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The Intimate Link between Income Levels and Life Expectancy: Global Evidence from 213 Years

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ABSTRACT

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Contrary to previous findings, we find a systematic and economically sizeable relationship between income levels and life expectancy in a panel dataset of 197 countries over 213 years. By itself, GDP/capita explains more than 64 percent of the variation in life expectancy. The Preston curve prevails, even when accounting for country- and time-fixed effects, country-specific time trends, and alternative control variables. Quantile regressions and instrumental variable estimations suggest this link to be persistent across different levels of life expectancy and unaffected by reverse causality. If policymakers want to prolong people's lives, economic growth appears to be the predominant medicine.

JEL Classification: I15, I31, J11, H51

Keywords: historical panel data, income levels, life expectancy, quantile regression analysis

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1 Introduction

In a seminal work, Samuel Preston (1975) outlined the non-linear relationship between a country's income levels and the expected lifespan of its citizens. Labeled the "Preston curve," the hypothesis states that poor countries enjoy a substantial increase in life expectancy when they grow, whereas this effect diminishes, yet remains positive, for richer countries. Recently, however, Preston (2007) himself has questioned this relationship, arguing that GDP per capita may at times explain no more than 16 percent of the variation in life expectancy. Similarly, Spence and Lewis (2009) argue the Preston curve "may not hold within countries over time," lamenting the unavailability of long-run data to test the Preston curve (see also Leon, 2007, and Mackenbach, 2007).

This paper provides a systematic long-term study of the relationship between income levels and life expectancy, using data for 197 countries and 213 years. Our first result produces considerable evidence for a powerful income-life expectancy link. By itself, GDP per capita (linear, squared, and cubic) is able to explain over 64 percent of the variation in life expectancy for our full sample of 4,325 country-decade observations.[1] This constitutes four times the explanatory power suggested by Preston (2007).

Second, a major advantage of using repeated country-level data comes from the opportunity to control for any country- and time-specific heterogeneity via fixed effects. Naturally, countries differ vastly in terms of history, culture, institutional roots, as well as geography. Many of these factors could independently be associated with life expectancy. However, the predictive power of income levels remains strong (both in terms of statistical significance and magnitude) after controlling for country- and time-fixed effects, country-specific time trends, population size, conflicts, health care spending, the occurrence of Malaria, and political institutions. Causality appears to be running from income

[1]Even between 1930 and 1970, where previous papers have claimed that the explanatory power of income has weakened, the corresponding R^2 never drops below 47 percent.

to life expectancy (employing instrumental variables) and the relationship does not vary at different stages of life expectancy (using quantile regressions).

Finally, our results allow for a quantitative interpretation of the derived relationship. In our most complete estimation, income levels remain a strong positive predictor of life expectancy until approximately US$15,478 (corresponding to about 95 percent of observations in our sample), after which the relationship flattens out. Indeed, our findings lend support to the traditional intuition of the Preston curve, as poor countries experience larger jumps in life expectancy when their economy grows. Furthermore, the effect remains robust and remarkably stable in terms of magnitude throughout all time periods.

From a policy perspective, our findings suggest that large parts of the relative ill health in poor countries is a result of their being poor. The predominant medicine for longer lives seems to be raising the level of income per capita to that of rich countries. International health interventions and innovation may contribute to raising life expectancy, but existing and fundamental differences in life expectancy between countries are mostly due to differences in income. Thus, higher incomes buy a longer life.

We proceed with a discussion of the related literature in Section 2. The data and the empirical strategy are presented in Section 3, whereas Section 4 provides the main results, along with several robustness checks and extensions. Section 5 offers concluding remarks and policy implications.

2 Literature and Background

Large gains in life expectancy have been a global phenomenon over the course of the 20th century. In our sample of 197 countries, the average life expectancy more than doubled from the year 1900 to 2000 from 33.42 years to 68.18 years.[2] Nevertheless, citizens in poor countries continue to live shorter lifes than those of rich countries. In general, little doubt remains that raising incomes can help to improve the level of health and extend life expectancy. However, the dominant drivers of life expectancy are hotly debated and opinions diverge (see Strauss and Thomas, 1998, Acemoglu et al., 2001, McArthur and Sachs, 2001, Acemoglu and Johnson, 2007, and Weil, 2007, among others).

In a seminal paper, Preston (1975) declares innovations in modern medicine as the driving forces in explaining large upward shifts in life expectancy, arguing that income only exerts an indirect effect via the consumption of health items. To underpin his thesis, Preston (1975) conducts a cross-country analysis of national income per capita and mortality rates for the 1900s, 1930s, and 1960s. The respective samples include ten, 38, and 57 countries.[3] Plotting both variables for the available countries and time periods in one diagram, he draws the so-called "Preston curve" through the corresponding data points which provide a clear relationship between the two variables with an upward shift for each of the observed time periods.

Since then, the Preston curve has been investigated extensively (see Cutler et al., 2006, Bloom and Canning, 2007, Leon, 2007, Wilkinson, 2007, Mackenbach and Looman, 2013, and Edwards, 2016). Empirical results have been mixed and a common critique of the Preston curve relates to the idea that other, exogenous factors are driving developments in life expectancy, such as the introduction of new vaccines, medical treatments, or post-war campaigns.

Revisiting the topic, Preston (2007, p.486) himself argues that "[f]actors exogenous

[2] Oeppen et al. (2002) suggest there is no reason to believe humanity will stop pushing the boundaries of life expectancy and Soares (2007) discusses the development of life expectancy in poorer nations in the 20th century.

[3] Data used for life expectancy and income per capita are mainly taken from the UN Demographic Yearbook in 1967 (for updated data, see http://unstats.un.org/unsd/demographic/products/dyb/dyb2.htm) and the UN Statistical Yearbook.

to a country's current level of income probably account for 75-90% of the growth in life expectancy for the world as a whole between the 1930s and the 1960s." Similarly, Dalgaard and Strulik (2014) estimate the Preston curve for the year 2000 and only find a modest direct effect of income on longevity, but a much larger indirect impact via health care efficiency (see also Evans et al., 2001, and Joumard et al., 2010). Thus, income levels may only play a minor role. In turn, Pritchett and Summers (1996) argue that GDP per capita carries a large and causal impact on life expectancy.[4] In a cross-country analysis of five-year intervals from 1960 to 1990, they find changes in income to be responsible for approximately 40 percent of the observed improvements in life expectancy. The causal direction is underpinned by an instrumental variable regression structure, using the terms of trade as instruments, among other variables.

How can we reconcile these findings and how important are income levels in extending the average life span? Our study accounts for endogeneity via the inclusion of country- and time-fixed effects, country-specific time trends, and variables capturing alternative explanations in civil conflict, health care expenditure, the prevalence of malaria, and political institutions. In particular, controlling for two-way fixed effects allows us to isolate the income-life expectancy relationship from country- and time-specific heterogeneity.[5] For example, colonial history and institutional roots (e.g., see Acemoglu et al., 2005, and the literature cited therein), as well as geographical aspects, such as climate zones, disease prevalence, and distance to the coast, have been suggested as drivers of development levels (e.g., see Sachs, 2003). Similarly, cultural particularities are likely associated with income levels (see Tabellini, 2010) and such characteristics may plausibly exert independent effects

[4]Lindahl (2005) provides micro evidence from analyzing lottery prize winners and finds a robust and sizeable effect of income on life expectancy and Angel (2016) reports negative effects of low income and over-indebtedness on health for 25 European countries.

[5]The introduction of country- and time-fixed effects has affected a number of standard results in the literature. Examples can be found for economic growth (Islam, 1995), democracy (Acemoglu et al., 2008), and government size (Ram, 2009).

on life expectancy, e.g., through the degree of risk aversion in living one's life. All such time-invariant country-specific characteristics will be absorbed by country-fixed effects.

Related to time-fixed effects, we can think of specific global developments that may influence life expectancy and income levels simultaneously, such as major wars or technological advancements. For example, if the invention of new vaccines (see Preston, 2007) or the post-war period in the middle of the 20th century were largely responsible for global upward shifts in life expectancy, then time-fixed effects would soak up that variation and income levels should lose their explanatory power in terms of statistical relevance and magnitude.[6] Finally, incorporating country-specific time trends acknowledges the idea that each society has emerged in its own unique way and we wish to ensure that the income-life expectancy link is not driven by such heterogeneity.[7] Note that previous studies did not have rich panel data at their disposal to account for unobservable heterogeneity along the country and time dimension (Pritchett and Summers, 1996, is a notable exception).

In fact, data availability has long been a major concern in the associated literature and studies using repeated country-level observations have struggled to find evidence for the role of GDP per capita. For instance, Mackenbach (2007) highlights that increasing interdependencies between countries make the usage of cross-sectional data less reliable. Spence and Lewis (2009, p.9) argue that "[a]lthough the Preston curve shows a close relationship between income and health in the cross-sectional data, longitudinal data will suggest that this relationship may not hold within individual countries over time." Our results show the opposite, employing panel data for 197 countries and 213 years. Even in the contested time period between 1930 and 1970, income levels alone are able to explain

[6]Contrary to Preston, 2007, we can also think of a hypothesis under which medical innovations *strengthen* the relationship between income and life expectancy; new treatments usually become available worldwide, but are only used in countries where people have sufficient means to pay for them.

[7]For example, Leon (2007) argues that in some African countries life expectancy declines due to HIV/AIDS and in post-Soviet countries institutions prohibit life expectancy from rising. Similarly, sharp increases in life expectancy occurred in different eras for the developed and less developed countries (see Preston, 2007).

47 to 66 percent of the cross-country variation in life expectancy.

3 Data and Empirical Strategy

3.1 Data

Our panel data set includes 197 countries for the years 1800 to 2012. The data set is almost completely balanced, as only one country is missing information for five decades (Morocco) and four countries are missing information for one decade (French Guiana, Guadeloupe, Martinique, and Reunion). To alleviate concerns about measurement errors, we follow the associated literature (e.g. Pritchett and Summers, 1996) in averaging all annual variables over a decade. Nevertheless, all derived results are consistent when employing five- or 20-year averages (corresponding results can be found in Table A3). The first decade ranges from 1800 until 1809, whereas the second decade spans the years 1810 to 1819, and so on. In the final period, we average annual values from 2010 until 2012.

For the two main variables of interest, life expectancy and GDP per capita, we access data provided by the Gapminder Foundation (Rosling, 2009). Data on life expectancy is compiled and standardized from several official international statistics, historical sources, and estimates made by the Gapminder statisticians. Among the main sources are the Human Mortality Database (Wilmoth et al., 2014), the World Population Prospects (United Nations, 2013), and the Human Lifetable Database (Max Planck Institute for Demographic Research, 2016).[8] Data on income per capita is compiled in a similar way.[9]

[8]Initial data sources can be accessed via www.mortality.org, http://esa.un.org/unpd/wpp/, and www.lifetable.de. Gapminder data is available under http://www.gapminder.org/data/. Gapminder provides a complete documentation how the data is compiled and standardized on its website.

[9]Gapminder states that "[c]ross-country data for 2005 by the International Comparison Program forms the main source of the reference year. Real income per capita growth rates were linked to the 2005 levels." Several sources are employed, among others the data of Angus Maddison, available under The

Importantly, country-fixed effects in our analysis account for the notion that measurement in some countries can be more problematic than in others. Time-fixed effects are intended to control for the idea that data quality may have improved over time. Finally, our analysis also controls for country-specific time trends, accounting for specific national developments over time.

Following the previous literature, we also control for independent effects of population size, conflict prevalence, health care expenditure, the incidence of malaria, and the degree of democracy (see Pritchett and Summers, 1996, Acemoglu et al., 2005, Plümper and Neumayer, 2006, or Acemoglu et al., 2008).[10] These estimations are intended to evaluate whether any changes in life expectancy associated with income levels could be driven by an omitted variable beyond our fixed-effects framework. All variables come from standard sources of country-level data and summary statistics are referred to Table A1. Finally, Table A2 provides a list of all sample countries with their average life expectancy and income levels.

3.2 Main Empirical Strategy

Our main empirical strategy employs a multiple regression approach, where we regress life expectancy in years on a linear, a quadratic, and a cubic term of GDP per capita, acknowledging the original concept of the Preston curve (Preston, 1975).

Our first goal is to estimate how much of the variation in life expectancy can be explained by income levels alone. Following previous studies, we then subsequently incorporate country-fixed effects (represented by δ_i in the following), measures for population size and conflict incidence (included in $\boldsymbol{X_{it}}$), time-fixed effects (ϑ_t), and country-specific

Maddison-Project (2013).

[10] Note that earlier data for population size has been interpolated linearly, in order to preserve sample size. Nevertheless, our results show that population size does not play a relevant role in affecting the income-life expectancy link.

time trends (ω_{it}).[11] In extensions, we also include health care spending, a measure for malaria prevalence, and the degree of democracy which are excluded from the main analysis because of limited data availability. In particular, we estimate

$$LE_{it} = \beta_0 + \beta_1 (\frac{GDP}{cap})_{it} + \beta_2 (\frac{GDP}{cap})^2_{it} + \beta_3 (\frac{GDP}{cap})^3_{it} + \delta_i + \boldsymbol{X_{it}}\beta_4 + \vartheta_t + \omega_{it} + \epsilon_{it}. \quad (1)$$

Finally, ϵ_{it} constitutes the conventional error term. Note that standard errors are clustered on the country-level throughout all estimations.

3.3 Quantile Analysis

Our final check for the income-life expectancy link considers specific ranges of life expectancy. In econometric terms, an OLS analysis produces coefficients at the mean of the distribution, allowing for a general conclusion. However, it is possible that income levels have raised the average lifespan more so when lives were generally shorter in the early time period of our sample. Advances may have been simpler when life expectancy was still relatively low, whereas substantial jumps may be more difficult if a country already exhibits an average life expectancy of, say, 60 years.

To test for such heterogeneity, we employ a quantile regression approach for panel data, as introduced by Harding and Lamarche (2009) and Canay (2011). In particular, this technique allows us to account for unobserved heterogeneity and heterogeneous effects of the covariates. Further, we follow Canay (2011) in applying the deviation of the country-specific mean in life expectancy, thereby acknowledging country-specific particularities. The resulting two-stage estimator remains consistent and asymptotically normal, with

[11] Population size and life expectancy are considered to have a recursive relation where one can reinforce or hamper the other (Acemoglu and Johnson, 2007). Plümper and Neumayer (2006) argue that inner-or inter-state (armed) conflicts have direct negative effects on people's life expectancy (victims of military operations), but also indirect restrictive effects through limited agricultural production, insufficient public health care provision and social disorder.

standard errors computed using a bootstrap methodology. These estimations allow us to consider the income-life expectancy nexus from another angle, testing whether the main results hold up for different ranges of life expectancy.

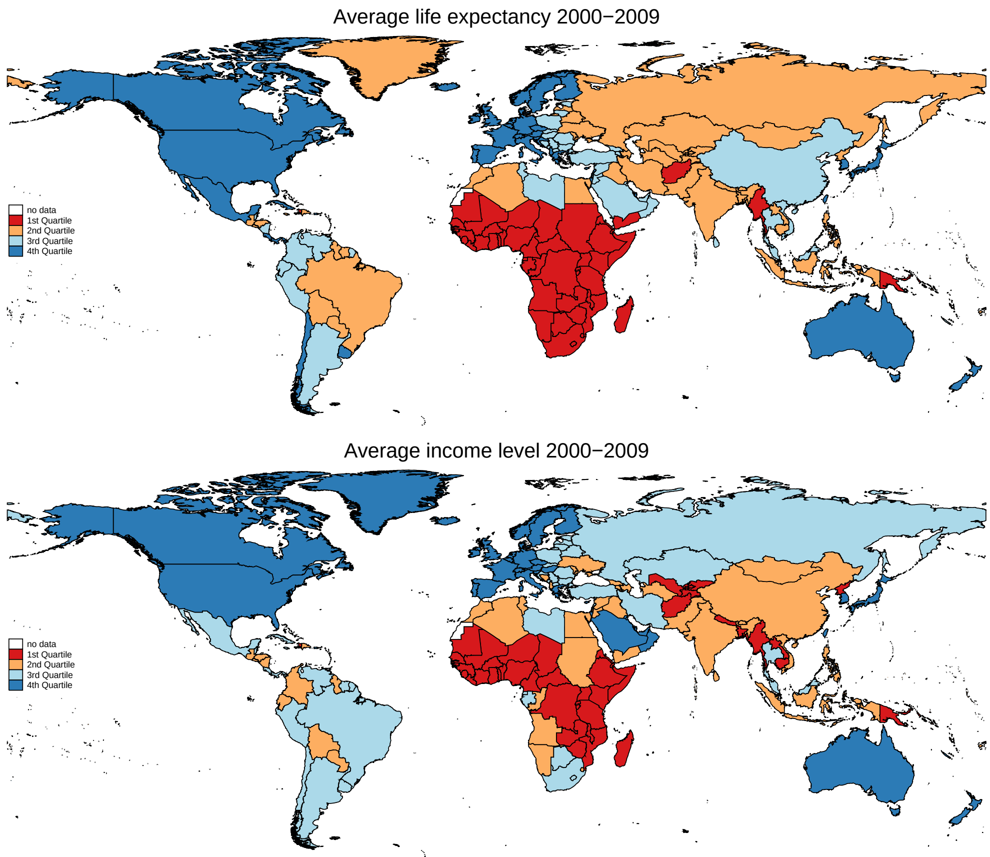
4 Empirical Findings

4.1 Main Results

To get an idea of the global situation on our key variables, Figure 1 visualizes life expectancy and income levels in the first decade of the 21st century. Just from comparing both maps, we can already tell that the two variables are intimately related, at least in recent years.

Table 1 turns to our regression results from estimating equation 1. Column (1) displays results from a univariate regression and income indeed offers itself as a strong predictor of life expectancy. Over 39 percent of the variation in life expectancy can be explained by a linear term of GDP per capita alone. Column (2) introduces the familiar shape of the original Preston curve, taking into account a squared and a cubic term of income levels. Indeed, we find evidence for nonlinearity and saturation appears to set in at approximately US$26,246 (which would affect less than 2.5 percent of our sample observations). After this value, the income-life expectancy relationship is suggested to flatten out.

Note that the model's fit is improved substantially in column (2) and we are now able to explain over 64 percent of the variation in life expectancy across countries over time which is a high explanatory power when analyzing social phenomena with a single variable. These basic regressions suggest a much more intimate relationship between a country's wealth and the duration of the average life than previously suggested. In particular, Preston (2007, p.487) states that only 16 percent of the increase in life expectancy between



Notes: Life expectancy is categorized into quartiles: LE<62.65, 62.65<LE<71.52, 71.52<LE<75.45, and LE>75.45. Similarly, income levels are categorized into quartiles: GDP/cap<2,102, 2,102<GDP/cap<6,435, 6,435<GDP/cap<15,677, and GDP/cap>15,677.

Figure 1: Map of average life expectancy and income levels from 2000 – 2009.

Table 1: Results from OLS regressions, estimating life expectancy in years. All variables are taken as 10-year averages and the overall sample timeframe includes the years 1800 – 2012.

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable: Life expectancy in years						
GDP/cap in US$ 10,000	13.958***	46.594***	50.954***	36.065***	14.331***	4.100***
	(1.850)	(2.742)	(3.556)	(3.532)	(1.785)	(1.442)
(GDP/cap in US$ 10,000)^2		-11.900***	-13.013***	-9.210***	-3.723***	-1.617***
		(1.369)	(1.713)	(1.280)	(0.708)	(0.545)
(GDP/cap in US$ 10,000)^3		0.768***	0.845***	0.594***	0.247***	0.126***
		(0.133)	(0.160)	(0.108)	(0.061)	(0.045)
Population size				6.612***	1.357***	1.684**
				(1.058)	(0.416)	(0.734)
Conflict				0.522***	-0.144	-0.116
				(0.190)	(0.097)	(0.071)
Country fixed effects			yes	yes	yes	yes
Time fixed effects					yes	yes
Country-specific time trends						yes
Threshold value GDP/cap[a]		26,246	26,332	26,241	25,946	15,478
# of countries	197	197	197	197	197	197
# of decades	21	21	21	21	21	21
N	4,325	4,325	4,325	4,325	4,312	4,312
Adjusted R^2	0.391	0.644	0.693	0.806	0.925	0.956

Notes: Standard errors clustered on the country level are displayed in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
[a]GDP/cap value above which the income-life expectancy link flattens out.

1938 and 1963 for the world as a whole would be attributable to increases in average income per se. Our results, using global data for 213 years, provide a much stronger conclusion in favor of the income-life expectancy link.

The statistically significant linear, quadratic and cubic terms imply an S-shaped relationship between income and life expectancy. This S-shape is suggestive for the causal link going from income to life expectancy. Suppose causality ran instead from life expectancy to income, then income would have to rise independently for low and high levels of life expectancy to satisfy the S-shape in the GDP per capital-life expectancy plain. While possible, this does not seem probable to us. On the other hand, it is intuitively conceivable that additional income at initially low and high levels of economic development has only modest effects on life expectancy: For low levels for GDP per capita, additional income is first spend on current consumption with little impact on life expectancy and for high levels of GDP per capita, additional income only buys relatively little health as higher life expectancy comes at ever higher marginal costs.[12] We further explore the causal relationship between income and life expectancy in the next section.

To further investigate Preston's specific claim related to the middle of the 20th century, Figure 2 visualizes the respective R^2 values when estimating a pure cross-sectional regression for each decade. Regressions only incorporate GDP per capita (linear, squared, and cubic) to predict life expectancy. Ever since the early 20th century income levels alone explain between 45 and 66 percent of the cross-country variation in life expectancy.[13] Only before 1880 do we observe R^2 values under 0.42, but even then the suggested contribution of 16 percent is comfortably surpassed, as the minimum R^2 we derive reaches a value of 0.25 (years 1800 – 1809). Note that it is possible that early values suffer from

[12] Note that we do not suggest that there are no potential effects of life expectancy on income. Rather, the main driver of life expectancy seems to be income which buys health.

[13] In alternative estimations, we also employed the natural logarithm to income levels. The corresponding regressions produce even higher R^2 values throughout over entire sample and the respective graph is referred to Figure 3.

measurement error, which may explain less statistical precision, compared to data from the 20th and 21st century.

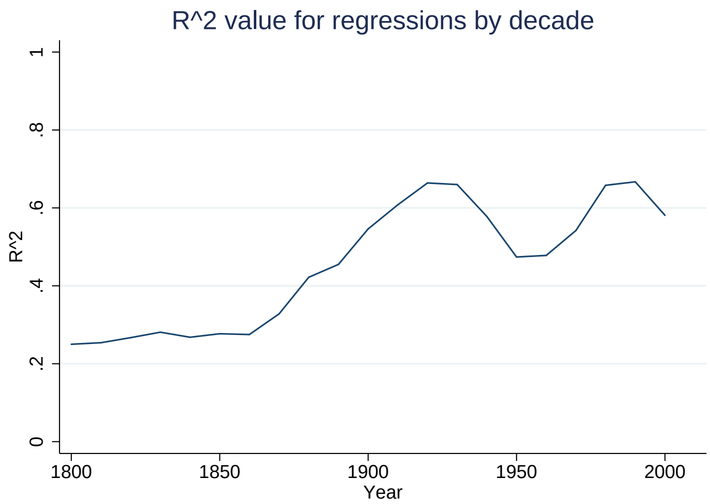


Figure 2: R^2 values for cross-sectional regressions by decade.

Returning to Table 1, column (3) includes country-fixed effects, yet the relevance of income levels remains virtually unchanged. Note that we estimate an almost identical threshold level after which the suggested relationship flattens out with US$26,332. Thus, it is unlikely that unobservable heterogeneity on the country level is driving the importance of income levels. In fact, running a regression where we only use country-fixed effects to predict life expectancy (absent income levels) produces an R^2 value of only 0.154 – not even one quarter of the 64.4 percent explained by income levels alone in column (2). Thus, income levels are much stronger in predicting longer lives than any country-specific characteristics, such as cultural particularities or historical aspects.

Columns (4) to (6) add further control variables to improve the model's precision and to check whether the power of income levels can be explained by other factors. Specifically, we include population size, conflict status, time-fixed effects, and country-specific time trends. However, all three income variables retain their explanatory power and remain statistically significant on the one percent level. Note that the inclusion of time-fixed effects implicitly controls for the alternative explanation of global health care developments (e.g., vaccines and treatments). Finally, once country-specific time trends are accounted for, the threshold level after which the income-life expectancy link flattens out diminishes to US$15,478. Although this value appears much less than in the previous regressions, it would only affect approximately five percent of the entire sample observations.

4.2 Alternative Explanations

With these benchmark results in mind, Table 2 turns to several alternative explanations for the strong link between GDP per capita and life expectancy. In particular, we check for the roles of health care expenditure per capita, the prevalence of malaria, the level of democracy, and potentially underlying endogeneity. In columns (1) through (6), we first replicate our baseline regression using only those observations for which each respective control variable is available. Then, we include the additional control variable to observe potential changes in our results. Note that we exclude country-fixed effects and country-specific time trends, given the limited number of observations of only two or three decades, respectively.

First, we further evaluate the role of medical developments by including health expenditure per capita. Several papers (e.g., Preston, 1975, and Dalgaard and Strulik, 2014) have argued that substantial advances in health care, specifically vaccines and medical breakthroughs between 1940 and 1959, are responsible for systematic changes in life expectancy. Indeed, we find that higher spending on health care is associated with longer lives. In quantitative terms, an increase of US$1,000 per capita is associated with living for 1.4 additional years, on average. Nevertheless, the role of income levels remains virtually unchanged, as the respective coefficients remain significant on the one percent level and the corresponding threshold level after which the income-life expectancy link flattens out changes only marginally.

Columns (3) and (4) conduct the same exercise for the prevalence of malaria. As expected, life expectancy increases if malaria is largely absent. Yet, here again, the importance of income levels prevails and malaria prevalence is not able to explain the importance of GDP per capita. Moving to a measure for formal institutions, columns (5) and (6) consider the level of democracy, applying the Polity IV indicator (variable *polity*2, ranging from -10, total autocracy, to +10, total democracy). The results indicate that people in more democratic nations enjoy longer lives, but these findings are not able to account for the importance of income levels.

Finally, columns (7) through (10) address potential endogeneity concerns related to reverse causality. Intuitively, longer lives may in turn affect GDP per capita, a possibility that has received attention in the associated literature via several channels (e.g., see Acemoglu and Johnson, 2007, and Oster et al., 2013). In general, it is well known that endogeneity concerns in macroeconomic variables are difficult to disentangle. Ideally, a researcher requires an instrumental variable that is completely unrelated to the outcome variable, but strongly correlated with the potentially endogenous regressor. We offer four instrumental variable (IV) strategies as a remedy.

Our first solution focuses on using lagged values of the potentially endogenous regressor as instruments – a popular solution in the literature.[14] In our context, values of life expectancy in a decade are unlikely to affect income levels today. Our second solution follows Easterly et al. (1993) and Pritchett and Summers (1996) by subsequently employing trade (measured in percent of GDP) and the investment-to-GDP ratio as instruments.

[14]See Temple (1999), Schularick and Steger (2010), and Mirestean and Tsangarides (2016) for using lagged values of endogenous variables to estimate economic growth. Bhattacharyya and Hodler (2010) instrument democracy with its lagged value and Arezki and Brückner (2011) employ lagged corruption values as an instrument for corruption today.

Table 2: Robustness checks and extensions. Displaying results from OLS and IV regressions, estimating life expectancy in years. All variables are 10-year averages and the overall timeframe is 1800 – 2012.

Dependent variable: Life expectancy in years	(1) Health Care	(2)	(3) Malaria	(4)	(5) Polity IV	(6)	(7)	(8) IV regressions	(9)	(10)
Panel A: Regression results										
GDP/cap in US$ 10,000	18.551***	17.752***	23.627***	19.246***	10.897***	9.710***	2.311***	7.433***	16.166***	11.267***
	(1.663)	(1.711)	(1.899)	(1.956)	(2.214)	(2.162)	(0.243)	(1.992)	(4.766)	(2.095)
(GDP/cap in US$ 10,000)^2	-4.756***	-5.012***	-7.431***	-5.860***	-3.724***	-3.340***				
	(0.647)	(0.694)	(0.818)	(0.800)	(0.716)	(0.696)				
(GDP/cap in US$ 10,000)^3	0.347***	0.381***	0.670***	0.518***	0.297***	0.267***				
	(0.062)	(0.068)	(0.089)	(0.084)	(0.057)	(0.055)				
Health care spending/cap in US$ 10,000		14.257**								
		(5.956)								
Malaria				-0.368***						
				(0.073)						
Polity IV						0.143**				
						(0.056)				
Population size & conflict incidence	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	
Country FE					yes	yes	yes			
Panel B: Threshold of income levels										
Threshold value GDP/cap^a	28,215	24,623	23,138	24,163	18,907	18,753				
Panel C: IV statistics										
Instrumental variable							Lagged GDP/cap	Trade	Investment	Oil
GDP/cap from OLS regression							2.629***	5.169***	5.726***	8.755***
							(0.392)	(0.720)	(1.025)	(1.602)
F-statistics 1^{st} stage^b							112.74***	12.59***	10.51***	10.66***
Panel D: Regression statistics										
# of countries	179	179	197	197	165	165	197	188	94	186
# of decades	3	3	2	2	22	22	20	6	6	9
N	534	534	390	390	1,681	1,681	4,115	903	551	1,416
Adjusted R^2	0.594	0.598	0.629	0.677	0.914	0.916	0.905	0.918		0.307

Notes: Standard errors clustered on the country level are displayed in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. [a]GDP/cap value above which the income-life expectancy link flattens out. [b]Testing for weak instruments produces F-values above the commonly suggested threshold value of ten (Stock et al., 2002; Stock and Watson, 2012).

In particular, a country's extent of international trade is likely related to income levels, but meaningful independent channels to life expectancy are difficult to imagine.[15] Levine and Renelt (1992) show that the ratio of investment is robustly related to growth (also see detailed explanation in Pritchett and Summers, 1996). In our final attempt at circumventing reverse causality concerns, we employ oil reserves as an instrumental variable. Such natural phenomena are directly linked to income levels (e.g., Brückner et al., 2012), yet are unlikely to be related to life expectancy through other meaningful channels.[16] Note that we exclude country-fixed effects from the final three regressions, as the statistical variation from the respective instruments is not sufficient to produce meaningful IV estimates. We also intended to instrument for squared and cubic values of income levels, but the corresponding higher order values of the respective instruments do not provide sufficient statistical variation, rendering them unsuitable.

To conveniently assess whether the corresponding IV results are in line with results from analogous OLS regressions, Panel C of Table 2 displays the respective coefficient on the linear term of GDP per capita. For example, in column (7), when employing lagged values of GDP per capita, the coefficient from the IV regression reaches a value of 2.3, whereas the corresponding coefficient from an OLS regression (using the same sample) returns a value of 2.6. Thus, we observe little difference in the quantitative relationship between income levels and life expectancy in the IV framework. In terms of statistical relevance, the derived coefficient remains statistically significant on the one percent level. Similarly, the respective coefficients in columns (8) through (10) confirm the importance of income levels. In these estimations, the coefficient from employing the respective IV structure even surpasses the OLS estimate. Thus, overall, Table 2 produces little evidence for the claim that reverse causality may drive the role of income levels in explaining life

[15] For the trade-income link, we refer to classical trade models, such as Heckscher-Ohlin, or recent empirical contributions, e.g., from Irwin and Terviö (2002).

[16] We access data provided by Cotet and Tsui (2013) for oil reserves per capita.

expectancy.

4.3 Quantile Regression Results

Finally, we move to results from quantile regressions, evaluating whether the role of income levels persists across the entire spectrum of life expectancy. Table 3 displays the corresponding results, where we resort to the baseline regression format of employing linear, squared, and cubic values of GDP per capita to estimate life expectancy. We also include our main control variables with population size and conflict incidence.

Table 3: Quantile regression results, estimating life expectancy in years. All variables are 10-year averages and the overall timeframe is 1800 – 2012.

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	Q 0.1	Q 0.25	Q 0.5	Q 0.75	Q 0.9
Dependent variable: Life expectancy in years						
GDP/cap in US$ 10,000	14.331***	15.141***	15.800***	14.653***	12.951***	14.420***
	(1.785)	(0.951)	(1.107)	(1.164)	(1.480)	(1.420)
(GDP/cap in US$ 10,000)^2	-3.723***	-3.714***	-4.280***	-4.472***	-3.971***	-4.459***
	(0.708)	(0.502)	(0.573)	(0.598)	(0.757)	(0.867)
(GDP/cap in US$ 10,000)^3	0.247***	0.228***	0.278***	0.360***	0.326***	0.372***
	(0.061)	(0.059)	(0.075)	(0.076)	(0.096)	(0.124)
Population size & conflict incidence	yes	yes	yes	yes	yes	yes
Time fixed effects	yes	yes	yes	yes	yes	yes
Threshold value GDP/cap^a	25,946	27,193	24,132	22,491	22,592	22,511
# of countries	197	197	197	197	197	197
N	4,312	4,312	4,312	4,312	4,312	4,312
Adjusted R^2	0.915					

Notes: Standard errors clustered on the country level are displayed in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
^{a}GDP/cap value above which the income-life expectancy link flattens out.

Column (1) replicates the OLS result to provide a benchmark of comparing the qualitative and quantitative effect of income on life expectancy. The remaining regressions display results for the 10th and 25th percentile, the median, the 75th percentile, and the 90th percentile of the distribution. The corresponding coefficients remain remarkably consistent throughout these estimations. In addition, the associated threshold level after which the link flattens out remains stable and never falls below US$22,000. These findings suggest that the income-life expectancy link prevails across all observed spans of life expectancy.

5 Conclusions

This paper revisits the relationship between income levels and life expectancy, analyzing data for 197 countries over 213 years (1800 to 2012). We investigate two central research questions. Firstly, how strong is GDP per capita in predicting life expectancy? And secondly, does the income-life expectancy link hold up once country- and time-specific heterogeneity is accounted for, as well as country-specific time trends and variables measuring alternative explanations, such as population size, conflicts, health expenditure, malaria prevalence, and political institutions?

The answer to the first question strongly confirms the initial hypothesis of the Preston curve, i.e., there exists a systematic non-linear relationship between income levels and the average lifespan *within* a country. All our estimations produce firm evidence of a consistently positive relationship until a value of approximately US$15,478 (using international price levels in 2005), corresponding to approximately 95 percent of the 4,325 sample observations. GDP per capita alone is able to explain over 64 percent of the variation in life expectancy across countries and years.

The second question challenges previous studies that suggest the Preston curve only holds in cross-sectional studies, but disappears once exogenous country- and time-specific characteristics were considered. Our findings do not confirm this hypothesis. In fact, all three terms of income levels (linear, quadratic, and cubic) remain statistically significant on the one percent level in all our estimations and meaningful in terms of magnitude. Considering potential other drivers of life expectancy does not change our conclusion. Further, this result is unlikely to be driven by reverse causality concerns. Finally, we conduct quantile regressions and verify that the effect of income prevails throughout different stages of life expectancy.

Overall, analyzing virtually the entire world population since 1800 suggests that income levels are by far the strongest factor in raising life expectancy across the globe. Of course, medical innovations increase longevity, but richer countries are more likely to use these innovations and perform treatments because they can pay for them. Higher incomes permit countries to buy longevity and wealthier indeed means healthier. The ill health and short lifespans of the poor tend to be a result of their being poor and promoting economic growth is most likely one of the most powerful tools to guarantee healthy and long lives (also see Deaton, 2003).

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Appendix

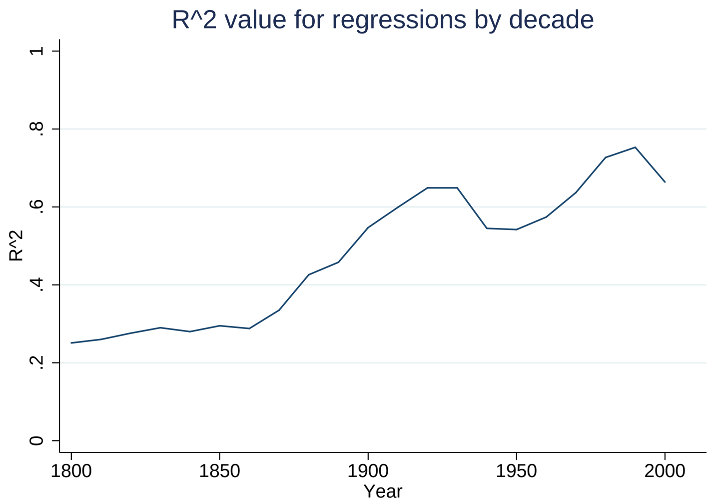

Figure 3: R^2 values for cross-sectional regressions by decade, using the natural logarithm of GDP (linear, squared, and cubic).

Table A1: Summary statistics.

Variable	Mean (Std. Dev.)	Min. Max.	N	Source[a]	Description
Life expectancy	42.51 (16.13)	20.45 (83.25)	4,325	Gapminder	The average number of years a newborn child would live if current mortality patterns were to stay the same
GDP/cap in US$ 10,000	0.36 (0.72)	0.03 (11.17)	4,325	Gapminder	Gross Domestic Product per capita by Purchasing Power Parities (in international dollars, fixed 2005 prices)
Population size (in millions)	288 (6,451)	0.002 (196,667)	4,325	Gapminder	Total Population, linearly interpolated for earlier decades[b]
Conflict incidence	0.37 (1.36)	0 (10)	4,312	Correlates of War	Number of intra-state and inter-state wars
Health care expenditure	0.09 (0.12)	0 (0.86)	534	World Bank	Health expenditure per capita, PPP (constant 2011 international $)
Malaria	2.80 (6.78)	0 (42.34)	392	WHO	Number of reported malaria cases in every 100,000 residents during the given year
Polity IV	-0.08 (0.99)	-10 (1.96)	1,692	World Bank	Degree of democracy, ranging from -10 (total autocracy) to +10 (total democracy), variable *polity*2
Trade (% of GDP)	79.93 (50.24)	0 (443.33)	906	World Bank	Exports plus imports divided by GDP
Investment (% of GDP)	22.09 (9.08)	1.82 (76.51)	551	PWT	Investment share of PPP converted GDP/capita at 2005 constant prices
Oil in thousands	258 (3,003)	0 (73,314)	1,416	Cotet & Tsui	Oil reserves per capita from all sources

Notes: All variables are averaged per decade. [a]Sources: Gapminder initially is introduced by Rosling (2009) and can now be found under http://www.gapminder.org/data/; World Bank: Group (2012); Correlates of War: Sarkees and Wayman (2010); WHO: World Health Organization (World Health Organization, 2015); PWT: Penn World Tables 7.1 (Aten et al., 2009, initially from Summers and Heston, 1991); Cotet & Tsui: Cotet and Tsui (2013). [b]To obtain continuous data for population size, we linearly interpolate yearly values from the years 1800-1950, where values for the years 1800 (available for 197 countries), 1820, 1870, and 1900 (available for most countries) are compiled from Gapminder.

Table A2: All 197 sample countries with their average life expectancy (LE) and GDP per capita from 1800 to 2012.

Country	LE	Income	Country	LE	Income	Country	LE	Income	Country	LE	Income
Afghanistan	33	671	Fiji	39	1,442	Martinique	43	3,792	Suriname	44	2,958
Albania	47	1,842	Finland	52	7,592	Mauritania	39	793	Swaziland	38	1,489
Algeria	39	2,503	France	54	8,805	Mauritius	41	2,634	Sweden	58	9,044
Angola	31	1,712	French Guiana	42	2,764	Mexico	41	3,668	Switzerland	56	12,208
Antigua and Barbuda	46	3,304	French Polynesia	39	7,161	Micronesia, Fed. Sts.	40	1,971	Syrian Arab Republic	42	1,850
Argentina	49	4,953	Gabon	38	4,274	Moldova	44	1,513	Taiwan, China	44	5,088
Armenia	47	1,264	Gambia, The	34	526	Mongolia	40	1,089	Tajikistan	38	1,401
Aruba	47	5,345	Georgia	45	1,624	Montenegro	48	3,444	Tanzania	38	660
Australia	54	10,067	Germany	53	9,615	Morocco	41	1,283	Thailand	42	1,610
Austria	51	9,384	Ghana	37	819	Mozambique	34	465	Timor-Leste	34	1,035
Azerbaijan	42	1,965	Greece	51	5,986	Myanmar	38	752	Togo	37	831
Bahamas, The	47	7,633	Greenland	44	8,542	Namibia	39	1,899	Tonga	42	1,622
Bahrain	42	6,958	Grenada	47	2,240	Nepal	39	591	Trinidad and Tobago	48	3,753
Bangladesh	36	757	Guadeloupe	41	2,054	Netherlands	56	9,756	Tunisia	39	1,860
Barbados	45	4,773	Guatemala	37	2,168	Netherlands Antilles	48	6,060	Turkey	43	2,538
Belarus	48	2,603	Guinea	35	541	New Caledonia	40	9,994	Turkmenistan	36	2,386
Belgium	55	9,250	Guinea-Bissau	37	455	New Zealand	53	8,642	Uganda	33	687
Belize	42	1,980	Guyana	43	1,885	Nicaragua	37	2,003	Ukraine	48	2,524
Benin	36	885	Haiti	36	1,152	Niger	35	582	United Arab Emirates	42	9,292
Bhutan	35	1,098	Honduras	43	1,791	Nigeria	35	1,032	United Kingdom	56	10,220
Bolivia	40	1,859	Hong Kong SAR, China	49	7,215	Norway	60	10,867	United States	55	13,388
Bosnia and Herzegovina	46	1,685	Hungary	49	5,528	Oman	41	5,376	Uruguay	47	4,139
Botswana	40	2,380	Iceland	55	8,575	Pakistan	36	1,009	Uzbekistan	40	969
Brazil	43	2,576	India	35	846	Palestine	42	1,944	Vanuatu	36	1,664
Brunei Darussalam	45	17,434	Indonesia	39	1,074	Panama	46	3,092	Venezuela, RB	44	4,025
Bulgaria	50	3,133	Iran, Islamic Rep.	36	3,341	Papua New Guinea	38	1,027	Vietnam	43	761
Burkina Faso	34	615	Iraq	41	3,270	Paraguay	47	1,947	Yemen, Rep.	32	1,010
Burundi	36	416	Ireland	54	7,670	Peru	44	2,741	Zambia	37	794
Cabo Verde	43	830	Israel	47	6,086	Philippines	42	1,317	Zimbabwe	40	458
Cambodia	40	859	Italy	50	7,100	Poland	49	4,450			
Cameroon	35	1,054	Jamaica	47	2,903	Portugal	48	5,091			
Canada	56	10,202	Japan	51	7,324	Puerto Rico	46	4,618			
Central African Republic	34	633	Jordan	43	1,616	Qatar	44	17,911			
Chad	35	791	Kazakhstan	39	3,010	Reunion	43	2,143			
Chile	45	3,648	Kenya	35	849	Romania	47	4,034			
China	42	1,450	Kiribati	36	1,676	Russian Federation	42	4,448			
Colombia	43	2,030	Korea, Dem. Rep.	39	1,227	Rwanda	36	515			
Comoros	39	1,024	Korea, Rep.	41	3,722	Samoa	37	2,342			
Congo, Dem. Rep.	36	548	Kuwait	40	21,405	Sao Tome and Principe	40	980			
Congo, Rep.	39	1,524	Kyrgyz Republic	38	1,161	Saudi Arabia	42	7,316			
Costa Rica	46	2,875	Lao PDR	39	956	Senegal	33	918			
Cote d'Ivoire	36	1,111	Latvia	50	3,407	Serbia	47	4,325			
Croatia	48	4,372	Lebanon	43	3,274	Seychelles	51	4,168			
Cuba	48	3,744	Lesotho	38	520	Sierra Leone	29	790			
Cyprus	52	5,451	Liberia	36	559	Singapore	47	8,066			
Czech Republic	51	6,825	Libya	42	4,469	Slovak Republic	50	5,248			
Denmark	58	9,423	Lithuania	47	4,925	Slovenia	50	6,519			
Djibouti	37	1,295	Luxembourg	53	14,935	Solomon Islands	36	844			
Dominican Republic	41	1,504	Macao SAR, China	48	7,934	Somalia	34	808			
Ecuador	43	3,013	Macedonia, FYR	47	2,732	South Africa	40	3,702			
Egypt, Arab Rep.	41	1,855	Madagascar	37	845	South Sudan	31	1,090			
El Salvador	40	2,392	Malawi	35	439	Spain	48	6,586			
Equatorial Guinea	34	1,575	Malaysia	43	2,784	Sri Lanka	45	1,212			
Eritrea	36	486	Maldives	40	1,048	St. Lucia	42	2,651			
Estonia	51	4,206	Mali	31	528	St. Vincent and the Grenadines	40	1,953			
Ethiopia	34	518	Malta	49	4,439	Sudan	39	1,104			

Table A3: Results from OLS regressions, estimating life expectancy in years (1800-2012) and averaging over five, ten and 20 years.

	(1) 5 year avg	(2) 10 year avg	(3) 20 year avg
Dependent variable: Life expectancy in years			
GDP/cap in US$ 10,000	4.489***	4.100***	8.000***
	(1.284)	(1.442)	(1.572)
(GDP/cap in US$ 10,000)^2	-1.670***	-1.617***	-3.300***
	(0.498)	(0.545)	(0.677)
(GDP/cap in US$ 10,000)^3	0.127***	0.126***	0.302***
	(0.041)	(0.045)	(0.069)
Population size	1.589**	1.684**	1.573**
	(0.704)	(0.734)	(0.667)
Conflict incidence	-0.169*	-0.116	-0.024
	(0.099)	(0.071)	(0.053)
Country & time fixed effects	yes	yes	yes
Country-specific time trends	yes	yes	yes
Threshold value GDP/cap^a	16,573	15,478	15,360
# of countries	197	197	197
# of decades	21	21	21
N	8,428	4,312	2,160
R^2	0.947	0.953	0.959

Notes: Standard errors clustered on the country level are displayed in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
^{a}GDP/cap value above which the income-life expectancy link flattens out.