Revisiting the Preston Curve: An Analysis of the Joint Evolution of Income and Life Expectancy in the 20th Century

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1. INTRODUCTION

Investigation of the association between health and economic well-being is a well trodden territory with numerous researches spanning several decades. And yet unravelling the exact nature of this association is deemed difficult and complicated. Contentious policy views about the role of economic development and public health services in the decline of mortality arise because of the uncertain, and probably complex, nature of the association between health and income. In the realm of the macro-level debate concerning the role of economic development in enhancing population health, this paper analyses the relationship between life expectancy and income by using cross-country macro data to examine their joint evolution and infer about their causal relationship.

Preston (1975) plotted life expectancy against income per capita for a cross section of countries for the years 1900, 1930, and 1960, showing an increasing and concave relationship, shifting upward over time. While the cross-sectional correlation is more or less stable over time, Preston's estimate attributes only between 10-25% of the overall improvement in the life expectancy between 1930s and 1960s to national income per head. About 75-90% of the growth in life expectancy for the world as a whole between the 1930s and the 1960s is credited to factors exogenous to a country's current level of income (e.g. public health interventions, including diffusion of health sector innovations). Amidst the traditional intellectual predilection in the mid seventies that higher incomes must improve health (e.g. Mckeown, 1976), the intriguing article by Preston (1975) stimulated conventional scholarship and invoked policy debate. His work highlights the extent of disassociation of mortality from economic level, and provides grounds for investigating the health selection impact - i.e. the impact that exogenous health improvements may have on economic growth. This paper contributes to the existing literature by revisiting the Preston curve with a wider data spectrum (i.e. 1930-2000), and by providing insightful descriptive statistics and Granger causality tests to shed light on the causality issue. The analysis is supplemented by the description of cross country convergence (or divergence) of aggregate health and income indicators, the role of global health interventions, and the resulting trends of the death rates from different diseases.

2. CROSS-REGION EVOLUTION OF INCOME AND HEALTH

An examination of the global pattern of income and health over time is a logical starting point in the process of unfolding the intricate income-health relationship at the aggregate level. Bourguignon and Morrisson (2002) assembled historical data, comprising the last two centuries, on GDP per capita and life expectancy for 33 countries or groups of countries.[1] Their data suggest that average life expectancy in the world has more than doubled, rising from 26 years in 1820 to 60 years at the beginning of the 21st century. However, progress was very slow until the World War II – an improvement of only about seven years in more than a century (Bourguignon and Morrisson, 2002, p.741).

Table 1 reveals the pattern of evolution of mean life expectancy and shows that between 1820 and 1929, Africa and Asia registered limited improvements by only 6 and 5 years respectively. The

[1] The list of 33 countries and country-groups used in the study by Bourguignon and Morrisson (2002) are the following: **1) Africa:** Egypt, Nigeria, North Africa, South Africa, Cote d'Ivoire-Ghana-Kenya, and 46 African countries; **2) Asia:** China, India, Indonesia, Bangladesh-Burma-Pakistan, Thailand-Philippines, and 45 Asian countries; **3) Japan-Korea-Taiwan:** Japan, Korea-Taiwan; **4) Latin America:** Brazil, Mexico, Colombia-Peru-Venezuela, and 37 Latin American countries; **5) Eastern Europe:** Bulgaria-Greece- Romania-Yugoslavia, Poland, Russia, Turkey; **6) Western Europe and European offshoots:** Argentina-Chile, Australia-Canada-New Zealand; Austria-Czechoslovakia-Hungary, France, Germany, Italy, Scandinavian countries, Spain-Portugal, Switzerland-Benelux-and microstates, United Kingdom - Ireland, United States.

mean life expectancy increment was 9 years for Japan, Korea and Taiwan; 11 years for the Latin America; 17 years for the Eastern Europe; and 23 years for the Western Europe and European offshoots. Interestingly, the increase of the mean life expectancy between 1929 and 1992 is relatively dramatic but more equally distributed. Over this time-span (i.e. 1929 to 1992) life expectancy increased by 20, 26, 26, 24, 24, and 15 years for Africa, Asia, Japan-Korea-Taiwan, Latin America, Eastern Europe, and Western Europe and European offshoots, respectively.

Table 1: Mean life expectancy at birth and GDP per capita by regions

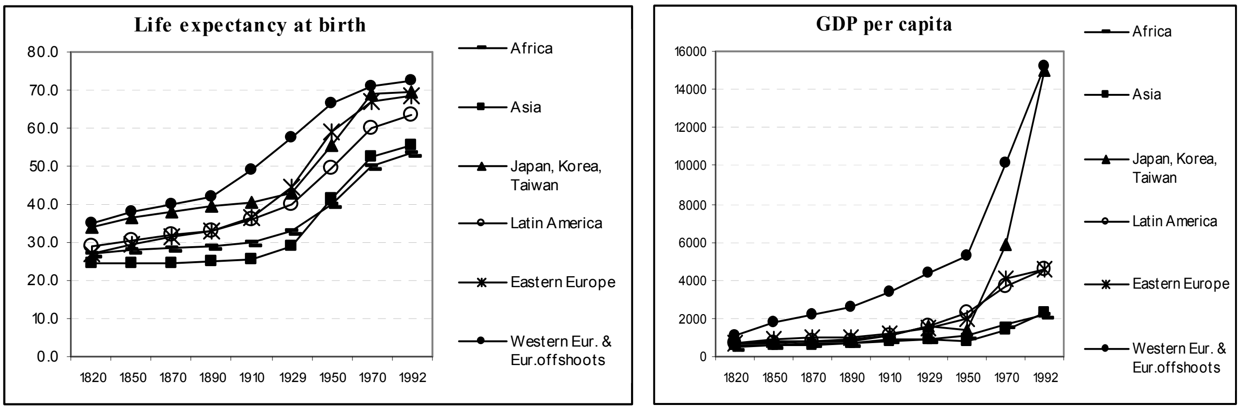
	1820	1850	1870	1890	1910	1929	1950	1970	1992
				Mean Life Expectancy					
Africa	27.2	28.0	28.5	29.0	30.2	33.2	40.2	50.2	53.5
Asia	24.3	24.5	24.7	24.8	25.5	29.2	41.5	52.8	55.5
Japan, Korea, Taiwan	34.0	36.4	37.9	39.5	40.8	43.3	55.5	69.0	69.5
Latin America	29.0	30.7	31.9	33.0	36.0	40.0	49.4	60.1	63.5
Eastern Europe	27.3	29.7	31.4	33.0	36.6	44.5	59.3	66.9	68.5
Western Eur. & Eur.offshoots	34.8	37.8	39.8	41.8	49.2	57.6	66.5	71.0	72.6
				Mean GDP per capita					
Africa	546	608	650	692	854	932	1127	1720	2157
Asia	572	612	639	666	784	900	810	1346	2294
Japan, Korea, Taiwan	685	761	811	862	1078	1551	1382	5913	14973
Latin America	667	742	791	841	1104	1553	2259	3656	4549
Eastern Europe	730	861	948	1035	1239	1469	2021	4095	4567
Western Eur. & Eur.offshoots	1126	1742	2152	2563	3371	4339	5282	10181	15195

Note: Data from Bourguignon and Morrisson (2002) is used to produce the unweighted mean values by region. Data for 1850 and 1890 are interpolated based on a per year constant increment assumption. GDP per capita are in 1990 International Geary-Khamis dollars.
(see, http://unstats.un.org/unsd/methods/icp/ipc7_htm.htm)

Between 1820 and 1992, the GDP per capita increased approximately threefold for Asia and Africa, 21 fold for Japan-Korea-Taiwan, six-fold for Latin America, fivefold for Eastern Europe, and 12 fold for Western Europe and its offshoots. Similar to the progress in life expectancy, the progress in per capita income had been moderate before World War II, and remarkable afterwards. Between 1820 and 1929 GDP per capita increased by only 0.71, 0.57, 1.26, 1.33, 1.01, and 2.85 fold for Africa, Asia, Japan-Korea-Taiwan, Latin America, Eastern Europe, and Western Europe and European offshoots, respectively. However, unlike the egalitarian pattern of region-wise spectacular improvements of life expectancy during 1929 to 1992, increase of GDP per capita had been non-egalitarian and disproportionate across regions during the same period. For instance, between 1929 and 1992, while the GDP per capita increased by 8.7 fold for Japan, Korea, and Taiwan, the regions of Africa and Asia registered the increments by only 1.3 and 1.5 folds, respectively.

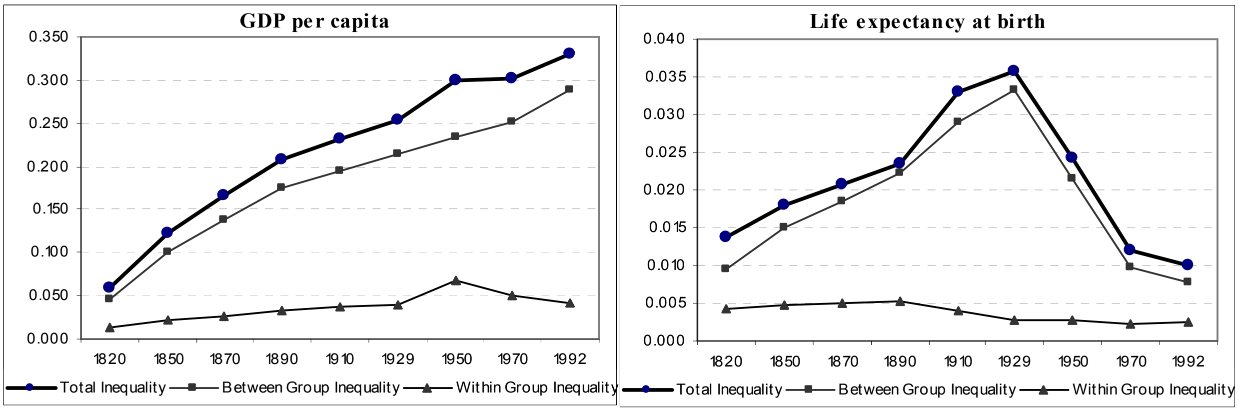
This pattern of health and income evolution is also evident from Figure 1. For all the regions, except the Western Europe and its offshoots, the trend of the increase in life expectancy is moderate until the 1930s. All the regions apparently registered remarkable and sustained progress in achieving longevity from 1930s onward. The trend for Western Europe took an accelerated path since the beginning of the 20th century. On the other hand, the GDP per capita trends for all the regions apart from Western Europe and its offshoots did not become steeper until the 1950s. Western Europe registered a steeper trend throughout, but more remarkably after the 1950s. Therefore, for all the regions, the increase in life expectancy precedes that in GDP per capita.

Figure 1: Evolution of the mean life expectancy and GDP per capita by regions (1882 – 1992)



Source: Produced using the data from Bourguignon and Morrisson (2002). Data for 1850 and 1890 have been interpolated based on a per year constant increment assumption.

Figure2: Inequality trend for GDP per capita and life expectancy (1820 – 1992)



Note: The Theil indices of inequality (including the Theil decompositions) are derived using the data from Bourguignon and Morrisson (2002) for the 33 countries and groups of countries. Theil coefficients for 1850 and 1890 are based on interpolated data based on a per year constant increment assumption.

The consequential evolution of world inequality in life expectancy took a more or less similar path as did inequality in GDP per capita until World War II. It took a dramatic reverse path in the post war period. Figure 2 presents the Theil inequality index[2], which is calculated using the Bourguignon and Morrisson (2002) historical data for the 33 countries (and groups of countries) of the six major

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[2] The formulae for Theil indices and its decomposition are derived and extracted from Theil (1967).

$$\sum_{i=1}^{N} y_i \log\left(\frac{y_i}{1/\ N}\right) = \sum_{g=1}^{G} Y_g \log\left(\frac{y_g}{N_g/\ N}\right) + \sum_{g=1}^{G} y_g \left[\sum_{i \in S_g} \frac{y_i}{y_g} \log \frac{y_i/\ y_g}{1/\ N_g}\right],$$

where y_i is the individual country share in the totals of the respective variables (i.e. life expectancy or GDP per capita). Therefore, $\sum_{i=1}^{N=33} y_i = 1$. Again, $y_g = \sum_{i \in S_g} y_i$, where there are G sets (e.g. the major 6 regions) $S_1, \ldots\ldots\ldots, S_g$ and $\sum_{g=1}^{G} N_g = N$.

The left-hand provides the total Theil index of inequality. This measure for total inequality has been decomposed into two parts in the right hand side: the explained (between-set inequality) and the unexplained (within-set inequality) parts. The first term on the right, which is the between-set inequality provides us information about the contribution of different factors (i.e. in this case the six regional groupings of the 33 countries and groups of countries) in the total inequality.

regional blocks. As Figure 2 demonstrates, around the 1930s, a divergent trend in life expectancy gave way to a dramatic convergent trend. No such turning point is evident for income, albeit a moderate deceleration of divergence after 1950.

The empirical investigation of this paper mainly refers to the decennial data since the 1930s. Table 1 shows the decennial standard deviation statistic of the world based on the observed individual country level data from 1930 till 2000. In line with the earlier findings, Table 1 data reveals a similar pattern for the cross country evolution of GDP per capita and life expectancy over the post-WW2 20th century, i.e. there exists a divergent trend for the former and convergent trend for the latter, albeit a remarkable improvement of the both.

Table 1: Convergence and Divergence: Standard Deviations

	Log per capita GDP	Life Expectancy	Infant Mortality	Child Mortality	Adult Mortality Rate (Female, per 1000 adult female)	Adult Mortality Rate (Male, per 1000 adult male)
			Standard Deviations n = number of observation (countries)			
1930	0.62 (n=51)	11.33 (n=40)				
1940	0.69 (n=54)	12.15 (n=54)				
1950	0.94 (n=140)	12.24 (n=160)				
1960	0.96 (n=140)	12.07 (n=178)	60.95 (n=151)	105.70 (n=151)	152.48 (n=151)	152.63 (n=152)
1970	1.02 (n=140)	11.24 (n=179)	55.05 (n=154)	94.30 (n=154)	141.58 (n=158)	142.67 (n=158)
1980	1.08 (n=140)	10.46 (n=183)	47.96 (n=172)	80.58 (n=172)	129.97 (n=160)	129.41 (n=160)
1990	1.06 (n=162)	10.52 (n=191)	43.37 (n=186)	71.84 (n=186)	121.02 (n=174)	120.29 (n=174)
2000	1.15 (n=162)	11.74 (n=193)	40.10 (n=185)	66.96 (n=177)		
			Standard Deviations **(Balanced Panel data for 43 countries)**			
1940	0.72	12.78				
1950	0.86	11.29				
1960	0.88	10.75	46.07	76.48	142.62	134.07
1970	0.92	8.29	39.39	63.27	101.88	83.89
1980	0.92	7.18	33.59	51.07	76.80	69.38
1990	0.94	5.83	25.06	35.95	56.79	53.69
2000	0.95	5.07	18.93	25.94		

Note: Life Expectancy, infant mortality, child mortality, adult mortality rates are from WDI (2006). In case of the adult mortality rate data in 2000, WDI (2006) contains data for only 34 countries, and therefore was not reported. Life expectancy data for 1930 and 1940 are from Acemoglu and Johnson (2007). Since WDI does not contain data for per capita income prior to 1960, these data are taken from the Maddison (2003). The balanced panel data consist of the following 43 countries, as indicated by the respective three digit ISO country codes: ARG, AUS, AUT, BGD, BRA, CAN, CHE, CHL, CHN, COL, CRI, DNK, ECU, ESP, FIN, FRA, GBR, GTM, HND, HUN, IDN, IND, IRL, ITA, KOR, LKA, MEX, NIC, NLD, NOR, NZL, PAK, PAN, PER, PHL, PRT, PRY, SLV, SWE, THA, URY, USA, VEN. See appendix 1 for country codes and names. Due to unavailability of data for some countries in the balanced panel set, statistics for the year 1930 is not presented. Data on adult mortality rates for 2000 exist only for 16 out of those 43 panel countries, and therefore were not reported.

The measures of dispersions for various health and income indicators in Table 1 are unweighted, which assumes each country as a unit whose mortality and income experience provides unique example from the universe of all possible such histories. Since the number of observations varies significantly across the decades, in order to get a sound picture, Table 1 contains two panels: the upper panel reports the estimates based on all possible observations at each point in time; the lower panel presents the statistics of a balanced panel, consisting of observed data for 43 countries at each time point.[3]

The standard deviations of the logarithm of per capita GDP reproduce the familiar finding that there is no convergence in log GDP around the world; indeed, the standard deviation of logarithms rises from 0.62 in 1930 to 1.15 in 2000. A similar pattern is revealed in the balanced panel data of 43 countries. The standard deviation of life-expectancy shows a different pattern. The pattern differs from that of the life GDP per capita, as well as between the upper and lower panels of the table. While there is no evidence of divergence in the life expectancy, the statistics based on the panel of 43 countries show a discernible decline of the standard deviations, and thereby reflects convergence. The (not so obvious) convergent pattern in the upper panel may be attributable to significant differences in the number of observations (i.e. countries), whereas in the latter decades the statistics from the poorer regions of the world became more available. Also, after 1990, with the collapse of the Soviet Union and the deterioration in life expectancy in several ex-socialist countries, and above all, with the onset of HIV/AIDS, convergence may have turned to divergence (Deaton, 2006; Soares, 2007).[4]

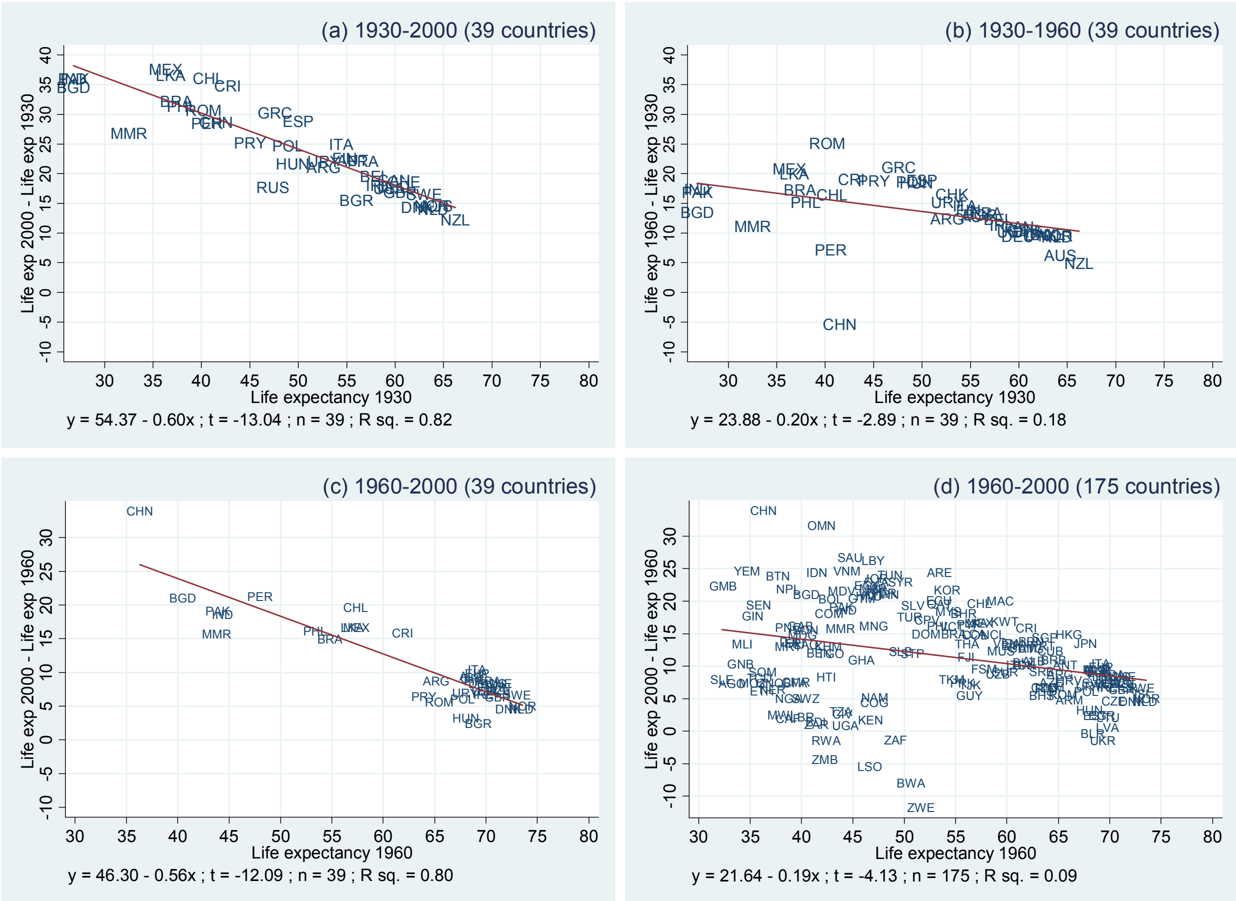
The cross-country international dispersion of infant and child mortality rates has fallen continuously since 1960. This is evident even in the face of the negative consequences that AIDS/HIV may have on children. Also, as Deaton (2006) asserts, whether there is divergence or convergence in infant and child mortality depends on whether we work in ratios or in levels. Given that infant and child mortality rates have continued to decline in the low mortality rich countries alongside the poorer counterparts, even small absolute reductions are proportionately large. The inequality measure between the poorer and richer countries in this case may manifest divergence. It is inevitable, however, that infant and child lives saved in absolute numbers are much higher for the poorer countries than their richer counterparts.

Figure 3 plots the change in life expectancy between two periods against the initial period. Panel (a), (b), and (c & d) present the scatter plots and associated fitted lines between the periods 1930 and 2000, 1930 and 1960, and 1960 and 2000, respectively. The figures show that countries starting with high life expectancy levels tended to experience smaller gains than countries that have low initial levels of life expectancy.

The unweighted regression line for the 70 year period (i.e. between 1930 and 2000) in Figure 3 (a) shows that life expectancies ten years higher in 1930 were associated, on average, with gains in life expectancy 6 years lower in the following 70 years. When the fitted line is observed for the same 39 countries for two sub-periods (i.e. 1930-1960 and 1960-2000) the regression mean is evidently stronger for the period 1960-2000.[5] However, the regression line produced with data for 175 countries (WDI, 2006) for 1960-2000 shows that the countries with life expectancy ten years higher are associated, on average, with gains in life expectancy 1.9 years lower in the following 40 years. The scatter plot in Figure 3 (d) is clearly much more dispersed than the one in Figure 3 (c). This is mainly attributable to the inclusion of the African countries in the scatter plot.

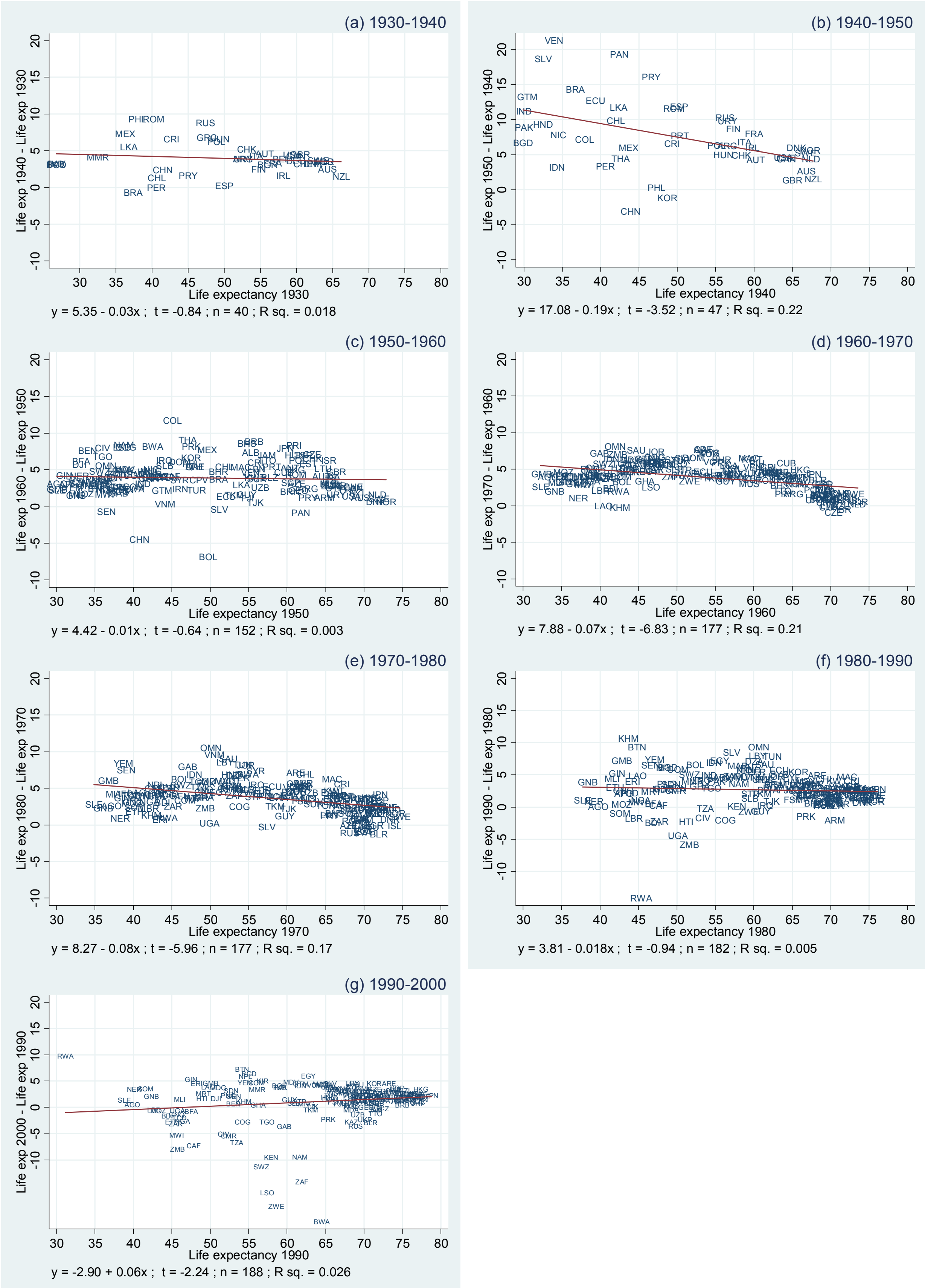
[3] The list of countries in the panel does not contain African countries.
[4] Albeit a great deal of uncertainty about the measurement of life expectancy in sub-Saharan Africa, and the precise extent to which it has fallen, there is no doubt about the phenomenon itself, or the widening in international health inequalities that it has produced (Deaton, 2006, p.8).
[5] The life expectancy data for the year 1930 was available for 39 countries (League of Nations Health Organization, 1933).

Figure 3: Cross-country regression to the mean in the life expectancy



A breakdown of the regression to the mean into each of the decades reveals the pattern of cross-country life expectancy evolution more clearly. This is shown in Figure 4 (a-g). A more or less homogenous performance in improving life expectancy, irrespective of the initial levels, is observed during the decade 1930-1940. Large improvements in life expectancy are observed for the decade 1940-1950 with the countries with lower initial levels of life expectancy gaining much higher increments. For the decade 1950-1960, the countries, on average, gained about 5 years in life expectancy irrespective of their initial life expectancy levels. This pattern changed for the subsequent two decades, as seen in Figure 4 (d) and (e). During 1960-1980, the countries with lower initial levels of life expectancy registered higher gains in life expectancy than those with higher initial levels of life expectancy. This relationship between initial life expectancy and gains in life expectancy began to reverse in the subsequent decades, (i.e. 1980-2000) with the advent of AIDS epidemic in the African countries during the eighties and its overwhelming effects throughout the nineties. The fitted line turned into the one with a positive slope indicating that the countries with lower initial levels of life expectancy, on average, performed poorly compared with the countries with higher life expectancies. The reduction of life expectancy during the end of the twentieth century in countries like Botswana, Lesotho, Namibia, Swaziland, Zimbabwe, Zambia., as evident from 4 (g), contributed to the negative mean life expectancy gain as well as the positive slope of the fitted line. Nevertheless, in general, the countries with a low level of life expectancy achieved higher life expectancies during the post World War II period that led convergence toward higher levels of life expectancy and reduced inequality in life expectancy.

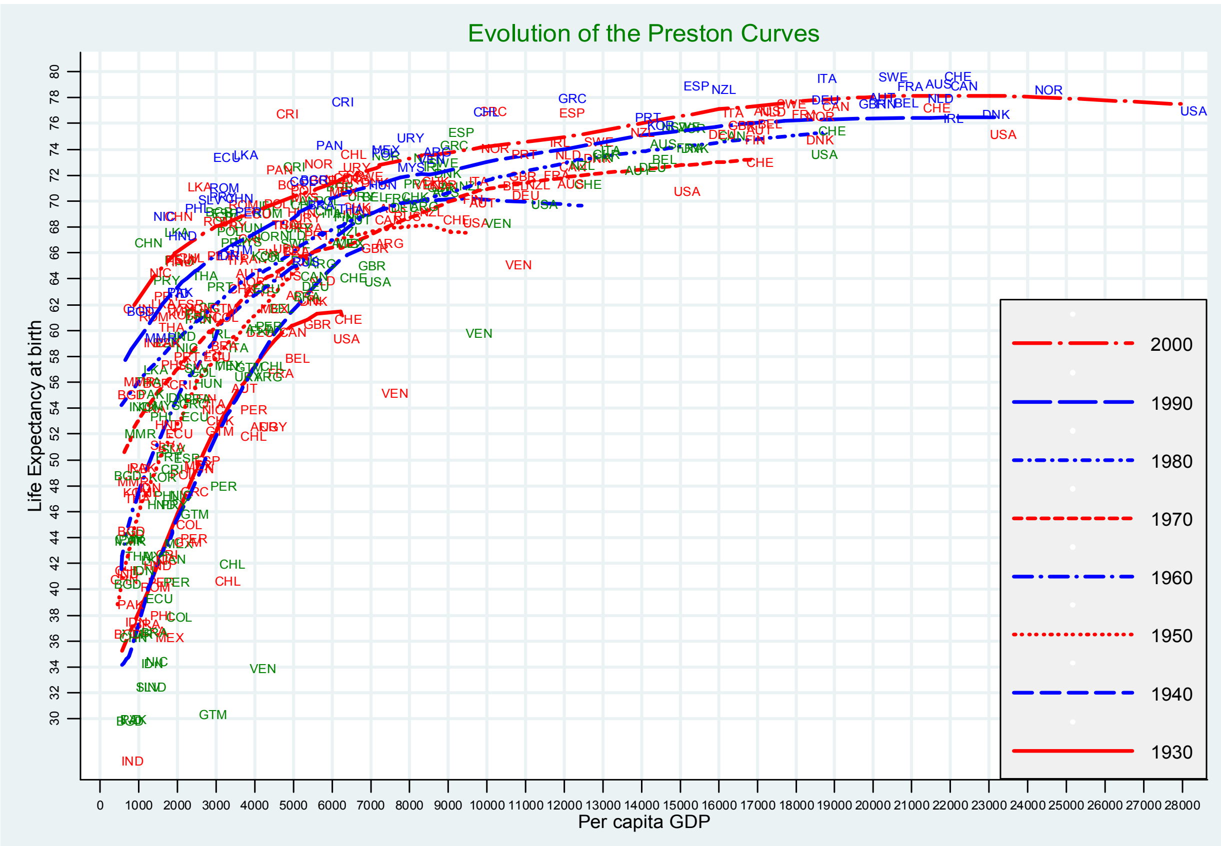
Figure 4: Cross-country regression to the mean in the life expectancy in ten-year intervals, 1930-2000



2.3. EXPLORING THE FACETS OF THE PRESTON CURVE

Figure 5 reproduces the Preston curves for all the decades since 1930 through 2000. Life expectancy at birth is on the vertical axis and the GDP per capita is on the horizontal axis. A Lowess (locally weighted least squares) curve is calculated by fitting a line to the local neighbourhood of each data point, and aggregating the line segments into a curve. The Preston curves in general show that among the poorest countries small changes in income are associated with large increases in life expectancy. Among the richer countries (i.e. on the right side of any curve) increases in income are associated with small, albeit positive, increases in life expectancy. The conventional view postulates that as GDP per capita increases the countries should move approximately along the contour of the Lowess curve. If, however, the Preston-curve shifts upward or rightward over time, then the conventional conjecture based on the cross sectional relationship becomes fallacious. An upward move of the curve means the countries being able to achieve increments in life expectancy without increases in GDP per capita. A rightward shift on the other hand would imply that countries were not able to increase their life expectancy despite increments in GDP per capita. It is evident from Figure 5 that not only the Preston curves have prominently moved upward over the decades, albeit at different rates between two time periods, there is a continuous flattening of the curves with possible rightward shift particularly in the recent decades. This entails the progressive disassociation of income from the level of mortality.

Figure 5: Preston Curves (1930 – 2000) for a panel of 53 countries



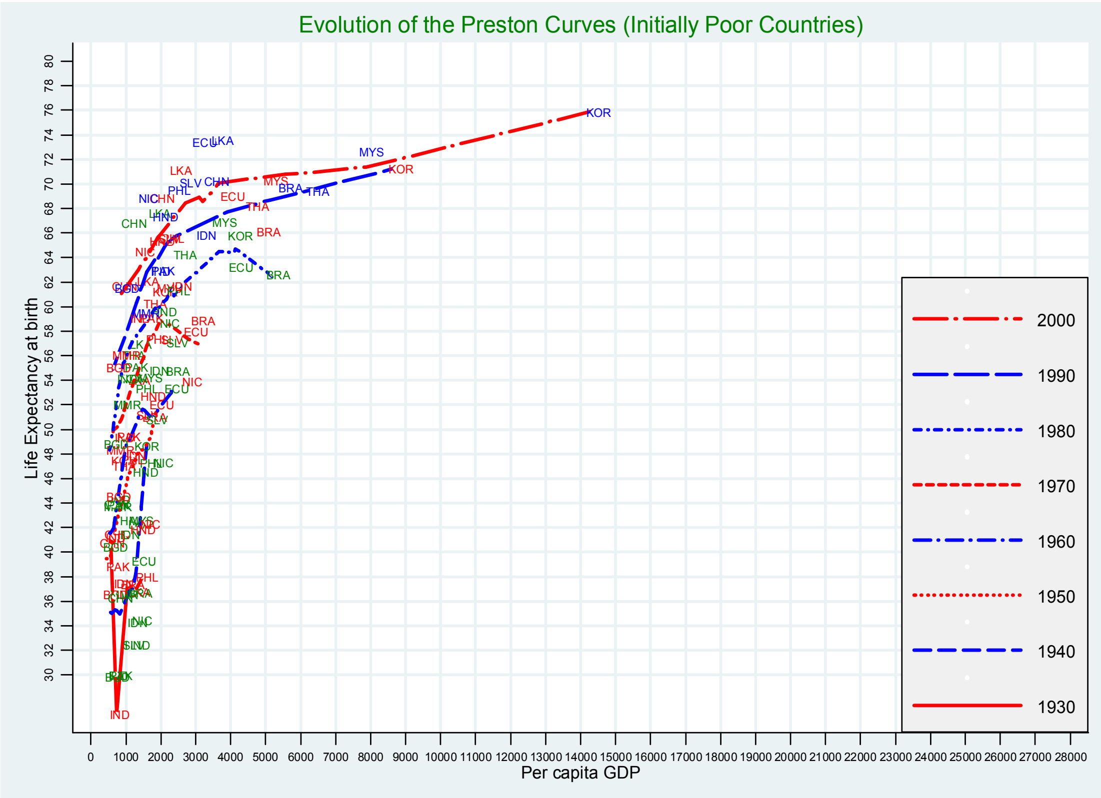
Note: Life Expectancy data are from the World Bank data series (WDI, 2006). Life expectancy data for 1930 and 1940 are from Acemoglu and Johnson (2007), the 1950 data are from the Demographic Year Book (1954); and the data for the nearest year have been used where the exact 1930 and 1940 data were unavailable. Since WDI does not contain data for per capita income prior to 1960, these data are taken from the Maddison (2003) data series. The number of countries covered is 53, which includes the initially rich (11 countries), middle income (20), and poor (16) countries. Additionally 6 East European countries are also included: Bulgaria, Czechoslovakia, Hungary, Poland, Romania, and Russian Federation (see Acemoglu and Johnson, 2007). There are few data gaps for different years; therefore data does not form a completely balanced panel throughout the decades.

In order to extract a clearer picture, the following section presents the Preston curves sliced into three segments: one for the initially poor countries, one for the initially middle income countries, and the other for the initially rich countries. Figure 6 presents the part of the Preston curve corresponding to the initially poor countries only. The curve does not postulate any discernible pattern for the year 1930. The length of life of the people in China was 41.5 years with a GDP per capita of 567 dollars. In contrast Brazil with almost twice as much GDP per capita (i.e. 1048 dollars) shows that the people there lived on average only 37.4 year. Even worse is the case for India, where people had GDP per capita of 726 dollars but a miserable figure of only 26.8 years of average life expectancy across the population. The curve began to take a very steeply upward slopping shape, almost vertical, since 1940 through to 1960. However, during the 1940s, China remains as an aberration. For instance, the per capita GDP of China and the Indian sub-continent (i.e. Bangladesh, India, and Pakistan) are close to each other, but people in China expected to live 13 years more than the people in the Indian sub-continent. The shape of the curve became progressively flatter since the 1970s, mainly attributable to the remarkable economic progress of the East-Asian countries (e.g. Malaysia, Korea, Thailand). In general, there is a continuous upward shift of the curves in successive decades. The poor countries in general gained life expectancy irrespective of the levels of their GDP per capita. How this group of low-income countries managed to make such rapid and sustained gains in survival is discussed in the next section.

Figure 7 produces the decennial Preston curves for the initially middle-income countries. The curves reveal an upward slopping concave pattern throughout; however much steeper during the early decades, and became progressively flat with apparent rightward shifts during the latter decades. There are some eccentricities in the relationship attributable to some countries. For example, life expectancy for Norway has been quite high irrespective of its income ranks. The data for 1930 shows that the life expectancy in Norway was 63.8 years with per capita GDP of 3731 dollars, whereas France registered a life expectancy of only 56.7 with a per capita GDP of 4531. Chile, with a per capita GDP of 3142, shows a life expectancy of only 40.7 years – i.e. 13 years less than Norway. Again, the length of life of the people in Venezuela was relatively very short despite a relatively very high per capita GDP, which caused the curves to be notably kinked downward until the 1960s. The life expectancies for Venezuela in 1940 and 1950 were 33.9 and 55.2 with per capita GDP of 4045 and 7462 dollars, respectively. Despite a large leap of life expectancy between these two decades, these were relatively low in comparison to other countries with a per capita GDP of similar range. After 1960, Venezuela's life expectancy was gradually attuned to the average pattern for the initially middle income countries.

Turning to the initially rich countries in Figure 8, the Preston curves are nearly horizontal, with continuous upward and rightward shifts throughout. The horizontal lines imply similar levels of life expectancy despite different income per capita; the upward shifts imply improvement of longevity independent of income; and the rightward movements imply stagnant longevity despite increases in income per capita.

Figure 6: Preston Curves (1930 – 2000) for the initially poor countries



Note: See the note in Figure 5.

Figure 7: Preston Curves (1930 – 2000) for the initially middle income countries

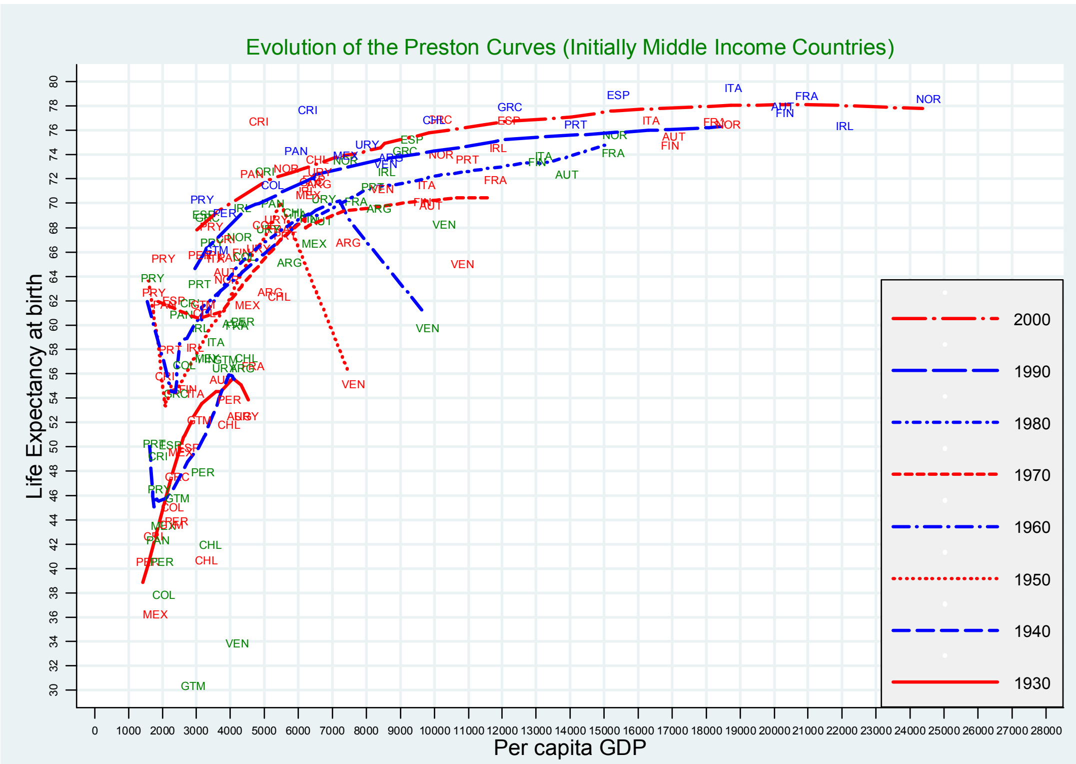
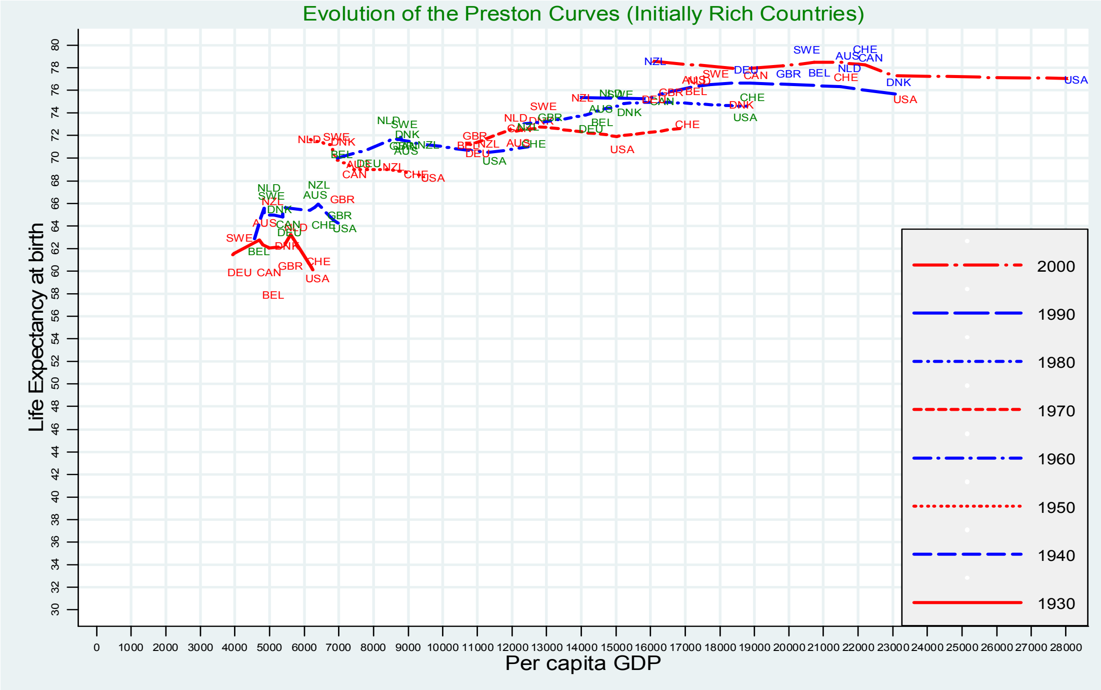
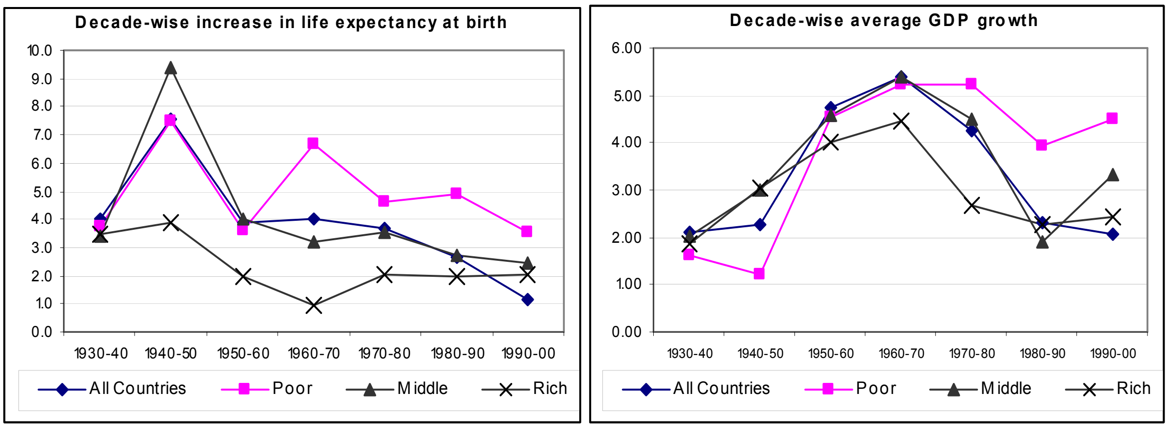


Figure 8: Preston Curves (1930 – 2000) for the initially rich countries



In general, the Preston curves seemingly shifted upwards at differential rates in successive decades. Figure 9 reveals important features of the increase of life expectancy and GDP per capita during each decade from 1930 till 2000. The life expectancy for all the countries in the sample increased by 26.9 years on average, with the highest gain by the poor countries (34.59 years) followed by the middle income (28.72 years) and rich (16.33 years) countries. Evidently, there is a large shift upward from 1940 to 1950. During this period the world as a whole registered the highest increase of life expectancy by 7.57 years; but the increase in GDP per capita was the third lowest (2.26 percent) in the seven decades we are considering here.

Figure 9: Decennial increase in life expectancy (in absolute years) and average GDP growth



Data Source: The Life Expectancy data are from the World Bank data series (WDI, 2006). Life expectancy data for 1930 and 1940 are from Acemoglu and Johnson (2007), the 1950 data are from the demographic year book (1954); and the data for the nearest year have been used where the exact 1940 data were unavailable. The GDP per capita data are taken from the Maddison data series.

The growth of GDP per capita was the highest (5.4%) during the period 1960-70, followed by a 4.73% increase during 1950-1960. GDP growth was even lower during 1930-40 (2.12%) and 1940-

50 (2.26%). However, we see the largest increment in longevity – i.e. 7.57 years – during 1940-50. This large shift in the length of human life occurred notably for the poor countries (7.5 years) and middle income countries (9.36 years). Interestingly, despite a remarkable increase of 3.05% in GDP per capita in the rich countries during 1940-1950, life expectancy increased by less than four years in those countries. Moreover, during the periods 1960-70 the rich countries experienced the most remarkable increase in per capita income (4.44%) and the least progress in the life expectancy (i.e. 0.96 years). Therefore, the periods of high growth neither accompanied nor preceded the periods of high gains in terms of life expectancy. However, the periods of high life expectancy gains (e.g. 1940-50) preceded the periods of high growth in per capita GDP (e.g. 1950-70). This provides us with an empirical cue about the causal relationship between income and health. *Time order* - that cause should precede effect, is usually deemed as a precondition to causal inference. Given that life expectancy gains in general preceded the periods of high growth at least shed doubt on the prominence of the role of income in improving health.

A simple statistical exercise that tracks correlations between the health status (H_t) expressed in term of the life expectancy at birth and the income status (Y_t), i.e. per capita GDP, reveals an interesting feature: in general, the correlations between the initial health status and the per capita income of the subsequent decades are higher than the correlations between the initial income status and the life expectancy of the subsequent decades.

- *Correlation between H_t, Y_{t+k} > Correlation between Y_t , H_{t+k} , where t = 1940, 1950….1990 and k = 10, 20, or 30 … years.*

Table 2: Correlation Matrix: Initial Health and Income Conditions

	(1)	(2)	(3)		(4)	(5)	(6)
	Initial Health Status (H_t) (Life Expectancy at birth)				**Initial Income Status (Y_t) (Income per capita)**		
Kendall Tau							
	H_{1940}	H_{1950}	H_{1960}		Y_{1940}	Y_{1950}	Y_{1960}
Y_{1940}	0.63			H_{1940}	0.63		
Y_{1950}	0.59	0.66		H_{1950}	0.65	0.66	
Y_{1960}	0.63	0.69	0.69	H_{1960}	0.67	0.65	0.69
Y_{1970}	0.65	0.72	0.73	H_{1970}	0.6	0.59	0.63
Y_{1980}	0.66	0.73	0.76	H_{1980}	0.61	0.59	0.62
Y_{1990}	0.67	0.71	0.74	H_{1990}	0.59	0.61	0.61
Spearman Rank Correlation							
	H_{1940}	H_{1950}	H_{1960}		Y_{1940}	Y_{1950}	Y_{1960}
Y_{1940}	0.81			H_{1940}	0.81		
Y_{1950}	0.76	0.85		H_{1950}	0.86	0.85	
Y_{1960}	0.78	0.87	0.87	H_{1960}	0.87	0.86	0.87
Y_{1970}	0.82	0.89	0.91	H_{1970}	0.82	0.8	0.83
Y_{1980}	0.85	0.91	0.93	H_{1980}	0.81	0.79	0.82
Y_{1990}	0.87	0.89	0.92	H_{1990}	0.79	0.77	0.81

Countries covered: ARG, AUS, AUT, BEL, BGD, BGR, BRA, CAN,,CHE, CHK, CHL, CHN, COL, CRI, DEU, DNK, ECU, ESP, FIN, FRA, GBR, GRC, GTM, HND, HUN, IDN, IND, IRL, ITA, KOR, LKA, MEX, MMR, MYS, NIC, NLD, NOR, NZL, PAK, PAN, PER, PHL, POL, PRT, PRY, ROM, RUS, SLV, SWE, THA, URY, USA, VEN.
Data Source: The Life Expectancy data are from the World Bank data series (WDI, 2006). Life expectancy data for 1940 are from Acemoglu qand Johnson (2007), the 1950 data are from the United Nations Demographic Year Book (1954); and the data for the nearest year have been used where the exact 1940 data were unavailable. The GDP per capita data are taken from the Maddison data series.

'Granger causality' tests (perhaps more appropriately stated as Granger non-causality tests) are statistical tests of causality in the sense of determining whether lagged observations of another variable have incremental forecasting power when added to a univariate autoregressive representation of a variable. Therefore, the notion of Granger causality implies that if lagged values of *X* help predict current values of *Y* in a forecast formed from lagged values of both *X* and *Y*, then *X* is said to '*Granger cause Y'* (Thurman and Fisher, 1998). This notion is then implemented by regressing life expectancy on lagged life expectancy and lagged GDP per capita: if the coefficients on lagged GDP per capita are significant as a group, then GDP per capita causes life expectancy. In order to test the reverse causality a symmetric regression is applied; i.e. regressing GDP per capita on lagged GDP per capita and lagged life expectancy. Tests are estimated using single equation OLS models.[6]

Time series data on GDP per capita and life expectancy at birth for the period 1930 – 2001 is used to examine the causality issue for 47 countries. The selection of the countries is based on Acemoglu and Johnson's (2007) base panel set, where the 47 countries are classified into three income groups based on the per capita income of 1940: initially poor (16 countries), initially middle income (20 countries), and initially rich (11) countries. The upper benchmark income for distinguishing a country of the middle income group is the per capita income of Argentina in 1940. The upper limit benchmark income for the poor countries is the income per capita of Portugal in 1940, so that any country's per capita GDP below the level of Portugal is classified as poor. The data on GDP per capita is available for all the countries and for all the years (i.e. 1930 – 2001) from the Madisson (2003) series. However, there are data gaps in the life expectancy data. For example, many of the countries have data for two or three years per decade. These data gaps were filled by data interpolation techniques, assuming that the life expectancy data does not show abnormal deviations from trend between the two closest data points. The value of life expectancy (*LE*) at any point in year *T* is found by finding the closest points (LE_0, T_0) and (LE_1, T_1), such that $T_0<T$ and $T_1>T$, where LE_0 and LE_1 are observed, and calculating

$$LE_T = LE_0 + (T - T_0)\frac{LE_1 - LE_0}{T_1 - T_0}$$

Using the bivariate time series data for each of the countries, Granger causality tests are performed using one to three lags. The number of lags in each equation is the same for life expectancy and income. In order to conclude that one causes the other, we must find unidirectional causality from one to the other. In other words, we must reject the non-causality of the one to the other and at the same time fail to reject the non-causality of the other to the one. If either both cause each other or neither causes the other, the question will remain unanswered (Thurman and Fisher, 1998). The following two equations were estimated by OLS for each of the 47 countries.

$$LE_t = \alpha + \sum_{i=1}^{L} \lambda_1 LE_{t-i} + \sum_{i=1}^{L} \beta_1 PCY_{t-i} + \varepsilon_i \qquad \text{(a)}$$

$H_0 = \beta_1 = \beta_2 = ... = \beta_L = 0$ (i.e. per capita GDP does not Granger cause life expectancy)

$$PCY_t = \alpha + \sum_{i=1}^{L} \lambda_1 PCY_{t-i} + \sum_{i=1}^{L} \beta_1 LE_{t-i} + \varepsilon_i \qquad \text{(b)}$$

$H_0 = \beta_1 = \beta_2 = ... = \beta_L = 0$ (i.e. Life expectancy does not Granger cause per capita GDP).

However, regression analysis based on time series data implicitly assumes that the underlying time series are stationary. In practice most economic time series are non-stationary. Based on the Dickey-Fuller (DF) and augmented Dickey-Fuller (ADF) tests both the life expectancy and per capita GDP time series are found to be non-stationary.[7] Then regression of one time series variable on one or more time series variables can give spurious results resulting in spurious regression. In such cases, the often prescribed solution is to take the first-differenced values of the respective series hoping that they would produce a stationary series, and then perform the regression specification on the first

[6] Granger causality test, however, is beset with several limitations. It neither establishes causality in a theoretical sense, nor does it represent a test for strict exogeneity.
[7] For details on the DF and ADF tests, see Dickey and Fuller (1979), Greene (1997).

differenced series. However, the first differenced regression captures only the short run relationships and cannot unfold the long-run equilibrium relationship.

One way to guard against spurious regression with the levels of time series it is to find out if the time series are cointegrated. This implies that despite being individually non-stationary, a linear combination of two or more series can be stationary – therefore a valid long run or equilibrium relationship exists between the time series variables. One way to test whether two non-stationary series are cointegrated is to perform a DF or ADF test on the residual estimated from the cointegrating regression (Gujarati, 1995). In our case, we found the resultant residuals are, in all cases (with very few exceptions in models with lag 1), stationary. Therefore, we assume the long run relationship between life expectancy and income to be a valid one.

The test results for each of the 47 countries are presented in appendix 2. Table below summarizes the results.

Table 3: Summary of the Granger Causality Tests

	Number of countries showing that *Per capita GDP Granger Causes Life Expectancy*		Number of countries showing that *Life Expectancy Granger Causes Per Capita GDP*	
Country Status (number of countries examined)	Number of countries	Conclusive inference	Number of countries	Conclusive inference
	Model with number of lags = 1			
Initially Poor (16)	10	3	11	4
Initially Middle Income (20)	6	4	12	10
Initially Rich (11)	3	3	7	7
Total (47)	**19**	**10**	**30**	**21**
	Model with number of lags = 2			
Initially Poor (16)	1	1	7	7
Initially Middle Income (20)	2	2	5	5
Initially Rich (11)	3	3	3	3
Total (47)	**6**	**6**	**15**	**15**
	Model with number of lags = 3			
Initially Poor (16)	1	1	5	5
Initially Middle Income (20)	3	3	3	3
Initially Rich (11)	2	1	3	2
Total (47)	**6**	**5**	**11**	**10**

In a single lag vector autoregressive model, 30 out of 47 countries show that life expectancy causes per capita GDP. Among these 30 countries, one can draw a conclusive inference on 21 countries that life expectancy Granger causes per capita GDP; for the remaining 9 countries the inferences are inconclusive, because those countries also show in the symmetrical reverse exercise that per capita GDP causes life expectancy. In the case of the two lag model, 15 countries show that the causality runs from life expectancy to income; and all of them produce conclusive evidence (i.e. in the reverse equation none of the 15 countries show that income causes life expectancy). In the three-lag model, the number of countries producing conclusive evidence is reduced to 10.

On the other hand, the number of countries demonstrating that GDP per capita causes life expectancy is much lower in all the models. For instance, in the single lag model 19 countries show that per capita GDP causes life expectancy, but only 10 out of these 19 countries provide conclusive evidence. In the other two models the numbers are even lower (e.g. 6 countries in the two lag model, and 5 countries in the three lag model).

Given the majority number of countries failing to show that life expectancy causes per capita GDP and vice versa, the Granger causality exercise does not provide us with a clear-cut causality inference. Nevertheless, the evidence that the lagged values of the life expectancy better predict the income variable are more powerful than the reverse scenario. This perhaps reinforces the notion that the relationship between health and income is complex and may be working in both directions. However, if health improvements occur due to some exogenous factors other than income, one can use the exogenous variations in health and put this in the context of a growth modeling framework to explain the income outcomes. Below we discuss the causes of the mortality reductions during the 20th century.

4. DRIVERS OF THE LARGE GAINS IN THE POST-WAR POPULATION HEALTH

From the perspective that income determines the health outcomes, the preceding analysis has at best demonstrated a weak relationship between income and health at the aggregate level. What are the drivers of the large gains in population health? Cutler et al. (2006) provide a detailed synthesis of the determinants of mortality reductions with a retrospective of cross-country historic health and wealth evolutions since the early eighteenth century. The study identifies three phases of mortality reductions. The first phase, from the middle of the eighteenth century to the middle of the nineteenth century, is the one where improved nutrition and economic growth is perceived to have played the major role in health determination, along with incipient public health measures. In the closing decades of the nineteenth century and into the twentieth, the second phase occurred, in which public health mattered more - first negatively, because of high mortality in cities, then positively in the delivery of clean water, removal of waste, and advice about personal health practices. The third phase, dating from the 1930s on, has been the era of big medicine, starting with vaccination and antibiotics, and moving on to the expensive and intensive personal interventions.

Acemoglu and Johnson (2007), referring to Preston (1975), mention three major factors contributing to the dramatic improvement in population health in the post war era. The first factor was the wave of global drug innovations offering preventions and cures effective against major fatal diseases in developing countries. Secondly, the establishment of the World Health Organization (WHO), which greatly facilitated the spread of medical and public health technology to poorer countries. From the 1950s, the WHO, together with other UN-related bodies, most significantly, UNICEF, was the driving force behind the public health and immunization drives. The third factor was a change in international values to curb diseases. The consequence of the combination of these three factors was a dramatic improvement in life expectancy around the world, especially in the less developed parts of the globe, starting in the 1940s (Acemoglu and Johnson, 2007, pp.935-36).

Appendix 3 and 4 present the decennial mean death rates (per 100,000) for 15 vital diseases for the period 1930 – 1980. The tables reveal the potential impacts of the health innovations around the world during 1930-1980, categorizing the countries by the initial income status and region-wise. For most of the diseases the largest declines in the death rates occurred during the 1940s and 1950s. The largest decline of the death rate for pneumonia occurred during the 1940s, when the death rate fell from about 179 to 86 per 100000 people. The rate of decline became relatively moderate in the subsequent decade. However, for the other greatest killer among the diseases – tuberculosis – the death rates declined sharply during 1930 – 1950 (i.e. from 204 to 52 per 100000 person), and continued to decline in the subsequent periods. Malaria registered the biggest decline during the 1950s. The profile for influenza and typhoid reveals an aberration. While the death rates continued the decline throughout the decades (the largest being during the 1940s), there is a sharp increase in 1980. The data in the lower panels reveals that the increases for influenza were mostly remarkable in the initially rich and middle income countries; additionally Appendix 4 reveals that it occurred in the region of Europe and Central Asia. On the other hand, the increased death rates for typhoid in 1980 are prevalent in the initially poor and middle income countries (Appendix 2), which are located in the regions of East Asia and Pacific, Latin America and Caribbean, and Sub-Sahara Africa (Appendix 4). Other diseases, except cancer, show continuous declines in the death rates till the 1970s, with some higher death rates for the year 1980. The death rates for cancer show increasing trends for the world as whole, as well as for the countries of different income status. Interestingly, the richer countries, where people's length of life is longer, reveal the highest and remarkably increasing death rates in cancer. The aforementioned trend in the fatality attributable to different diseases led the researchers to identify a form of international health transition (i.e. the rapid decline in mortality and improvement in health) - originating with the wave of international health innovations and improvements that began in the 1940s (Acemoglu and Johnson, 2007).

Figure 10: Contribution of major categories of disease to the total deaths

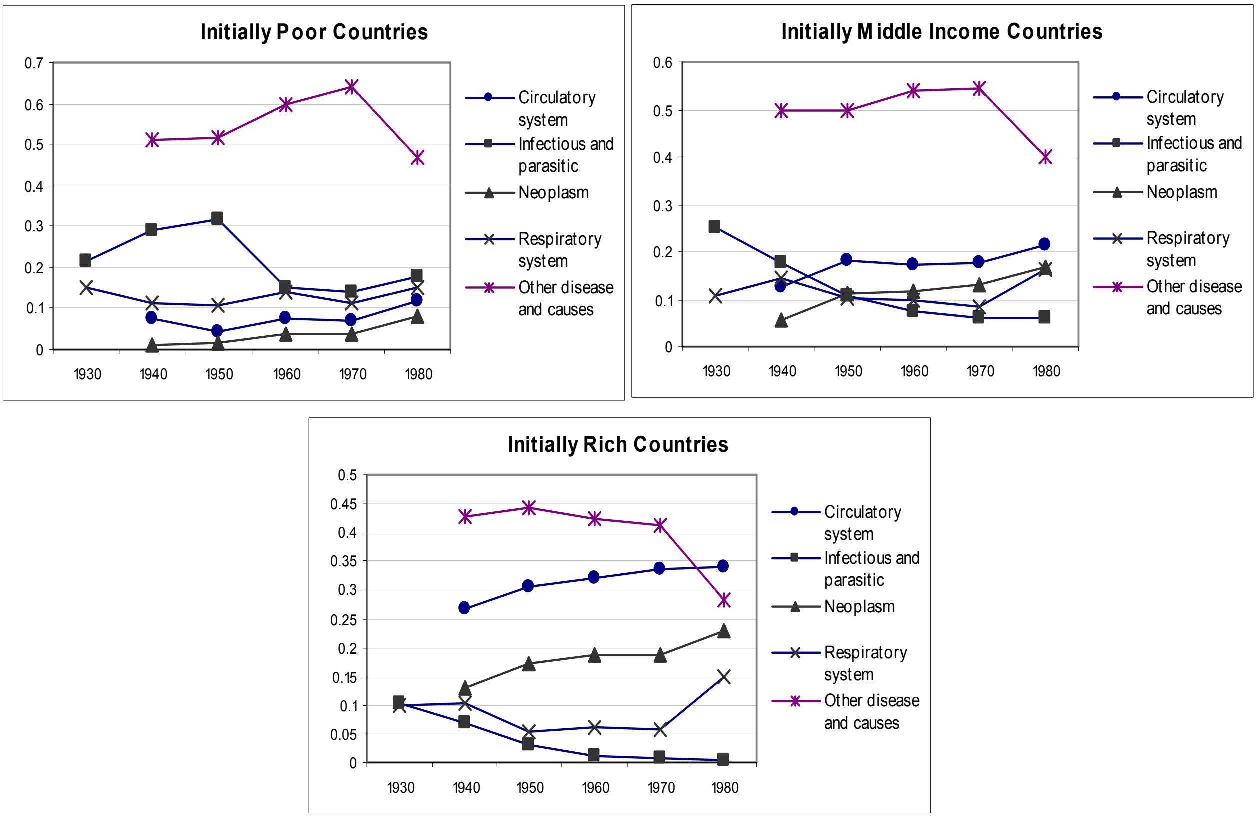


Figure 10 shows the trend contribution of major disease categories since 1930 until 1980, and suggests different health transition periods for countries with different initial economic status. The contribution of infectious diseases to total deaths in poor countries increased during 1930 to 1950; but during the 1950s the share decreased sharply (i.e. from 32% in 1950 to 15% in 1960). There was a concomitant, but modest, increase in the contribution of other three categories (i.e. diseases of the circulatory system, respiratory system, and neoplasm) and sharp increases in the deaths due to other diseases and causes.[8] Therefore the epidemiological transition is set during 1960s for the poor countries. In case of initially middle income countries, the figure shows a continuous and sharp fall in the share of infectious diseases in total deaths until 1970 (e.g. from 25% in 1930 to 7.4% in 1960), after which its contribution settled around six percent. This declining trend in the infectious diseases' contribution was accompanied by differential increases in the contribution of neoplasm,

[8] The "other diseases and causes" category includes diseases like deliveries and complications of pregnancy, childbirth and the puerperium, congenital malformations, birth injuries, postnatal asphyxia and atelectasis, infections of the newborn, ulcer of stomach and duodenum, appendicitis, intestinal obstruction and hernia, gastritis, duodenitis, enteritis and colitis, except diarrhoea of the newborn, cirrhosis of liver, nephritis and nephrosis, Diabetes mellitus, Anaemias, vascular lesions affecting central nervous system hyperplasia of prostate, other diseases peculiar to early infancy, and immaturity unqualified, senility without mention of psychosis, ill-defined and unknown causes, all other diseases residual, motor vehicle accidents, all other accidents, suicide and self-inflicted injury, homicide and operations of war.

respiratory system, and circulatory system. Also, there had been a moderate decrease in the contribution of the other diseases and causes category during 1930–1970-, after which the contribution declined sharply (i.e. from 54% in 1970 to 40% in 1980). The level of deaths from infectious diseases in the initially rich countries was already low, because the epidemiological transition was set in those countries long before the 20th century. Howsoever, the declining trend had been continuous during the observed period (e.g. 10 % in 1930 to 0.003% in 1980). Notably, apart from the category of other diseases and causes, most of the deaths were due to the diseases related to the circulatory system (around 30% throughout). Also, there had been a marked increase in the contribution of cancer related diseases (i.e. neoplasm). The decade of the 1970s also saw large increases in the deaths from respiratory system related diseases. Parallel to that, during the 1970s, there was a significant decrease in the deaths attributable to the other categories.

While economic gains contribute to the improvement in health, many of the gains are due to specific efforts to address major causes of disease and disability, such as providing quality and more accessible health services, introducing new medicines and health technologies, and promoting healthier behaviours (Levine et al., 2004). Examples of effective public health programs, not necessary hinging upon the national income level, exist to facilitate understanding the determinants of the changes in population health (see for example Levine *et al*., 2004; Chandra, 2006). Drawing on numerous successful cases of large scale public health interventions around the world Levine et al. (2004) identifies the elements of success: (i) predictable, adequate funding from both international and local sources; (ii) political leadership and champions; (iii) technological innovation within an effective delivery system, at a sustainable price; (iv) technical consensus about the appropriate biomedical or public health approach; (v) good management on the ground; and (vi) effective use of information. Reflecting on the above criteria, it has been found that large scale health interventions have worked successfully even in the world's most underdeveloped and remote regions, in the face of extreme poverty and weak health systems.

Recently, Sub-Saharan African countries set a remarkable example of public health success in reducing measles cases and fatalities. The deaths from measles fell by 75% (from an estimated 506,000 to 126,000) during 2001-2006, which is due to the firm commitment and resources of national governments, and support from the Measles Initiative (a consortium of the American Red Cross, the United States Center for Disease Control and Prevention (CDC), the United Nations Foundation, UNICEF and WHO) (UNICEF, 2007). Chandra (2006) asserts this incidence as striking in the context that the majority of these deaths have been preventable since 1960, when an economical and highly potent vaccine for measles was invented. It is apparent that the decline in child mortality is not associated with improvements in African incomes, but the result of an effective intervention that occurred 40 years after the discovery of the innovation of the measles vaccine. Success of such large scale public health intervention requires taking into account of the socio-cultural contexts, and addressing of the power and empowerment issues within the communities and in the context of political activism. In the area of large scale public health interventions, it is the participation of ordinary people in the effort that matters more than the technical knowledge and skill of the experts who give advice about disease prevention (Riley, 2007).

Therefore, a strand of literature emphasizes the importance of social growth, social capital, and social justice in enhancing the population survival in these poor countries (see e.g. Caldwell, 1986; Riley, 2007). Caldwell (1986), with reference to some economically poor lands as Kerala, Sri Lanka and Costa Rica, highlights that the poor countries achieved good health by emphasizing social justice rather than economic growth. The policies were formulated under the premise of social justice, e.g. equitable access to health care, education, and food, along with ensuring greater autonomy for women. Albeit being economically poor, in these lands women could find places in primary schools, participated in decision-making not only within the families in family matters but also in the wider community. There was an open political system, and a largely civilian society with no rigid class structure, and a history of egalitarianism and radicalism.

Banister and Hill (2004) analyses the spectacular improvements in the longevity of the people in China during the period 1964-2000, and attributes the improvements in the pre-reform Maoist period to a unique, less costly, simple, and egalitarian public health model. In particular, they mention four factors: (a) public health campaigns in combination with wide access to some level of health service at minimal cost; (b) aggressive and successful promotion of child vaccinations, as well as improved sanitation and water supplies in rural and urban areas; (c) expansion of primary and secondary education; and (d) increased numbers of medical personnel and health facilities, and a greater variety of pharmaceuticals (Banister and Hill, 2004). According to (Riley (2007, p.110), the impressive health status in China between the late nineteenth century and 1930s is due not only to Mao's communist ideas, but also by Western influences, including missionaries and the Rockefeller and Milbank Memorial Foundations, which attempt to develop medicine and public health during that period.

An account of the survival gain in Sri Lanka during 1920s to 1941 suggests that this relatively low-income state initiated significant public health improvements during 1910s with a strong campaign against hookworm which sought to persuade people to install better latrines. Also during 1930s and 1940s, Sri Lanka introduced a welfare system with free education, free health care for pregnant women, infants, and young children, and school meals and food subsidies. There was concomitant increase in the number of health centers and trained health personnel, which promoted maternal and infant health, health education, and sanitation (Riley, 2007, pp. 69-71). Cuba presents an interesting case. Despite inconstancy in the cycles of economic development, income distribution, access to health and sanitation services, political stability, corruption, and the development of literacy and education; the initiatives of the period 1900-25 appear to have created a strong enough public health infrastructure to withstand the inconstancy of these factors in the period 1925-59. The Cuban case suggests that a strong beginning in the development of public health and, later, medical services may be enough to carry a country forward for many years of indifferent investment or even disinvestment (Riley, 2007, pp.92-94).

Astorga et al. (2004) describes the trends of living standards and longevity of the Latin American countries during the twentieth century. For the six major economies in the Latin America (i.e. Argentina, Brazil, Chile, Colombia, Mexico and Venezuela), longevity increased an average of three years per decade during 1900 to 1940, rising to seven years per decade between 1940 and 1960, before returning to its previous rate of increase. Astorga et al. (2004) attributes this rapid increase in life expectancy in 1940–60 to public investment in potable water and sanitation, and to wider availability of standard medical treatment (e.g. cheap antibiotics), as well as rising incomes and the urbanization process.

Riley's (2007) in-depth analysis of 12 countries (i.e. Japan, Korea, Sri Lanka, Panama, Costa Rica, Cuba, Jamaica, Soviet Union, China, Oman, Venezuela, and Mexico) to understand the determinants of the population health in the twentieth century underlines that the gains in population health in theses countries are attributable to their ability to initiate and sustain social growth from a position of near poverty. These countries prioritized social growth and accumulation of social capital in five particular areas: public health; education; basic healthcare; the people's understanding of the health risks they faced and how to temper them; and people's participation in the effort to improve their own lives and their own survival. Riley (2007) asserts that, except Oman, all the twelve countries in his study managed to initiate sustained gains in population survival within the period 1890 to 1940, before many of the medical innovations came into being. This is mainly because these countries performed well at building the institutions, habits of mind, and behaviors of social growth. Higher income, in these cases, may have not been a necessary prerequisite. In the framework of Preston curves, such achievements move the Preston Curve upwards; survival improves without any change in incomes.

2.5. CONCLUSION

The political economy consequences of the nature of the relationship between health and income bear critical implications. Whereas the success indicator for economic prosperity is measured by how much income is added, social growth sets the goal of self- and community improvement. The cross-country evolution of income and life expectancy revealed with the Preston-curves postulate that the remarkable life-expectancy gains in general, and for economically poor countries in particular, may not be attributed only to the rising income. There are many other factors, not necessarily depending on the level of income, which may explain gains in survival. This makes the role of economic growth in raising life-expectancy, and the outright predilection towards the growth-first approach contentious. Nations in the twentieth century varied in their policy undertakings with regards to improving material life, and meeting people's expectations for a continually rising standards of living. Riley's (2007) analysis asserts that countries that put creation of social capital ahead of mere economic prosperity, performed better in raising life expectancy throughout the century. The three principal criteria he sets out are: (a) the attainment of a minimum threshold level of economic development to have the capacity to organise and manage programs in such areas as primary schooling, health education, devising low-cost strategies to solve public health problems, and taking useful advantage of briefly trained medical aids; (b) promote the goal of social development in some combination of education, public health, medicine, and popular participation that suits local preferences and serves local needs; and (c) ensure and establish people's perception that they can be engaged in controlling health risks, and that they themselves are the vital catalysts in social growth and improving health. Laverack's (2004) work complements this route of health promotion by emphasizing that successful health promotion strategies should embrace medical, behavioural, educational, client centred, and socio-environmental approaches, and appropriately take into account the power-relations and empowerment issues within the communities.

APPENDIX

Appendix 1: 3-digit Country codes and names

Codes	Name	Codes	Name	Codes	Name
AFG	Afghanistan	GHA	Ghana	NER	Niger
AGO	Angola	GIN	Guinea	NGA	Nigeria
ALB	Albania	GMB	Gambia	NIC	Nicaragua
ARE	United Arab Emirates	GNB	Guinea Bissau	NLD	Netherlands
ARG	Argentina	GNQ	Equitorial Guinea	NOR	Norway
ARM	Armenia	GRC	Greece	NPL	Nepal
AUS	Australia	GTM	Guatemala	NZL	New Zealand
AUT	Austria	GUY	Guyana	PAK	Pakistan
AZE	Azerbaijan	HKG	Hong Kong	PAN	Panama
BDI	Burundi	HND	Honduras	PER	Peru
BEL	Belgium	HRV	Croatia	PHL	Philippines
BEN	Benin	HTI	Haïti	POL	Poland
BFA	Burkina Faso	HUN	Hungary	PRI	Puerto Rico
BGD	Bangladesh	IDN	Indonesia	PRK	North Korea
BGR	Bulgaria	IND	India	PRT	Portugal
BHR	Bahrain	IRL	Ireland	PRY	Paraguay
BIH	Bosnia	IRN	Iran	QAT	Qatar
BLR	Belarus	IRQ	Iraq	REU	Reunion
BOL	Bolivia	ISL	Iceland	ROM	Romania
BRA	Brazil	ISR	Israel	RUS	Russian Federation
BWA	Botswana	ITA	Italy	RWA	Rwanda
CAF	Central African Rep.	JAM	Jamaica	SAU	South Arabia
CAN	Canada	JOR	Jordan	SDN	Sudan
CHE	Switzerand	JPN	Japan	SEN	Senegal
CHK	Czechoslovakia	KEN	Kenya	SGP	Singapore
CHL	Chile	KHM	Cambodia	SLV	El Salvador
CHN	China	KOR	South Korea	SRB	Serbia/Montenegro
CIV	Côte d'Ivoire	KWT	Kuwait	SVK	Slovakia
COG	Congo	LBN	Lebanon	SWE	Sweden
COL	Colombia	LBY	Libya	SWZ	Swaziland
COM	Comoro Islands	LKA	Sri Lanka	SYR	Syria
CPV	Cape Verde	LTU	Lithuania	THA	Thailand
CRI	Costa Rica	LUX	Luxembourg	TTO	Trinidad & Tobago
CUB	Cuba	LVA	Latvia	TUN	Tunisia
CZE	Czech Republic	MAR	Morocco	TUR	Turkey
DEU	Germany	MDA	Moldova	TWN	Taiwan
DJI	Djibouti	MDG	Madagascar	TZA	Tanzania
DNK	Denmark	MEX	Mexico	UGA	Uganda
DOM	Dominican Republic	MKD	Macedonia	UKR	Ukraine
DZA	Algeria	MLI	Mali	URY	Uruguay
ECU	Ecuador	MLT	Malta	USA	United States
EGY	Egypt	MMR	Myanmar (or Burma)	UZB	Uzbekistan
ESP	Spain	MNG	Mongolia	VEN	Venezuela
EST	Estonia	MOZ	Mozambique	VNM	Vietnam
FIN	Finland	MRT	Mauritania	YEM	Yemen
FRA	France	MUS	Mauritius	YUG	Yugoslavia
GAB	Gabon	MWI	Malawi	ZAF	South Africa
GBR	United Kingdom	MYS	Malaysia	ZMB	Zambia
GEO	Georgia	NAM	Namibia	ZWE	Zimbabwe

Appendix 2: Granger Causality Test Results

Country	Model with # of Lags	number of obs.	Does per capita GDP granger causes life expectancy?			Does life expectancy granger causes per capita GDP		
			Outcome	F-Value	P-Value	Outcome	F-Value	P-Value
INITIALLY POOR COUNTRIES								
Bangladesh	1	60	Yes	5.20	0.03	Yes	6.03	0.03
	2	59	No	0.44	0.65	Yes	3.06	0.05
	3	58	No	0.62	0.60	No	2.10	0.11
Brazil	1	70	No	2.05	0.16	Yes	3.99	0.05
	2	69	No	0.61	0.55	No	1.84	0.17
	3	68	No	0.45	0.72	No	1.24	0.30
China	1	70	No	0.10	0.75	Yes	4.11	0.05
	2	69	Yes	3.93	0.02	No	1.52	0.22
	3	68	Yes	3.43	0.02	No	0.86	0.47
Ecuador	1	60	Yes	8.58	0.00	Yes	4.66	0.04
	2	59	No	2.13	0.13	No	2.05	0.14
	3	58	No	1.33	0.27	No	1.28	0.29
El Salvador	1	60	Yes	9.64	0.00	Yes	5.25	0.03
	2	59	No	0.02	0.98	No	2.98	0.06
	3	58	No	0.43	0.73	No	1.90	0.14
Hondurus	1	60	No	2.17	0.15	Yes	9.63	0.00
	2	59	No	0.32	0.73	Yes	11.05	0.00
	3	58	No	0.32	0.81	Yes	7.09	0.00
India	1	70	No	1.66	0.20	No	2.20	0.14
	2	69	No	0.12	0.88	No	1.68	0.19
	3	68	No	0.08	0.97	No	1.17	0.33
Indonesia	1	60	Yes	108.54	0.00	Yes	11.65	0.00
	2	59	No	1.30	0.28	Yes	12.34	0.00
	3	58	No	0.81	0.49	Yes	7.90	0.00
Korea, Rep	1	61	Yes	10.34	0.00	Yes	7.28	0.01
	2	60	No	0.16	0.85	Yes	3.97	0.02
	3	59	No	0.34	0.79	Yes	3.47	0.02
Malaysia	1	60	Yes	63.25	0.00	No	2.66	0.11
	2	59	No	0.57	0.57	No	1.52	0.23
	3	58	No	0.41	0.75	No	1.99	0.13
Myanmar	1	60	No	0.90	0.35	Yes	10.42	0.00
	2	59	No	0.47	0.63	Yes	4.00	0.02
	3	58	No	0.74	0.53	No	2.46	0.07
Nicaragua	1	60	No	1.89	0.18	No	2.26	0.14
	2	59	No	0.33	0.72	No	0.64	0.53
	3	58	No	0.24	0.87	No	0.72	0.54
Pakistan	1	60	Yes	4.65	0.04	Yes	18.22	0.00
	2	59	No	0.51	0.60	Yes	7.18	0.00
	3	58	No	0.28	0.84	Yes	4.67	0.01
Philippines	1	70	Yes	35.69	0.00	No	2.94	0.09
	2	69	No	0.71	0.48	Yes	4.06	0.02
	3	68	No	0.49	0.69	Yes	3.75	0.02
Sri Lanka	1	70	Yes	3.90	0.05	No	2.24	0.14
	2	69	No	0.05	0.95	No	0.48	0.62
	3	68	No	0.52	0.67	No	0.28	0.84
Thailand	1	60	Yes	19.35	0.00	Yes	5.42	0.02
	2	59	No	0.48	0.62	No	1.72	0.19
	3	58	No	0.27	0.84	No	1.21	0.32

Country	Model with # of Lags	number of obs.	Does per capita GDP granger causes life expectancy?			Does life expectancy granger causes per capita GDP		
			Outcome	F-Value	P-Value	Outcome	F-Value	P-Value
INITIALLY MIDDLE INCOME COUNTRIES								
Argentina	1	70	No	1.44	0.24	Yes	4.30	0.04
	2	70	No	1.00	0.37	No	1.66	0.20
	3	69	No	1.24	0.30	No	1.50	0.22
Austria	1	71	No	1.30	0.26	Yes	8.17	0.01
	2	70	No	0.79	0.46	Yes	3.06	0.05
	3	69	No	0.58	0.63	No	1.53	0.21
Chile	1	70	No	1.88	0.17	No	0.96	0.33
	2	69	No	0.67	0.51	No	1.64	0.20
	3	68	No	0.29	0.83	No	0.95	0.42
Colombia	1	60	No	0.88	0.35	Yes	4.49	0.04
	2	59	No	1.39	0.26	No	2.39	0.10
	3	58	No	1.01	0.39	Yes	2.75	0.05
Costa Rica	1	71	No	0.44	0.51	No	3.05	0.09
	2	70	No	1.44	0.24	No	2.94	0.06
	3	69	No	1.38	0.26	No	1.85	0.15
Finland	1	71	No	0.12	0.73	No	2.31	0.13
	2	70	No	0.63	0.53	No	1.16	0.32
	3	69	No	0.80	0.50	No	0.81	0.49
France	1	71	No	0.71	0.40	Yes	17.21	0.00
	2	70	No	0.44	0.64	Yes	3.80	0.03
	3	69	No	0.57	0.63	No	2.29	0.09
Greece	1	71	Yes	22.73	0.00	Yes	9.95	0.00
	2	70	No	3.58	0.34	No	2.93	0.06
	3	69	No	1.47	0.23	No	2.36	0.08
Guatemala	1	60	No	3.28	0.08	Yes	8.87	0.00
	2	59	No	0.49	0.61	Yes	6.78	0.00
	3	58	No	0.73	0.54	Yes	5.58	0.00
Ireland	1	71	No	0.17	0.68	Yes	4.03	0.05
	2	70	No	1.01	0.37	No	2.67	0.08
	3	69	Yes	5.73	0.00	No	2.33	0.08
Italy	1	71	No	0.02	0.89	Yes	13.42	0.00
	2	70	No	1.71	0.19	Yes	6.11	0.00
	3	69	No	1.55	0.21	Yes	5.50	0.00
Mexico	1	71	No	0.45	0.50	Yes	6.61	0.01
	2	70	No	0.42	0.66	Yes	4.43	0.02
	3	69	No	0.25	0.86	No	2.06	0.12
Norway	1	71	No	1.98	0.16	Yes	5.28	0.02
	2	70	No	1.32	0.28	No	0.73	0.48
	3	69	No	1.42	0.25	No	1.02	0.39
Panama	1	60	Yes	30.31	0.00	No	0.39	0.53
	2	59	Yes	7.32	0.00	No	0.69	0.51
	3	58	Yes	5.55	0.00	No	0.62	0.60
Paraguay	1	60	Yes	12.77	0.00	No	1.32	0.26
	2	59	No	4.06	0.23	No	0.81	0.45
	3	58	Yes	8.57	0.00	No	1.05	0.38
Peru	1	70	Yes	109.05	0.00	No	0.01	0.91
	2	69	Yes	3.49	0.04	No	0.81	0.45
	3	68	No	2.38	0.08	No	1.59	0.20
Portugal	1	61	No	1.24	0.27	No	2.93	0.09
	2	59	No	2.72	0.08	No	1.62	0.21
	3	58	No	2.42	0.08	No	1.09	0.36

Country	Model with # of Lags	number of obs.	Does per capita GDP granger causes life expectancy?			Does life expectancy granger causes per capita GDP		
			Outcome	F-Value	P-Value	Outcome	F-Value	P-Value
Spain	1	71	Yes	7.81	0.01	Yes	12.89	0.00
	2	70	No	0.95	0.39	No	2.24	0.11
	3	69	No	1.56	0.21	No	1.81	0.15
Uruguay	1	71	No	0.02	0.89	Yes	8.76	0.00
	2	70	No	0.33	0.72	No	1.85	0.16
	3	69	No	0.93	0.43	No	1.40	0.25
Venezuela	1	61	Yes	12.03	0.00	No	0.37	0.55
	2	60	No	1.43	0.25	No	0.01	0.99
	3	59	No	1.34	0.27	No	0.46	0.71
INITIALLY RICH COUNTRIES								
Australia	1	70	Yes	23.03	0.00	No	0.00	0.98
	2	69	Yes	6.52	0.00	No	2.22	0.12
	3	68	Yes	4.76	0.00	Yes	2.71	0.05
Belgium	1	71	No	0.01	0.92	Yes	11.82	0.00
	2	70	No	2.43	0.10	Yes	6.54	0.00
	3	69	No	1.74	0.17	No	2.44	0.07
Canada	1	70	Yes	6.95	0.01	No	3.18	0.08
	2	69	Yes	4.45	0.02	No	0.36	0.70
	3	68	Yes	4.13	0.01	No	0.30	0.82
Denmark	1	71	No	0.13	0.72	Yes	5.49	0.02
	2	70	No	0.17	0.84	No	2.57	0.08
	3	69	No	0.34	0.80	No	1.79	0.16
Germany	1	71	No	2.64	0.11	Yes	4.50	0.04
	2	70	No	0.73	0.49	No	1.82	0.17
	3	69	No	2.01	0.12	No	1.34	0.27
Netherlands	1	71	No	0.32	0.57	Yes	8.06	0.01
	2	70	No	0.24	0.79	No	2.50	0.09
	3	69	No	0.34	0.80	No	1.84	0.15
New Zealand	1	71	No	0.01	0.94	Yes	5.86	0.02
	2	70	No	0.85	0.43	Yes	5.65	0.01
	3	69	No	1.37	0.26	Yes	3.89	0.01
Sweden	1	71	No	0.71	0.40	Yes	4.08	0.05
	2	70	No	1.95	0.15	No	1.06	0.35
	3	69	No	1.53	0.22	No	0.91	0.44
Switzerland	1	71	No	0.06	0.80	Yes	10.98	0.00
	2	70	No	0.23	0.80	Yes	4.80	0.01
	3	69	No	0.31	0.82	Yes	3.06	0.03
United Kingdom	1	70	No	0.30	0.58	No	1.18	0.28
	2	69	No	0.15	0.87	No	0.51	0.61
	3	68	No	0.13	0.94	No	0.95	0.42
United States	1	71	Yes	5.51	0.02	No	1.47	0.23
	2	70	Yes	3.32	0.04	No	1.15	0.32
	3	69	No	2.04	0.12	No	0.82	0.49

Appendix3: Mean death rates from 15 important diseases (per 100000 person)

Year	Pneumo-nia	Tubercu-losis	Malaria	Influenza	Cholera	Typhoid	Small-Pox	Dysentery	Whooping Cough	Measles	Diphtheria	Scarlet Fever	Plague	Typhus Fever	Cancer
ALL OBSERVED COUNTRIES															
1930	183.19	204.62	60.98	24.57	118.47	11.01	4.12	17.22	9.21	8.37	5.98	2.77	7.21	0.81	
1940	178.92	121.94	28.68	20.27	102.45	12.97	2.63		13.57	14.86	5.09	1.36	0.33	3.92	97.48
1950	85.85	51.95	32.76	12.00	68.73	2.87	0.30	4.60	6.04	5.04	1.69	0.31	0.08	0.07	103.85
1960	85.07	26.30	10.39	10.99	0.00	2.18	3.29	4.20	5.15	5.92	1.39	0.14	0.15	0.51	98.19
1970	62.36	14.37	5.26	7.59	0.95	0.84	0.54	3.27	5.31	5.89	0.42	0.54	0.00	0.29	106.04
1980	39.62	0.71	0.26	93.21	6.18	16.69		1.18	1.48	2.03	0.14		0.27	0.10	143.40
INITIALLY POOR COUNTRIES															
1930	351.3	292.0	101.8	32.9	168.7	21.3	2.5	38.4	9.4	5.9	4.6	0.4	4.1	1.1	
1940	275.5	208.0	117.8	18.0	86.3	33.3	5.8		9.6	21.8	3.5	0.1	1.3	23.9	17.0
1950	95.8	52.0	103.0	14.4	40.5	7.2	0.3	8.6	3.3	6.1	0.9	1.1	0.0	0.0	15.3
1960	127.5	54.8	19.8	11.2	0.0	6.4	4.6	8.4	12.0	8.1	1.9	0.3	0.2	1.4	34.8
1970	76.3	29.5	7.6	8.0	1.0	2.5	0.3	2.8	17.5	12.9	1.2	0.1	0.0	0.1	26.2
1980	81.9	1.8	1.4	20.6	36.7	62.1		2.3	6.0	10.3	0.6		0.2	0.0	57.2
INITIALLY MIDDLE INCOME COUNTRIES															
1930	196.2	258.1	42.7	29.8	155.1	14.8	7.6	19.5	14.0	16.7	6.7	2.6	0.3	1.0	
1940	180.7	110.0	46.8	29.2	131.1	11.3	4.2		26.2	22.6	5.6	0.9	0.1	3.0	79.0
1950	107.4	63.4	24.4	25.2	48.8	2.7	0.2	8.3	16.2	10.9	1.7	0.4	0.1	0.2	124.4
1960	88.6	25.4	3.8	23.4		2.0	0.6	5.2	9.9	8.7	1.5	0.1		0.8	119.3
1970	70.1	15.2	0.9	13.1		1.0	0.0	5.0	6.5	9.5	0.4	0.1		0.4	125.7
1980	42.6	0.8	0.3	89.5	6.4	24.6		1.5	2.1	2.8	0.1		0.3	0.2	137.5
INITIALLY RICH COUNTRIES															
1930	89.6	92.1	0.4	27.7	15.2	1.5	2.2	0.4	4.1	3.0	4.6	1.1	0.0	0.0	
1940	85.5	54.7	0.2	17.8	10.3	0.7	0.0		3.1	1.4	2.8	0.8	0.0	0.0	145.3
1950	45.3	19.9	0.0	5.6		0.1	0.0	0.2	0.7	0.6	0.4	0.2		0.0	165.3
1960	47.5	8.0	0.0	11.1		0.0		0.1	0.2	0.2	0.1	0.0		0.0	181.3
1970	51.8	4.7	0.0	4.6		0.0		0.0	0.0	0.1	0.0	0.0	0.0	0.0	184.0
1980	35.3	0.0	0.0	109.7	1.3	0.7		0.8	0.0	0.0	0.0		0.2	0.0	219.3

Source: League of Nations Health Organisation (1933), Federal Security Agency (1947), WHO (1951), United Nations Demographic Yearbooks (1954, 1962, 1966, 1985)

Appendix 04: Mean death rates from 15 important diseases (per 100000 person)

	Pneumonia	Tuberculosis	Malaria	Influenza	Cholera	Typhoid	Small-Pox	Dysentery	Whooping Cough	Measles	Diphtheria	Scarlet Fever	Plague	Typhus Fever	Cancer
EAST ASIA & PACIFIC															
1930	336.93	305.50	98.47	22.03	39.15	26.95	1.02	56.20	4.88	2.07	2.65		12.01	0.20	
1940	286.05	325.85		16.51	25.83	14.29	0.35		0.77	17.44	3.81	0.00	0.44	0.01	
1950	156.70	107.10	22.70	19.50	40.50	2.10	0.00		1.50	4.10	0.70		0.00	0.00	9.00
1960	177.77	80.33	37.67	2.43	0.00	7.33	0.05	17.50	0.63	2.83	2.27	0.37	0.10	2.40	26.13
1970	82.30	52.45	2.45	4.35	0.95	1.10	0.10	2.45	0.20	3.25	0.95	0.15		0.00	21.00
1980	103.80	2.50	2.40	16.80	59.30	34.30		2.70	0.20	12.20	1.00		0.20		57.70
EUROPE & CENTRAL ASIA															
1930	129.38	191.06	3.03	18.38	43.78	5.64	0.13	1.48	5.97	2.49	11.01	5.97	0.00	0.56	
1940	169.02	154.08	1.84	10.63	54.28	5.36	0.06		5.97	4.55	9.06	5.73	0.00	0.30	102.42
1950	54.20	75.00	7.40	7.90		1.30	0.80	1.70	1.90	0.00	1.90	0.70	0.20		9.30
1960	82.78	33.48	0.00	6.33		0.62		0.63	0.90	3.15	1.07	0.13		0.00	119.43
1970	66.78	19.06		8.24		0.05		0.16	0.30	0.46	0.00	0.03		0.00	165.04
1980	37.37	0.00		154.65	6.35	1.77		1.07	0.20	0.48	0.00		0.13	0.00	176.90
LATIN AMERICA & CARIBBEAN															
1930	221.95	317.05	94.96	37.50	281.84	17.21	8.12	28.36	18.24	16.43	4.34	1.46	0.60	1.85	
1940	197.34	109.91	93.76	31.17	190.56	16.47	7.23		38.66	37.71	3.86	0.66	0.32	13.50	43.94
1950	126.80	60.94	104.11	27.38	66.00	7.88	0.50	15.28	27.66	20.26	2.18	0.80	0.10	0.45	57.14
1960	99.95	25.23	10.36	23.64		4.49	0.93	7.36	18.65	14.57	1.93	0.11	0.20	1.28	59.61
1970	70.67	16.04	3.96	15.51		1.71	0.65	5.46	15.82	15.41	0.73	1.85	0.00	0.74	68.32
1980	46.88	0.84	0.50	47.68	8.22	43.69		1.41	3.44	4.16	0.13		0.17	0.18	84.91
MIDDLE EAST & NORTH AFRICA															
1930	198.45	191.61	3.33	11.31	336.62	13.65	4.40	3.83	3.77	15.78	4.58	2.13	0.90	1.06	
1940	447.30	53.10	0.90	2.30	1060.50	15.00	0.00		1.40	37.50	16.90	0.00	1.80	5.50	24.50
1950	264.50	49.50	0.20	0.50		8.40		2.90	0.50	6.40	5.40	0.00		0.10	20.40
1960	136.70	8.90	0.60	0.10		2.20		0.10	0.10	27.60	2.00				11.50
1970	99.15	6.60	0.00	0.15		1.00		0.25	0.05	3.95	0.50			0.00	15.35
1980	47.40	0.80	0.00	9.80	4.50	7.10		0.40	0.00	3.80	0.40		0.50		30.80
SOUTH ASIA															
1930	449.62	193.77	29.22	20.15	59.08	19.15	6.76	46.87	2.29	3.10	4.75		4.97		
1940	348.75	195.74		21.70	14.71	61.72	12.43		2.43	19.95	4.00		3.38	0.00	
1950	112.40	53.30	25.20	12.10		8.90	0.00	10.90	1.30	0.70	2.10	0.10		0.00	14.90
1960	122.30	47.95	0.35	2.45	0.00	4.25	24.80	5.85	0.70	3.25	2.85				30.10
1970	45.20	14.50	1.40	2.00		0.90		4.50	0.30	0.30	1.40	0.00		0.00	30.60
SUB-SAHARAN AFRICA															
1930	86.90	65.70	204.97	25.01	50.20	1.92	1.40	35.32	5.73	3.07	1.58	1.85	24.18	3.46	
1950	71.30	67.55	144.35	5.65	176.70	2.60	0.70	0.90	2.00	1.40	4.60	0.10	0.00	0.10	75.85
1960	106.12	23.38	69.00	4.66		1.22	0.80	10.54	4.40	6.63	1.85	0.50		0.25	25.60
1970	70.54	16.80	25.76	6.95		0.85		4.14	4.50	9.44	0.50	0.05		0.00	19.67
1980	30.00	6.10		50.00	12.20	93.60		0.70		11.50			1.70		74.40

Source: League of Nations Health Organisation (1933), Federal Security Agency (1947), WHO (1951), United Nations Demographic Yearbooks. (1954, 1962, 1966, 1985)

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