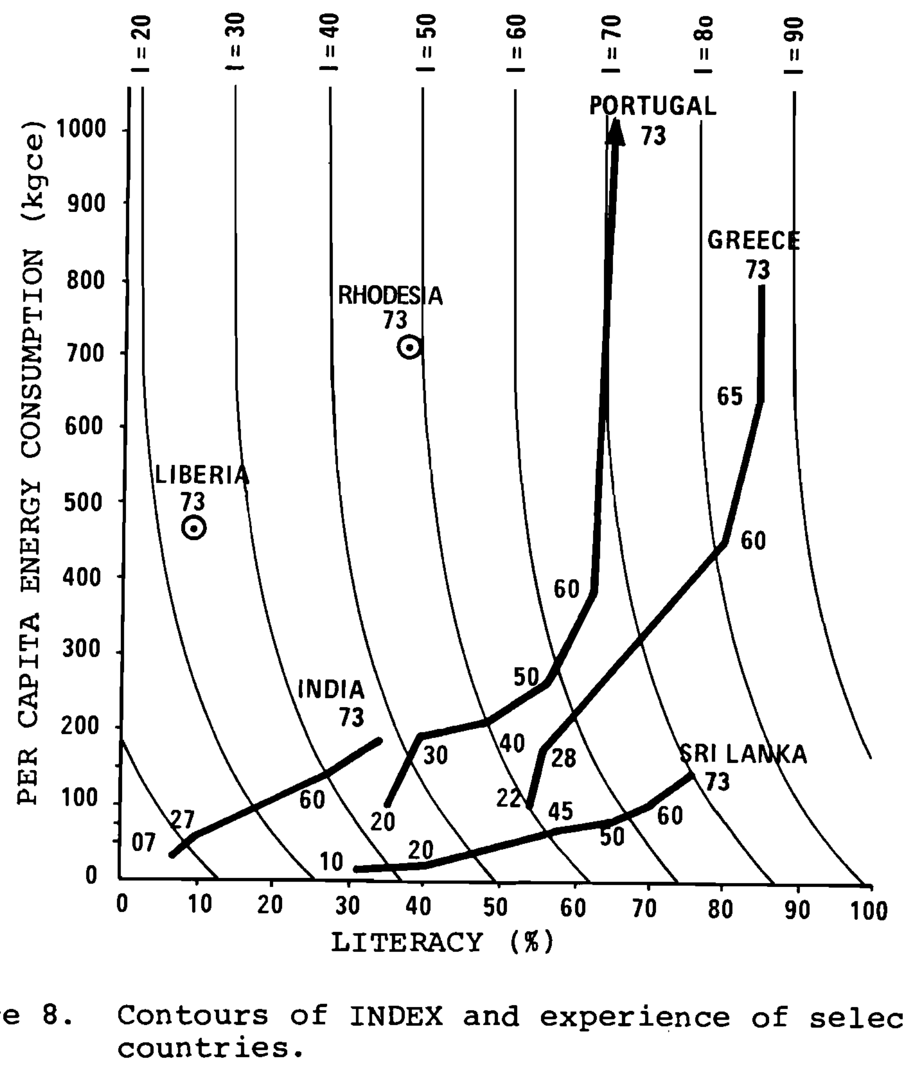

Figure 8. Contours of INDEX and experience of selected countries.

linking the two. The ability to read and write simple instructions is a skill crucial to participation in an industrialized society. The existence of high levels of illeteracy constitutes evidence of immense numbers of personal tragedies for the illiterate adults who are thereby prevented from escaping poverty and mental isolation. Illiteracy is also an obstacle to peaceful and friendly international relations and to democratic processes within countries. Low levels of literacy act as brakes on the advance of countries along the paths of social and economic development and political power.

We have formulated four plausible avenues through which literacy may directly or indirectly influence health:

- Literacy opens the door for improving the individual's and society's economic condition leading to improved nutrition, sanitation, and medical care.
- Ability to read exposes the population to health education literature and to overcoming detrimental traditional practices. Literacy also facilitates the individual's access to other opportunities, resources, and services which otherwise may be denied him.
- Literacy is the key to adopting "modern" values including a heightened concern for the individual's life and mental well being, as well as achievement, motivation, and a conviction of one's ability to influence one's own destiny (see for example [5,6]).
- A high degree of literacy may lead to a more equitable and therefore effective distribution of resources and services.

On the other hand, per capita commercial energy consumption has also been used in demographic studies as an indicator of modernization (see for example [18,19]. Hauser adds that:

> "The availability of nonhuman energy for the production of goods and services is perhaps the best single measurement available of differences in capital investment, know-how, and technology which account for the great differences in productivity and, consequently, in the size of the aggregate product available for distribution." [20]

Furthermore, increased commercial energy consumption is considered an indicator of the existence and effective utilization of more modern forms of the division of labor and other aspects of social organization [21,22]. In this sense the effect of energy consumption on health can be viewed as largely indirect.

We see the principal conclusions from the use of our INDEX as the isolation of two separate factors in mortality reduction, the economic factor and the time effect. Our results lead us to believe that an increase in the INDEX from 0 to 100 is associated with an increase in longevity of approximately 35.6 years. The United States, the United Kingdom, and Sweden, for example, had reached indices of 90 or more at the beginning of this century and had already reaped the benefit of the major portion of this increase. The subsequent extension of longevity in those countries during this century we attribute almost wholly to the time effect from which all nations have benefited independently of economic development. Life expectancy in the United States, for example, increased from 47.3 in 1900 to 71 in 1976. Of this 23.7 year increase, we calculate 18.4 years to be the result of the time effect alone and the remainder, 5.3 years, to be mostly the result of further economic development reflected by an 8.7 point increase in the INDEX. For Sweden, longevity has increased by 16.1 years in the interval 1920-1976 (the longest period for which complete data are available). Of this, 14.2 years is the result of the time effect and 1.9 years were precisely predicted by a 5 point increase in its INDEX (94 to 99). Similar figures apply for the United Kingdom and other highly developed countries.

That the benefits of economic development should be independent of time, at least during this century, suggests that these benefits do not depend on the level of current technology, or medical care delivery, an observation noted by others as well [23]. In fact, it may not be related to technologic innovation at all. Eighty percent of the force of our equation depends on literacy. If we are correct in interpreting literacy as a proxy for "modern" values, then the level of current technology would be unimportant, and that appears to be the case.

The regularity noted in the rate of progress of health development, which appears to require approximately 120 years to more from the 10th to the 90th INDEX level, needs further confirmation. We analyzed longitudinal literacy data and observed the same regularity in progress and that the period required for an increase in literacy from 10 to 90 percent was also 120 years. If this period of time is inherent in the process of development, then certain policy implications would emerge, namely, only limited expectations of development programs would be justified. Indeed, no fundamental change in the rate of health development can be detected during the postwar period, in spite of intensive efforts by national and international organizations to accelerate the process of development. The rapid rise in longevity rates among recently developing countries as compared to the slower rate in Western Europe in the 19th century we attribute to the simultaneous contributions of the time and development effects. However, since we were able to obtain adequate data only from the 20th century, we cannot rule out the possibility that the development process was slower before this century. We are not aware of other estimates of the rate of health development either in this or previous centuries.

So far we have discussed the development factor. We have also isolated a time effect operating independently of and in addition to the effect of development. The time effect has been noted by others [24], but we may be the first to quantify it. It may be described as follows:

- By time effect we mean an increase in longevity that can be identified among all countries of the world, regardless of the level of economic development.
- Beginning shortly before 1900, this effect has progressed steadily to the present time, producing an increase of 18 years in longevity and reducing infant mortality by 100.
- It has followed a trend approximated well by a logistic curve, approaching its upper plateau in the 1970s. This does not exclude the possibility that a separate logistic time effect may now begin to appear and further lengthen longevity.

We have no adequate explanation for this phenomenon. An adequate theory explaining the time effect must be consistent with the above description as well as the following general observations:

- The time effect appeared at that time in history when substantial portions of the world's population were undergoing economic development.
- The primary reductions in mortality have been directly due to the disappearing effect of infectious diseases.
- We believe that the time effect is not due to improvements in medical care, sanitation, or nutrition. This statement does not exclude some contribution from these variables to the development effect.

A plausible but unexplored explanation of the mechanism underlying the time effect is a change in the virulence of infectious agents, an improvement in human resistance, or both.

SUMMARY

We have presented an INDEX which has two components, energy consumption and literacy. The latter is four times more powerful than the former in predicting changes in longevity and infant mortality. Development, as measured by this INDEX, is associated with an increase in longevity of 36 years and a reduction of infant mortality of 150 per thousand live births. We estimate that, on the average, 120 years are required for a country to move from the 10th to the 90th percentiles of the INDEX.

We have also found evidence of a time effect operating independently of healthy development. This factor has been observed to increase longevity by 18 years and reduce infant mortality by 100 over the past 75 years.

REFERENCES

[1] *The International Development Strategies: First Overall Review and Appraisal of Issues and Policies*, Report of the Secretary General, United Nations, New York, 1973.

[2] Afifi, A.A., and L.A. Sagan, *Energy Consumption as an Indicator of Longevity*, PP-78-6 , International Institute for Applied Systems Analysis, Laxenburg, Austria, 1978.

[3] Sagan, L.A., and A.A. Afifi, Health and Economic Development I: Infant Mortality, RM-78-41, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1978.

[4] Sagan, L.A., and A.A. Afifi, Health and Economic Development II: Longevity, RM-78-42, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1978.

[5] Lerner, D., *Passing of Traditional Society: Modernizing the Middle East*, Free Press, New York, 1963.

[6] Inkeles, A., and D.H. Smith, *Becoming Modern: Individual Change in Six Developing Countries*, Harvard University Press, Cambridge, Mass., 1974, p. 290.

[7] *Demographic Yearbook*, United Nations, New York, various issues from 1945 to 1975.

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

[9] Darmstadter, J., P. Teitelbaum, and J. Polack, *Energy and the World Economy*, John Hopkins Press, Baltimore, 1971.

[10] Banks, A.S., *Cross-polity Time Series Data*, MIT Press, Cambridge, Mass., 1971.

[11] US Agency for International Development, Bureau for Population and Humanitarian Assistance: *Annual Report FY 1973*, US Government Printing Office, Washington, DC, 1973.

[12] Progress of Literacy in Various Countries, *UNESCO Monographs on Fundamental Education, No. 6*, Paris, 1953.

[13] *Historical Statistics of the United States, Colonial Times to 1970*, US Department of Commerce, Washington, DC, 1975.

[14] Coale, A.J., and E.M. Hoover, *Population Growth and Economic Development in Low Income Countries: A Case Study of India's Prospects*, Princeton University Press, 1958, Chap. 2.

[15] Sewell, J.W., *The United States and World Development: Agenda 1977*, Praeger, New York, 1977, p. 147.

[16] Hart, H., and H. Hertz, Expectation of Life as an Index of Social Progress, *American Sociological Review*, 9, 1944, 609-621.

[17] Rottenberg, S., C.A. Anderson and M.J. Bowman, (eds.) in *The International Exchange of Knowledge in Education and Economic Development*, Aldine, Chicago, Ill., 1965.

[18] Wellen, R.H., and D.F. Sly, Modernization and Demographic Change: A World View, *Rural Sociology*, 34, 1969, 313-326.

[19] Christian, B., D. Ray, A. Benyoussef, and T. Tanahashi, Health and Socio-Economic Development: An Intersectorial Model, *Social Science and Medicine*, 11, 1977, 63-69.

[20] Hauser, M., Demographic Dimensions of World Politics, *Science*, 131, 1960, 1641-1647.

[21] Cottrell, F., *Energy and Society*, McGraw-Hill, New York, N.Y., 1955.

[22] Gibbs, J., and W. Martin, Urbanization, Technology and the Division of Labor: International Patterns, *American Sociological Review*, 27, 1962, 667-677.

[23] Stewart, C.T., Allocation of Resources to Health, *Journal of Human Resources*, 6, 1971, 103-122.

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