Economics and Human Biology 48 (2023) 101212

Contents lists available at ScienceDirect

Economics and Human Biology

journal homepage: www.elsevier.com/locate/ehb

# Health, income, and the preston curve: A long view

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A R T I C L E I N F O

*JEL Classification:*
F60
I15
N30
O50

*Keywords:*
Well-being
Life Expectancy
Per Capita Income
Inequality
Health Transition
Preston Curve

A B S T R A C T

Well-being is increasingly viewed as a multidimensional phenomenon, of which income is only one facet. In this paper I focus on another one, health, and look at its synthetic measure, life expectancy at birth, and its relationship with per capita income. International trends of life expectancy and per capita GDP differed during the past 150 years. Life expectancy gains depended on economic growth but also on the advancement in medical knowledge. The pace and breadth of the health transitions drove life expectancy aggregate tendencies and distribution. The new results confirm the relationship between life expectancy and per capita income and its outward shift over time as put forward by Samuel Preston. However, the association between nonlinearly transformed life expectancy and the log of per capita income does not flatten out over time, but becomes convex suggesting more than proportional increases in life expectancy at higher per capita income levels.

## 1. Introduction

Human well-being is increasingly viewed as a multidimensional phenomenon, of which income is only one facet. The Report of the Commission on the Measurement of Economic Performance and Social Progress to France's President Sarkozy (Stiglitz, Sen, and Fitoussi, 2009) triggered a new round of criticism of GDP that questioned its ability to gauge well-being in broad terms, and was accompanied by a plea for a comprehensive measure of quality of life, including health (OECD, 2011). Most economists continue, however, to rely on GDP to assess well-being. Empirical observations suggesting that per capita GDP does provide an 'informative indicator of welfare' (Jones and Klenow, 2016) and is highly correlated with non-monetary dimensions of well-being (Oulton, 2012) lend support to their view.

In this paper I put this persistent assumption to the test by looking beyond GDP and focusing on life expectancy at birth, as a synthetic measure of health, and its relationship with per capita income over the past one and a half centuries. The comparison between the trends in average life expectancy and GDP per head and their distribution for a large country sample since 1870 challenges per capita GDP as a comprehensive measure of well-being.

The paper argues that life expectancy at birth and real per capita GDP behaviour differed in their average trends and international distribution during different phases of the past 150 years. Long-run improvements in life expectancy depended on economic growth and the public provision of health but also and significantly on advances in medical knowledge. This feature helps explain the sustained advance in life expectancy during 1920–1970, a period that includes the globalisation backlash (1914–1950) in which average income levels stagnated or declined across countries. The diffusion of the health transitions drove life expectancy trends and distribution. The new results confirm the outward shift in the relationship between life expectancy and per capita income over time, as Samuel Preston (1975) put forward. However, when life expectancy is non-linearly transformed, its association with (the natural log of) per capita income does not flattens out over time but, on the contrary, becomes convex, suggesting more than proportional increases of life expectancy as per capita income reaches higher levels.

## 2. Method and data

### 2.1. Measuring achievements in life expectancy

Social variables such as life expectancy or height are often used in their raw form (Acemoglu and Johnson, 2007; Hatton and Brey, 2010). Yet, the fact that these non-income variables are bounded raises concerns about the use of their original values to make comparisons over space and time. For example, Amartya Sen : 292) (1981), noticed that 'as … longevity becomes high, it becomes more of an achievement to raise it

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https://doi.org/10.1016/j.ehb.2022.101212
Received 24 April 2022; Received in revised form 15 November 2022; Accepted 9 December 2022
Available online 14 December 2022

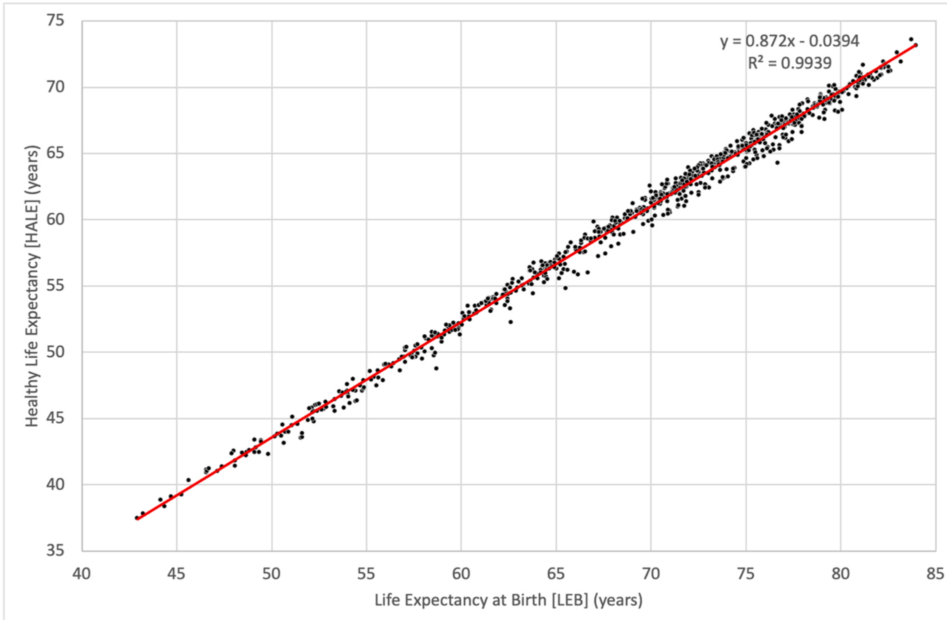


**Fig. 1.** Healthy Life Expectancy (HALE) and Life Expectancy at Birth (LEB) 1990–2016. Sources: *Global Burden of Disease Study* (2016). Note: Pool of 1990, 2000, 2006, and 2016 benchmarks.

further'. And Partha Dasgupta (1990) asserted, 'Equal increments are possibly of less and less ethical worth as life expectancy rises to 65 or 70 years and more. But we are meaning performance here. So it would seem that it becomes more and more commendable if, with increasing life expectancy, the index were to rise at the margin'.

Thus, the transformation of the original values of life expectancy into index form presents a challenge. An option is a linear transformation into an index (*I*) as it reduces the size of the denominator by introducing maximum and minimum values (goalposts) and widens the index's range.

$$I = (x - M_{min}) / (M_{max} - M_{min}) \quad (1)$$

where *x* is the observed value of life expectancy of birth, and $M_{min}$ and $M_{max}$ are the chosen minimum and maximum values to facilitate comparison over time. The index ranges between 0 and 1.

However, when either original values or linearly transformed social variables are used to compare countries or time periods, identical absolute changes result in a smaller proportional improvement for the country or time period with the higher starting level. Consider, for example, a 10-year improvement in life expectancy at birth, in one case, from 30 to 40 years, and in another, from 70 to 80 years. Although these changes are identical in absolute terms, the second is smaller relative to the initial level. Placed in equation [1] and accepting 85 and 20 years as maximum and minimum levels (UNDP, 2014), the first country would see a 100% improvement from 0.15 to 0.31, while the second would see a 20% improvement from 0.77 to 0.92. If we move now from a hypothetical to a practical example, we observe that, in developing countries, the main increase in life expectancy at birth results from the decline in infant mortality as infectious disease falls. Meanwhile, in advanced countries, gains in life expectancy at birth are driven by the mortality reduction of the elderly as a cardiovascular and respiratory diseases recede. Using original values of life expectancy at birth in expression [1] the same absolute gain implies a larger relative improvement for the developing country than for the advanced one, that is, saving the lives of younger people is given more weight than saving the lives of older people. This led Angus Deaton : 9) (2006) to claim, 'the use of life expectancy at birth as an overall measure of [health] benefit is not easily justifiable because its relatively heavy weighting for mortality reductions early in life is arbitrary'. Therefore, a linear transformation does not solve the problem of the comparability of bounded social dimensions across countries or over time.

Further drawbacks of linearly transformed measures emerge when we consider quality. Healthy life expectancy at birth (HALE) that is, a summary measure of health computed using age-specific death rates and years of life lived with disability per capita, and life expectancy at birth (LEB) have moved together since 1990, when data on HALE are available (Murray et al., 2017; Prados de la Escosura, 2021).

The evidence for the last three decades indicates that, although morbidity increased in absolute terms, it underwent a relative compression: the proportion of years lived in disability fell (Murray et al., 2017). With the increase in life expectancy, disability declined for each age-cohort, so the quality of life improved for the entire population (Mathers et al., 2001; Salomon et al., 2012; Murray et al., 2017).[2]

The Global Burden of Disease Study 2016 allows us to compare healthy life expectancy at birth (HALE) with conventional life expectancy at birth (LEB) for the period 1990–2016. This shows that healthy life expectancy at birth rises with raw life expectancy at birth (Fig. 1).[3]

Thus, when assessing life expectancy over time and across countries we need to bear in mind that original values of life expectancy are bounded and that life quality improves with the quantity of years lived. Therefore, we need to transform the original values of life expectancy at birth non-linearly in order to capture health achievements over time.

[2] Longer lives - due to a rapid decline in years of life lost - together with a more modest age-adjusted decline in years lived with disability -, have led to lower age-standardised disability-adjusted life years rates across the board (Murray et al., 2017). For the United States, Cutler et al. (2014) and Chernew et al. (2016) find that the reduction in disabled life expectancy runs parallel to the increase in healthy life expectancy, suggesting a compression of morbidity between 1990 and 2010. Nonetheless, previous historical evidence of an association between death and ill health is scant and far from conclusive (Riley, 1990; Howse, 2006; Bleakley, 2007, 2010).

[3] Four benchmark estimates for 1990, 2000, 2006, and 2016 from Murray et al., 'Global Burden of Disease' are pooled in Fig. 1. Canning (2012) reports a similar finding.

**Table 1**
Trends in Life Expectancy* and Real Per Capita GDP *Kakwani Index (Growth Rates %).

| | Kakwani index of Life Expectancy | Real Per Capita GDP |
|---|---|---|
| 1870–1913 | 1.1 | 1.3 |
| 1913–1950 | 2.7 | 1.0 |
| 1950–1970 | 2.2 | 2.9 |
| 1970–2015 | 1.2 | 1.8 |
| 1870–1880 | 0.8 | 1.1 |
| 1880–1890 | 1.0 | 1.1 |
| 1890–1900 | 1.3 | 1.4 |
| 1900–1913 | 1.3 | 1.4 |
| 1913–1925 | 2.0 | 0.6 |
| 1925–1929 | 4.6 | 2.3 |
| 1929–1933 | 2.6 | -3.2 |
| 1933–1938 | 1.8 | 3.3 |
| 1938–1950 | 3.2 | 1.3 |
| 1950–1955 | 2.4 | 3.2 |
| 1955–1960 | -0.5 | 2.2 |
| 1960–1965 | 4.7 | 3.3 |
| 1965–1970 | 2.1 | 2.8 |
| 1970–1975 | 1.5 | 1.8 |
| 1975–1980 | 1.4 | 1.9 |
| 1980–1985 | 1.0 | 0.8 |
| 1985–1990 | 0.9 | 1.5 |
| 1990–1995 | 0.8 | 0.9 |
| 1995–2000 | 1.1 | 2.2 |
| 2000–2005 | 0.9 | 2.5 |
| 2005–2010 | 1.0 | 2.3 |
| 2010–2015 | 2.1 | 1.9 |
| 1870–2015 | 1.7 | 1.6 |

Sources: https://frdelpino.es/investigacion/en/category/01_social-sciences/02_world-economy/03_human-development-world-economy/

The non-linear transformation proposed by Nanak Kakwani (1993) provides a short-cut to measure trends in health on the basis of crude evidence on life expectancy at birth.[4] He derived a normalised index from an achievement function in which an increase in the standard of living of a country at a higher level implies a greater achievement than would have been the case had it occurred at a lower level:

$$I = (\log\,(M_{max} - M_{min}) - \log\,(M_{max} - x)) \,/\, \log\,(M_{max} - M_{min}) \tag{2}$$

As in Eq. (1), $x$ is an indicator of a country's standard of living; $M_{max}$ and $M_{min}$ are the maximum and minimum values (85 and 20 years), respectively[5]; and *log* stands for the natural logarithm. The achievement function proposed by Kakwani is a convex function of $x$. It is equal to 0 if $x = M_{min}$, and equal to 1 if $x = M_{max}$, ranging between 0 and 1.

### 2.2. Data and sources

Different country samples have been used in the estimates, for which the longer the time span, the narrower the spatial coverage. Over the entire time span, 1870–2015, 115 countries are considered, with the number rising up to 121, 146, 161, and 162 countries for the samples starting in 1913, 1950, 1980, and 1990, respectively. The country samples represent over 90 per cent of the world population. Although the results of these samples are very similar, the levels of the Kakwani index of life expectancy and real per capita income have been spliced. However, in the case of the inequality estimates, as the results are so close, no splicing has been applied. The complete dataset and its sources are freely accessible at.

https://frdelpino.es/investigacion/en/category/01_social-sciences/02_world-economy/03_human-development-world-economy/.

## 3. Results

### 3.1. International trends in life expectancy and per capita GDP

The Kakwani index of life expectancy presents four phases in its evolution with 1913, 1950, and 1970 as divides, with its fastest progress achieved during the central decades of the twentieth century -but for a setback due to China's mortality during the Great Leap Forward, 1958–61-, and resulting in a level 11.5 times higher in 2015 than in 1870.[6]

How does life expectancy compare to GDP per head? The Kakwani Index of life expectancy exhibits slightly faster long-run growth than GDP per capita: 1.7 per cent per annum compared to 1.6 per cent, respectively, from 1870 to 2015. However, a closer look reveals an apparent development puzzle: the progress in economic growth and life expectancy does not match (Table 1). During the backlash against economic globalization between 1914 and 1950, real per capita GDP growth slowed down as world commodity and factor markets disintegrated, while life expectancy experienced major gains across the board.[7] However, from mid-twentieth century onwards, life expectancy achieved, on average, smaller gains to GDP per head particularly during the 1950 s and the post-1990 globalization era.

These findings are at odds with a stylised fact in the literature, namely, that global health improvements only occurred in the era following World War II, when, with the help of international institutions, new drugs from the West reached the rest of the world (Acemoglu and Johnson, 2007: 935–936; Cardona and Bishai, 2018; Klasing and Milionis, 2020). Average life expectancy in the world exhibited a major advance before 1950 and this implies that improvements in life expectancy took place across the board much earlier than has been presumed.

But how representative are these findings? A look at the distribution of health improvements and economic growth provides the answer.

I have measured population-weighted inequality with the generalised entropy class G(0), also known as Theil L or Mean Logarithmic Deviation (MLD) index, which is sensitive to the bottom of the distribution (Theil, 1967).

$$\text{MLD} = \text{G}(0) = \sum p_i \ln\,(p_i/y_i) \tag{3}$$

with $p_i$ and $y_i$ representing country $i$ shares in total population [Ni] and social indicators (*Si*) [Si*Ni], the Kakwani index of life expectancy here.

Although population-weighted measures implicitly assume perfectly

[4] As an alternative solution to bounded variable problem, Sen (1981) suggested considering the relative shortfall reduction, which measures, for a given dimension, the relative fall in the distance between the country's initial level and some chosen upper bound, that is, the extent to which, the distance from a potential maximum is reduced. However, Sen's solution is not additive, unlike Kakwani's. Therefore, in Sen's approach, improvements over different sub-periods do not amount to the improvement over the entire time span considered, making difficult over time comparisons.

[5] The idea of having fixed thresholds is to establish 'objective upper and lower bounds' to the values of life expectancy over time (UNDP, 1994; Klugman et al., 2011: 252). The values assigned to the goalposts can be challenged as being discretionary (Herrero, Martínez, and Villar, 2012) but it can be argued that as a natural floor often exists, lower goalposts simply aim at capturing subsistence levels. For example, historical evidence on life expectancy at birth indicates that 20 years was most probably a floor in human societies going back to Neolithic times (Fogel, 2009; Steckel, 2009). At the same time, 85 years is a maximum for average life expectancy at birth in 2015.

[6] Three times higher when original values of life expectancy are compared.

[7] The paradox increases further when we consider that some research suggests that recessions increase mortality (Doerr and Hofmann, 2020). A growing stream of research stresses, however, the pro-cyclical nature of mortality, increasing at times of expansion and declining at times of recession (Ruhm, 2015). In fact, research on the United States during the Great Depression finds an increase in suicide mortality but no deterioration in health levels (Tapia Granados and Diez Roux, 2009).

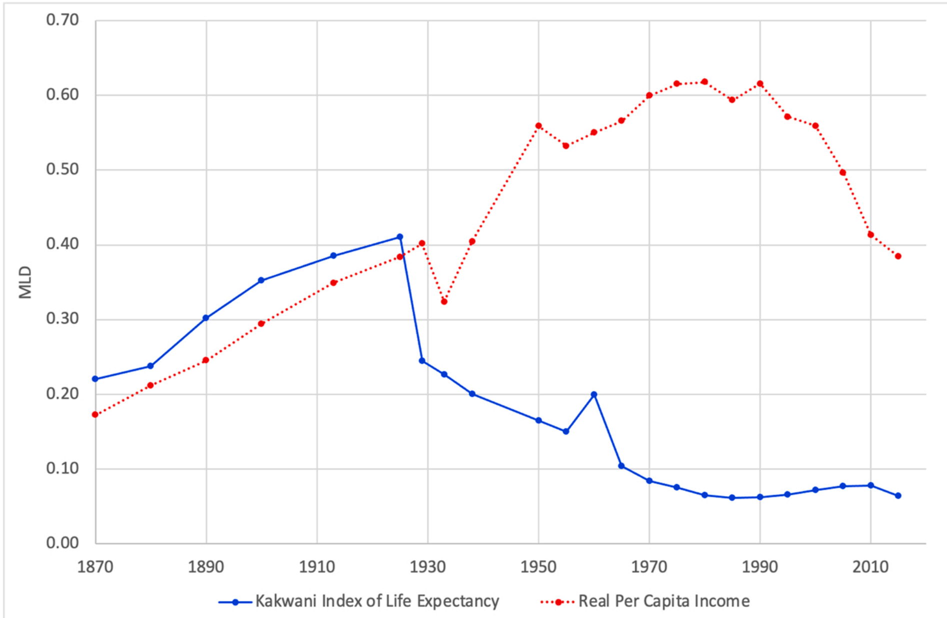


**Fig. 2.** International Inequality in Life Expectancy* and Real Per Capita income, 1870–2015 *Kakwani Index (Population-weighted MLD).
Sources: See the text.

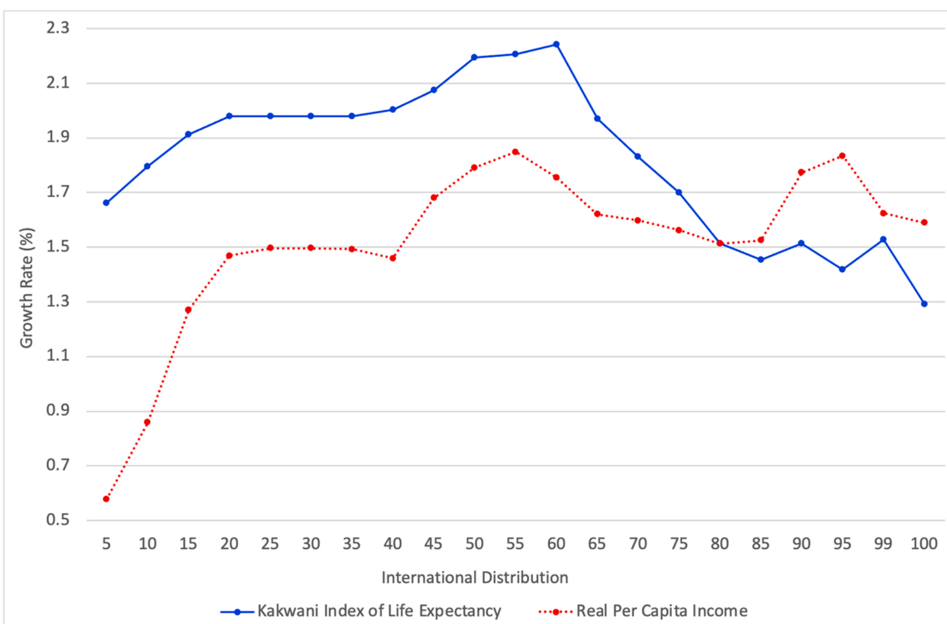


**Fig. 3.** Growth Incidence Curves for Life Expectancy* and Real Per Capita income, 1870–2015 (%) *Kakwani Index.
Source: See the text.

equal within-country distribution, they get us closer to a measure of world distribution by assigning higher value to more populated countries (Milanovic, 2005: 7–8). Unfortunately, no data on within-country distribution of social dimensions of well-being are available for such a large sample and long time span. The assumption here is, then, that inter-country dispersion provides a lower bound measure of global inequality.[8]

Main phases can be observed in the evolution of life expectancy inequality, measured on the basis of the Kakwani index, a rise from 1870 to the mid-1920 s, followed by a sustained fall until the early 1980 s, and a partial rebound over 1990–2010 (Fig. 2). The sharp and temporary reversal in 1960 captures the impact of the increase in mortality in China during the Great Leap Forward famine (Meng et al., 2015).

In the case of per capita income, a sustained rise in inequality took place shadowing that of life expectancy until the mid-1920 s and continuing up to the mid-1970 s, stabilising, then, and falling sharply since 1990, to return to the level of the late 1920 s by 2015. The inequality rise was punctuated by a severe contraction in the Great Depression and a sharp increase during and after World War II.

[8] See confirming evidence for income inequality in Bourguignon and Morrisson (2002); van Zanden et al., 2014; and for post-1950 life expectancy inequality in Jordá and Niño-Zarazúa (2017) and Permanyer and Scholl (2019).

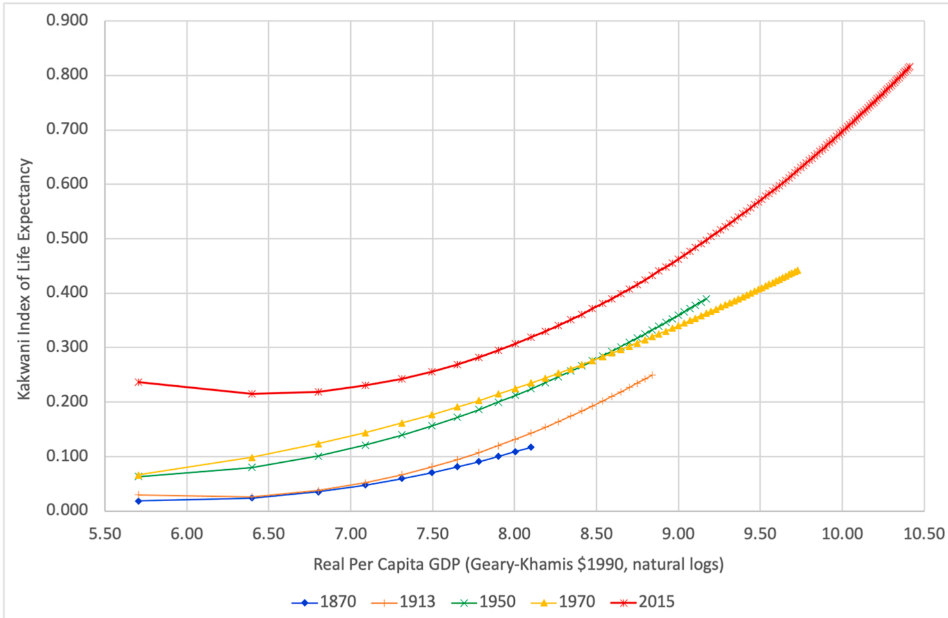


**Fig. 4.** Revisited Preston Curve, 1870–2015. Sources: Predicted values obtained with cross-section polynomial regressions in Appendix A, Table A2.

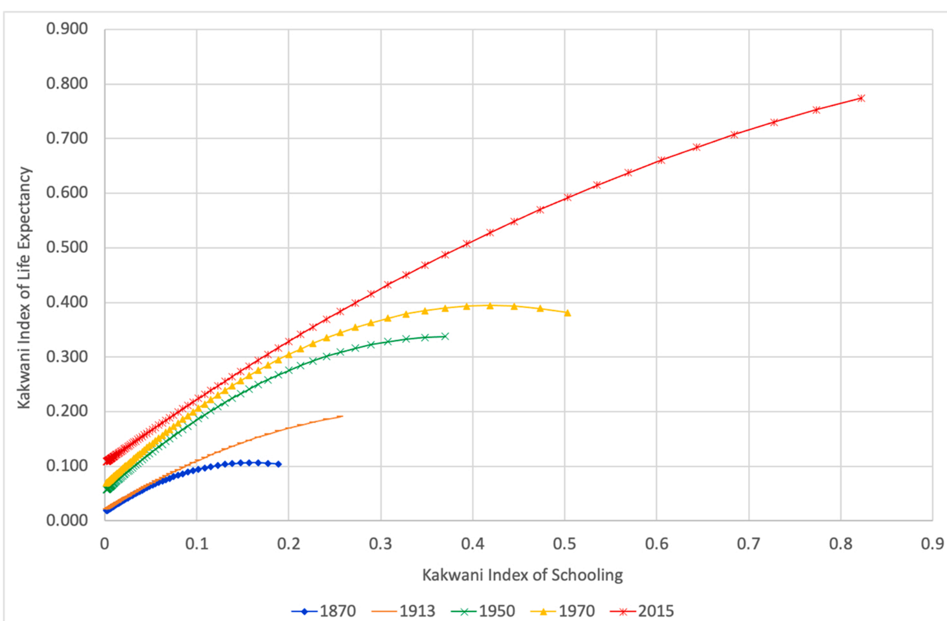


**Fig. 5.** 'Education' Preston Curve, 1870–2015.
Sources: Predicted values obtained with cross-section polynomial regressions in Appendix A, Table A3.

The annual cumulative growth rate by percentiles, from bottom to top, the so-called the Growth Incidence Curve (GIC), provides a more nuanced picture of the international distribution of gains for life expectancy and per capita income over time.

Fig. 3 shows that, in the case of life expectancy, the middle of the distribution experienced the main relative gains in the long run, followed by the lower-middle ventiles, and the smallest gains accrued to those at the top. As for per capita income, the bottom ventile achieved the lowest relative gains while the middle and the top of the distribution experienced the main relative gains.

A sharp distinctive pattern of international distribution emerges, then, for life expectancy and per capita GDP.

### *3.2. Accounting for health and income differences: a look at the preston curve*

What explains the pace and breadth of life expectancy gains? It is commonly assumed that economic progress largely does. By raising average incomes modern economic growth facilitates better nutrition which strengthens the immune system and reduces morbidity. For example, Thomas McKeown (1976) attributed most of the mortality decline in Britain during late nineteenth and early twentieth centuries to the improvement in living standards and hardly to medical advancement. And Robert Fogel (2004) associated the long-term mortality reduction to improved nutrition in England and the United States since the late eighteenth century.

**Table 2**
Breakdown of Per Capita Income and Medical Knowledge's Contributions to Life Expectancy Gains, 1870–2015 (world population-weighted average).

| | | | | % Average Contribution | |
|---|---|---|---|---|---|
| Predicted Value | Counterfactual 1 | Counterfactual 2 | Predicted Value | Per Capita Income | Medical Knowledge |
| **1870** | **1913** | **1913** | **1913** | **1870–1913** | |
| 0.034 | 0.050 | 0.042 | 0.065 | 63.5 | 36.5 |
| **1913** | **1950** | **1950** | **1950** | **1913–1950** | |
| 0.065 | 0.087 | 0.127 | 0.149 | 26.3 | 73.7 |
| **1950** | **1970** | **1970** | **1970** | **1950–1970** | |
| 0.149 | 0.211 | 0.155 | 0.207 | 98.4 | 1.6 |
| **1970** | **2015** | **2015** | **2015** | **1970–2015** | |
| 0.207 | 0.342 | 0.289 | 0.439 | 61.3 | 38.7 |
| **1870** | **2015** | **2015** | **2015** | **1870–2015** | |
| 0.034 | 0.226 | 0.225 | 0.439 | 50.2 | 49.8 |

Notes:
**KLEB-Y**, statistical association between the Kakwani Index of life expectancy (***KLEB***) and real per capita income (in natural logs) (***Y***)
**Counterfactual 1**, ***KLEB-Y*** association in the initial year; ***Y*** values in the end year.
**Counterfactual 2**, ***KLEB-Y*** association in the end year; ***Y*** values in the initial year.
Per capita income's contribution has been alternatively computed as 1) and 2) and the results averaged.
1) (**counterfactual 1** value – **predicted** value at **initial** year)/ (**predicted** value at **final** year – **predicted** value at **initial** year)
2) (predicted value at final year – **counterfactual 2** value)/ (**predicted** value at **final** year – **predicted** value at **initial** year)
Medical knowledge's average contribution equals 100 less the average contribution of per capita income.
*Sources*: See the text.

**Table A1**
Revisited Preston Curve: Country Sample, 1870–2015.

| Argentina | Angola | Swaziland |
|---|---|---|
| Bolivia | Benin | Tanzania |
| Brazil | Botswana | Togo |
| Chile | Burkina Faso | Tunisia |
| Colombia | Burundi | Uganda |
| Cuba | Cameroon | Zambia |
| Ecuador | CAR | Zimbabwe |
| Jamaica | Chad | Bahrain |
| Mexico | Congo | Cambodia |
| Peru | Congo DR | China |
| Uruguay | Côte d'Ivoire | Hong Kong |
| Venezuela | Egypt | India |
| Albania | Ethiopia | Indonesia |
| Austria | Gabon | Iran |
| Belgium | Gambia | Iraq |
| Bulgaria | Ghana | Japan |
| Czechoslovakia | Guinea | Jordan |
| Denmark | Guinea-Bissau | Korea, South |
| Finland | Kenya | Laos |
| France | Lesotho | Lebanon |
| Germany | Liberia | Malaysia |
| Greece | Libya | Myanmar |
| Hungary | Madagascar | Nepal |
| Ireland | Malawi | Oman |
| Italy | Mali | Philippines |
| Netherlands | Mauritania | Saudi Arabia |
| Norway | Mauritius | Singapore |
| Poland | Morocco | Sri Lanka |
| Portugal | Mozambique | Syria |
| Romania | Namibia | Taiwan |
| Russia | Niger | Thailand |
| Spain | Nigeria | Turkey |
| Sweden | Rwanda | Viet Nam |
| Switzerland | Senegal | Yemen |
| UK | Sierra Leone | Australia |
| Yugoslavia/Serbia | South Africa | New Zealand |
| | | USA |

Sources: See the text.

**Table A2**
Revisited Preston Curve: Cross Section Polynomial Regressions.

| | constant | x | $x^2$ | $R^2$ |
|---|---|---|---|---|
| **1870** | 0.7035 | -0.2336 | 0.0199 | 0.5912 |
| **1913** | 1.1934 | -0.3808 | 0.0310 | 0.7870 |
| **1950** | 0.8436 | -0.2806 | 0.0252 | 0.7567 |
| **1970** | 0.3205 | -0.1256 | 0.0142 | 0.7426 |
| **2015** | 1.8157 | 0.4959 | 0.0384 | 0.8127 |

Sources: See the text.

**Table A3: '**
Education' Preston Curve: Cross Section Polynomial Regressions.

| | constant | x | $x^2$ | $R^2$ |
|---|---|---|---|---|
| **1870** | 0.0164 | 1.1183 | -3.4726 | 0.7514 |
| **1913** | 0.0190 | 1.0546 | -1.5048 | 0.8520 |
| **1950** | 0.0538 | 1.5109 | -2.0120 | 0.8527 |
| **1970** | 0.0664 | 1.5656 | -1.8690 | 0.8530 |
| **2015** | 0.1059 | 1.2093 | -0.4826 | 0.6749 |

Sources: See the text.

The increase in the public provision of health (including maternal care and clean water technologies) is another effect of higher average incomes (Pritchett and Summers, 1996; Loudon, 2000; Cutler and Miller, 2005; Alsan and Goldin, 2019; Gallardo-Albarrán, 2020). It has been suggested, for example, that increases in social sharing and public support for social services may explain the paradox of rising longevity at a time of economic distress in Britain during the war decades (Sen, 1999: 51), and that the success in improving well-being in the post-World War II era largely resulted from public intervention (Easterlin, 1999).

However, health improved across the board during the past hundred years, including countries in which social spending did not expand at times of sluggish economic growth (Riley, 2001). This lends support to the view that improvements in medical knowledge have been its main cause. For example, David Cutler et al. (2006) claim that scientific and technical advances should be seen as 'the ultimate determinant of health', with public health as the main driver from the late nineteenth century up to the 1930 s, and major medical advances, from then onwards.

Preston (1975) investigated the connections between life expectancy at birth and real per capita GDP at three cross-sections, 1900 s, 1930 s, and 1960 s. He found that the two dimensions of well-being were associated but that successive increases in per capita income resulted in less than proportional increases in life expectancy.[9] Moreover, the resulting concave relationship shifted outwards over time meaning that, as time went by, higher longevity corresponded to the same per capita income level (Preston, 1975: 236). He concluded that increases in per capita income only explained a minor proportion of the rise in the lifespan which was mainly attributable to non-income factors, in particular, the diffusion of medical advances resulting from the 'empirical validation' of the germ theory of disease (Preston, 1975: 237, 244). These exogenous factors had a universal impact on mortality, both in developing and developed countries.

Since Preston's pioneering work, researchers have investigated to what extent, and why, has the lifespan become increasingly dissociated from per capita income levels. Richard Wilkinson (2007) argued that material assets, as much as income, affect health, and David Bloom and David Canning (2007) considered that per capita income captures 'socioeconomic status and development', while Preston himself (2007)) accepted the existence of lags in the relation between income and mortality which may operate over the life cycle and through wealth-generating processes.

Different attempts have been made to explore the empirical association between life expectancy at birth and per capita income, the so-called Preston Curve, beyond the time span considered by Preston himself (1900–1960 s) at both the international level and specific historical contexts (e.g., Pérez Moreda et al., 2015: 293–299). Kakwani : 327) (1993) confirmed that the association between life expectancy at birth and GDP per head shifted upwards between the 1970 s and 1980 s, meaning higher longevity for a given per capita income level. Johan Mackenbach and Caspar Looman (2013) replicated Preston's exercise for 1900–2008. Their findings confirm Preston's interpretation for the pre-1960 period but their results suggest that per capita income explained most of the life expectancy gains from 1960 onwards. They attributed such a discrepant behaviour to the fact that, before 1960, the diffusion of medical knowledge to fight infectious disease, the leading cause of mortality reduction, was less dependent on income levels than in the late twentieth century, when the decline in mortality from cardiovascular disease, from which longer life expectancy resulted, had a much higher cost (Mackenbach and Looman, 2013: 1105).

On the basis of a large country sample over the last two centuries, Michael Jetter et al. (2019) confirmed the existence of a non-linear relationship between per capita income and life expectancy levels and claimed that economic growth has been the main driver of long-run gains in life expectancy while the impact of medical innovations was largely restricted to higher income countries.

Wolfgang Lutz and Endale Kebede (2018) also tested the Preston Curve but replacing per capita income with education attainment. They found a linear association between education and health with 'very little upward shift' due to medical progress.

I have tested Preston's association between life expectancy at birth and real per capita income for a sample of 112 countries over 1870–2015 (See Table A1 in the Appendix). But instead of using the original values of life expectancy at birth and real per capita GDP, I estimated the statistical relationship between the Kakwani index of life expectancy and the natural logarithm of real per capita GDP using polynomial regressions at different cross-sections, corresponding to 1870, 1913, 1950, 1970, and 2015, that mark the phases of life expectancy's evolution (Appendix, Table A2).[10] The predicted values for the health proxy (the Kakwani index of life expectancy) from the resulting relationship become convex, rather than concave, to the log of per capita income, suggesting that advances in medical knowledge lead to more than proportional gains in health as income rises (Fig. 4). Curves' length represents the range of per capita income values at each cross section. Moreover, the exercise confirms the existence of sustained outward shifts in the life expectancy-per capita income relationship over time, so the Preston Curve does not 'break down' (Pritchett and Viarengo, 2010). However, outward shifts do not have the same intensity between each pair of cross-sections. Thus, strong outward shifts between 1913 and 1950 and between 1970 and 2015 contrast with moderate ones during 1870–1913 and 1950–1970.

It worth noting that at high per capita income, the Preston curve for 1950 reaches higher levels than the 1970 one. The fact that other factors, such as education, political and civil liberties, etc., also condition the level of health may help explain it (Georgiadis et al., 2010). In fact, countries reaching high average income levels in 1950 (within 1990 G-K $ 5000–10,000) enjoyed higher education and civil and political liberties than those at the same income levels two decades later.[11]

I also tested the Preston curve using schooling instead of per capita income following Lutz and Kebede's (2018). Fig. 5 plots life expectancy against years of schooling, with both variables expressed as Kakwani indices.[12] Curves' length represents the range of the Kakwani index of schooling values at each cross section. Two main features can be observed. Firstly, the association flattens out as schooling reaches higher levels. Thus, increases in the Kakwani index of schooling above a given threshold are not corresponded by proportional increases in the Kakwani index of life expectancy. Secondly, the life expectancy-education relationship shifts outwards, with special intensity between 1913 and 1950. This means that higher life expectancy corresponds to the same schooling level as time goes by. This finding is at odds with Lutz and Kebede's assertion that once one allows for education there is no much room for the contribution of medical advance to life expectancy. Education, as Preston : 243) (1975) noted, is a key channel through which medical knowledge disseminated in developing countries helping to reduce mortality but, as Fig. 5 evidences, it is not the only one.

Next, I replicated Preston's attempt to 'factor out' the contribution of per capita income to life expectancy gains at each cross-section. Thus, in order to estimate the contribution of per capita income to the rise of the Kakwani index of life expectancy over, say, 1870 and 1913, I combined the parameters of their statistical relationship for the 1870 cross-section (the initial year) with the values of real per capita income (in logs) for 1870 to get the predicted level of the Kakwani index of life expectancy, and with the values of real per capita income (in logs) for 1913 to obtain the counterfactual level of the Kakwani index had there were no medical advancement during the period 1870–1913, and all the change resulted exclusively from a higher level of per capita income. These results were,

[9] Or, if transposed to a country's income distribution, 'a steep upward increase in life expectancy at the lower end of the GDP distribution and a much shallower increase and eventual plateau at the upper end of the GDP distribution' (Leon, 2007). Preston : 242) (1975) also hinted that 'life expectancy is lower the higher is the variance in the distribution of incomes'.

[10] Deaton : 33, 36) (2013) replicated the Preston curve using the log of real GDP per head to represent proportional changes, with the effect of reducing the concavity of the per capita income-life expectancy association. He kept, nonetheless, the original values of life expectancy.

[11] Western European countries and the Western Offshoots composed this income group in 1950 while southern and eastern European and Latin American countries dominated it in 1970.

[12] The data for schooling also come from https://frdelpino.es/investigacion/en/category/01_social-sciences/02_world-economy/03_human-development-world-economy/

then, weighted by each country's population to obtain predicted and counterfactual average levels for the Kakwani index of life expectancy. I, then, repeated the exercise but, this time, combining the parameters of the statistical relationship for the 1913 cross-section (the end year) with the values of real per capita income (in logs) for 1870 and 1913, respectively, and weighting the results by the population to get the predicted and counterfactual levels of the Kakwani index of life expectancy. For each set of estimates, the comparison between the predicted and the counterfactual change in the Kakwani index over 1870–1913 tell us how much the increase in per capita income would contribute to raising the lifespan. I have taken the average of the two estimates. The average contribution of non-income factors, that is, in the absence economic change but in the presence of advances in medical knowledge, is derived as a residual, that is, as 100 less the average contribution of per capita income.[13] I repeated, then, the exercise for each pair of cross-sections.

Table 2 offers the average contribution of real per capita income growth and advances in medical knowledge to health gains, expressed with the Kakwani index of life expectancy, for the main four phases observed the evolution of life expectancy as well as for the entire time span considered. It can be observed the distinctive behaviour of each phase in the evolution of life expectancy. Modern economic growth contributed above 60 per cent of the increase in the Kakwani index of life expectancy over 1870–1913 and, again, during the last period, 1970–2015. However, its contribution was substantially lower during the first of half of the twentieth century, when it only provided one-fourth of the Kakwani index gains, and three-fourths of them accrued to advances in medical knowledge. A finding that matches Preston's lower bound estimates. Conversely, during the Golden Age (1950–1970) the increase in per capita income accounted for entire improvement in the Kakwani index of life expectancy. Over the past one and a half centuries, economic growth and medical advances appear to have contributed alike to longevity gains.

## 4. Discussion

Life expectancy improvements can be depicted in terms of a health function (Easterlin, 1999). Movements along the function represent gains attributable to economic growth and outward shifts of the health function result from improvements in medical knowledge.

The strong outward shift in the health function during the first half of the twentieth century (Fig. 4) arises from the diffusion of epidemiological transition. Triggered by the germ theory of disease, the epidemiological transition initiated in Western Europe in the late nineteenth century and only started spreading worldwide from the 1920s (Riley, 2001).[14] Persistent gains in lower mortality and higher survival rates were achieved as infectious disease gave way to chronic disease as a major cause of death (Omran, 1971, 1998).[15] Two main consequences resulted from the diffusion of the germ theory of disease. On the one hand, medical technological progress that resulted in new drugs to cure infectious diseases and spread the health transition: new vaccines (since the 1890s) and drugs to cure infectious diseases: sulphonamides since the late 1930s, and antibiotics since the 1950s, along with chemicals such as DDT, instrumental in battling malaria (Easterlin, 1999; Jayachandran et al., 2010; Lindgren, 2016; Desowitz, 1991). One the other, and most decisively, low cost improvements in public health derived from the diffusion of preventive methods of disease transmission and knowledge dissemination often through school education. This second via of diffusion helps explain why the epidemiological transition spread in developing countries, at a time when a large proportion of the them was still under colonial rule -not precisely associated to public health initiatives-, and the new drugs were unaffordable for most of the population. The resulting reduction in mortality throughout the life course, particularly infant mortality and maternal death, contributed to the increase in life expectancy at birth in developing regions (Preston, 1975: 244; 2007: 502; Riley, 2001).[16]

The substantial increases in longevity during the epidemiological transition were not distributed equally throughout the world (Fig. 2). Lack of economic means and basic scientific knowledge prevented a fast and wide diffusion of new medical technology and health practice across countries. In the late nineteenth and early twentieth centuries, the increase in life expectancy inequality is associated to the fact that the first health transition was initially restricted to advanced western countries. The gradual international diffusion of the health transition favoured the reduction in life expectancy inequality between the late 1920 s and 1980. The inequality contraction was particularly intense during the 1930 s and 1940 s, when life expectancy improved in developing countries at a time of stagnant or declining per capita GDP and growing disparities across countries resulting from the Great Depression and World War II.

Although a second episode of longevity increase took place in the 1960 s, a decade of governmental activism in the developing world, by 1970 the diffusion of the epidemiological transition was largely exhausted. At the turn of twentieth century, however, another significant outward shift of the health function took place (Fig. 4). This was the outcome of what may be depicted as a *second* health transition in which mortality and morbidity fall among the elderly as a result of new medical knowledge that allows better treatment of respiratory and cardiovascular disease and vision problems (Cutler et al., 2006; Chernew et al., 2016; Eggleston and Fuchs, 2012; Deaton, 2013). New medical technologies, combined with better nutrition in early years of life result in longer and healthier lives (Mathers et al., 2001; Murray and Lopez, 1997; Salomon et al., 2012; Murray et al., 2017). The *second* health transition has been restricted so far to advanced countries due to its higher cost. Together with the AIDS-HIV pandemic in Sub Saharan Africa and the collapse of socialism in large areas of the world it help explain why the *West* forged ahead while the *Rest* fell behind in terms of health.

The finding that increases in per capita income contributed decisively to life expectancy gains from the late twentieth century onwards concurs with Mackenbach and Looman's (2013) results. However, what

[13] This amounts to computing the counterfactual level of the Kakwani index of life expectancy in, say, 1913 by applying the parameters of the statistical relationship for the 1913 cross-section to the values of real per capita income (in logs) in 1870 and compare it to the predicted level for 1870 derived with the statistical relationship for 1870. And also replicating the exercise by applying the parameters of the statistical relationship for the 1870 and 1913 cross-sections to the values of per capita income (in logs) in 1913 to get the counterfactual and predicted levels of the Kakwani index of life expectancy in 1913 and weighted the results by the population. The comparison for each set of estimates between the average counterfactual and the predicted levels shows the gains in the Kakwani index of life expectancy that would be obtained in the absence economic change but under higher medical knowledge and technology. The average of the two set of estimates should be, then, obtained.

[14] This depiction is more restricted than Riley's (2005), which associates the 'health transition' with persistent gains in survival and dates its beginnings in Denmark in the 1770 s, way before the germ theory of disease was designed and accepted. However, even with this broad definition, only a handful of countries had started it before the 1870 s, 8 out of a sample of 119 countries (Riley, 2005: 745).

[15] Riley : 19) (2001), disagrees and considers that unchecked or ineffectively checked disease rather than infectious disease was the main cause of death in pre-transition societies. For Omran (1971, 1998), the epidemiological transition is a very comprehensive concept, including health and parts of the demographic transition. The narrower concept used here overlaps Omran's second and third stages in Western societies, that is, the ages of 'receding pandemics' and 'degenerative and man-made diseases'.

[16] Later, the introduction of sulphonamides and, then, penicillin, represented a major leap forward in the reduction of maternal mortality (Loudon, 2000).

could be taken for a secular trend may actually be another phase in the diffusion of new medical knowledge and technology. In fact, a parallelism can be established between the late nineteenth and early twentieth centuries and the post-1970 era as, in both historical phases, new medical advances were restricted to countries that had the human and physical capital to adopt them, and this limited geographical impact also accounted for the observed increase in life expectancy inequality (Fig. 2).

## 5. Final remarks

Unlike conventional wisdom among economists, life expectancy at birth and real per capita GDP behaved differently in terms of trends and distribution during the past one and a half centuries. Long run improvements in life expectancy depended on advance of medical knowledge as much as on economic growth that facilitated better nutrition and the provision of health services.

The advance of medical knowledge in poorer world regions often resulted in better low-cost hygiene practices to fight infectious disease and, thus, while average income levels stagnated or declined across countries during the economic globalization backlash of the first half of the twentieth century, life expectancy achieved major gains across the board.

The new evidence provides an opportunity to re-assessing the relationship between life expectancy and per capita income, that is, the Preston Curve, from a historical perspective. When life expectancy is non-linearly transformed, the Preston Curve does not flattens out becoming concave over time (as per capita income increases); on the contrary, the Kakwani index of life expectancy and the natural log of real per capita income appear to have a convex relationship. The results confirm outward shifts in the relationship between life expectancy and per capita income that do not 'break down' over time.

An important historical lesson is that while health improvements are associated with government activism and intervention, this does not seem to be a sufficient condition, as there have been national experiences in which governments did not play an active role in longevity gains. Moreover, countries have often failed to provide steady social spending and to raise living standards that would result in improved nutrition and health care, but life expectancy improved all the same. Thus, focusing only on movements along the health function, which derive from increases in average incomes, ignores the important shifts in the function that are closely connected to the diffusion of new medical knowledge and, often, but not always, accompanied by new technology (new drugs).

## Conflict of interest

The author declares no conflict of interest.

## Data Availability

The data used in this paper can be freely and publicly accessed at https://frdelpino.es/investigacion/en/category/01_social-sciences/02_world-economy/03_human-development-world-economy/.

## Acknowledgments

An earlier version of this paper was presented at the European Society for Historical Demography Online Seminar. I thank participants, especially, my discussant, Guido Alfani, Michel Oris, and Diego Ramiro Fariñas, for their comments and suggestions. I also appreciate Daniel Gallardo-Albarrán and David Reher's feedback.

## Appendix

See in Table A1–A3.

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