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New Evidence of the Health Status and Economic Growth Relationship

Summary: Over the last two decades, the role of health as a determinant of growth has been gaining ground in economic analysis due to longer average life expectancy at birth or lower infant mortality experienced in developing and fast-growing emerging economies. The empirical approach to this problem, based primarily on econometric analysis, has focused on two alternative approaches; the growth accounting models and the “a la Barro” regressions. This study aims to measure the contribution of health to economic growth using a panel of 91 countries over the period 1960-2005, and to compare the estimated impact of better health status on long-run per capita income under those two approaches, controlling for potential endogeneity. Our main results show the marginal effect of the change in health status in the long-term income lies between 2.6% in the growth accounting models and 8.3% in the “a la Barro” regressions. These results are consistent with the marginal effects we simulate and quantify using the health-growth point estimates found in earlier literature.

Key words: Health status, Economic growth, Long-run income, Growth account, “a la Barro” regressions.

JEL: I15, O47.

In recent years, the role played by health as a theoretical and empirical determinant of growth has been gaining prominence in economic analysis (Guillermo López-Casanovas, Berta Rivera, and Luis Currais 2005; Robert Barro 2013) because of the increasing interest in explaining the role of human capital and living conditions as well as health-enhancing public policies on long-run growth, especially in converging countries over the last 60 years or so (Daron Acemoglu and Simon Johnson 2007).

In this paper, we conducted an empirical study of the contribution of health to economic growth changes by comparing two methods frequently used in the literature, namely the growth accounting and the “a la Barro” regressions, using a common comprehensive panel of countries from 1960 to 2005 and a common database of the explanatory variables. In addition, we control for potential endogeneity between our health and economic growth variables running instrumental-variable regressions. The main questions we addressed are: What is the marginal impact of health on long-term *per capita* income estimated from those approaches and how can they be made interpretatively comparable? How do these results contrast with those that can be calculated on the basis of earlier literature regressions?

This paper is organized as follows: Section 1 shows the literature review on the relationship between health and growth; Section 2 presents a methodological description of the expected marginal effects of health on growth; Section 3 shows the application of the model estimated to be drawing on standard results in the above-mentioned theoretical and econometric literature; Section 4 displays the econometric results; and Section 5 concludes and provides some policy insights.

1. Literature Review

The theory of economic growth has incorporated health as a determinant of long-run economic growth rates in various ways, but more generally as a component of human capital (Isaac Ehrlich and Francis Lui 1991; Barro 1996; Sebnem Kalemly-Ozcan, Harl Ryder, and David Weil 2000; Peter Howitt 2005; Adriaan Van Zon and Joan Muysken 2005; Rosa Aísa and Fernando Pueyo 2006; Thomas Osag and Jayanta Sarkar 2008; Manash Gupta and Trishita Barman 2010; Ehrlich and Yong Yin 2013). Nearly all of these reviews consist of endogenous growth models, part of them assuming overlapping generations and endogeneizing health as variable and simulating the growth equilibrium paths using calibration methods. Another approach to dissecting the effect of health on long-run growth is found in Acemoglu and Johnson (2007) study, who based on a statistical approach, argue that there are epidemiologic transitions when there are significant and long-term health-enhancing events such as new vaccines or medical treatments to cure widespread diseases. Now, how does health drive higher and sustained long-run economic growth rates? Ehrlich and Lui (1991) associate health with the probability of young and mature adults' survival, assuming a higher probability, and therefore an improved health status, will cause a larger investment in human capital and eventually a higher growth rate.

Barro (1996) identifies two channels through which health affects economic growth. First, there is a direct positive effect of health on labor productivity. Second, similar to Ehrlich and Lui (1991), there is an indirect effect through the probability of survival of the adult population. Along the same lines, Kalemly-Ozcan, Ryder, and Weil (2000) state that a higher life expectancy at birth causes a rise in human capital investment and hence on long-run growth rates.

More recently, and on a related research avenue, Ehrlich and Yin (2013) used an overlapping generations endogenous growth model to find that investing in children health protection raises returns to education, and by way of this knowledge, capital and economy's growth rate. However, unlike in previous related models, Ehrlich and Yin (2013) endogeneize the probability of young and mature adults' survival that in turn explains life expectancy and population ageing. This study will find out whether the income spent in health can reach a stationary state in an endogenous growth equilibrium framework, and which economic variables may produce that result and its dynamics.

Finally, Barro (2013) proposed a new theoretical framework with an extension of the neoclassical model that considers not only the impact of health status on economic growth, but also the possible effects of economic growth on health status. The author analyzes this considering three different institutional frameworks: health as a private good, health as a subsidized private, and health as a public good. The model captures a direct effect of health on productivity and an indirect effect linked to the downward effect of health status on mortality and disease rate thus generating a reduction in the rate of depreciation of human capital (both education such as health). Through this channel, an increase in the health status increases the demand for human capital, generating a positive effect on productivity.

On the empirical level, there have been two main avenues of research to address the problem of how much and when health determines economic growth. First, growth accounting, that is, models that measure how each factor of production, which can include the health status, contributes to the rate of economic growth. Second, the method commonly known as "a la Barro" or conditional convergence, which regresses the real *per capita* GDP growth rate against a wide range of variables of interest, including health indicators and/or their interactions with other control variables. Additionally, we can mention a less popular third approach, proposed by Acemoglu and Johnson (2007), who argue that there has been a major epidemiology transition in the 1940s to 1950s producing a major improvement in the health status and only marginal changes later on, based on a statistical approach covering a broad sample of countries.

Within the growth accounting literature, Stephen Knowles and Dorian Owen (1995), David Bloom, David Canning, and Jaypee Sevilla (2001, 2004), Almas Heshmati (2001), Scott McDonald and Jeniffer Roberts (2002), Rivera and Currais (2004), Bloom and Canning (2005), Weil (2007) and Hingyi Li and Liang Huang (2009) find a robust effect and economically significant effect of health on economic growth using different sample of countries and time spans including in the panel dimension or single country cases (Rivera and Currais 2004 for Spain; Li and Huang 2009 for China; Bloom, Canning, and Sevilla 2001 and 2004 for China and India). Most of these papers are the adjusted or extended version of the seminal work by Gregory Mankiw, David Romer, and Weil (1992).

For instance, Knowles and Owen (1995), estimate that the health status measured as 80 years minus life expectancy at birth implying the shortfall in average life expectancy at birth yields a significant impact on *per capita* income over the period of 1960 to 1985. These results are confirmed by McDonald and Roberts (2002) for a broader sample, up to 1989. Bloom, Canning, and Sevilla (2001, 2004) for their part, measured the impact of health on productivity using a database for a large group of countries, with observations every 10 years for the period 1960-1990, find that health has a positive and statistically significant effect on economic growth with a marginal effect of 4%. Heshmati (2001) analyzed conditional convergence in OECD countries in GDP and health care expenditure for 1970-1992 considering data every five years and comes up with a positive and significant effect of health status, as measured by *per capita* health care expenditure, on economic growth with a marginal effect of about 17.5%. Moreover, Rivera and Currais (2004) analyzed the impact of public health expenditure on economic growth for 17 regions of Spain over the period 1973-1993 using data every four years and find a positive and significant effect of health on economic growth with an effect on the growth rate of 13%. Bloom and Canning

(2005) concluded that 1% increase in the adult survival rate increases income by 3% in the long-term, thus showing that health plays a significant role as a determinant of economic growth, too. Finally, Li and Huang (2009) used annual data at the Chinese provincial level for the period 1978-2005, and found a significant and positive effect of health and education on economic growth with a marginal average effect health of about 3.4%.

Regarding the "a la Barro" regressions, Barro (1998), Alok Bhargava et al. (2001), Kwabena Gyimah-Brempong and Mark Wilson (2004), P. Duraisamy and Ajay Mahal (2005), Dean Jamison, Lawrence Lau, and Jia Wang (2005), and Bloom et al. (2010) highlighted the importance of health as an economic factor explaining long-rung *per capita* income growth in a "steady state".

Barro (1998), for a sample of 100 countries for the period 1960-1990 using average data every 5 years, obtains that the marginal increase in life expectancy at birth increases the growth rate by 4%. In the same way, but with a slightly different approach, Bhargava et al. (2001), using data from 1965-1990, and dividing the sample in developed and developing countries, found that there is a positive and significant effect of health (measured by the adult survival rate) on income with a marginal effect of about 4%, controlling for endogeneity.

Gyimah-Brempong and Wilson (2004) investigated the effect of health stock on economic growth for Sub-Saharan Africa and OECD countries, using an extended version of the Solow model that incorporates both the stock and investment in health. The authors used panel data over 20 years for African countries and 35 years for OECD countries and estimates made by the method of dynamic panel. They present a system of equations but estimated only the growth rate to be the focus of the work. Control variables include the degree of openness, political stability indicators and education. As a result, the authors found that health has a positive and significant effect on economic growth, with a marginal effect of health on growth of 11.1% for the countries of Africa and of 2.18% in the case of OECD countries.

On the other hand, we also emphasized the contribution of Jamison, Lau, and Wang (2005) who performed an analysis for 53 countries over the period 1965-1990, and using data every 5 years. The authors estimated the model by the maximum likelihood method, using the algorithm HLM, and comparing the results with those obtained using least squares under the existence of fixed and random effects. In these estimates, they found that the results under the different methods are consistent, in the sense that there is a positive and significant effect of health on economic growth. One *per cent* increase in the adult survival rate leads to an increase of about 4% in growth rate. Also, Duraisamy and Mahal (2005), controlling for endogeneity problems, found a positive and significant effect of health on economic growth with a marginal effect of about 6%. Finally, Bloom et al. (2010) explained the process of growth in China and India using data from a broad group of countries for the period 1960-1990 and estimated a positive, significant and robust effect on the growth rate, with a marginal effect of about 10.6%. Tables A1 and A2 in the Appendix summarize the main results of both strands of the literature in comparative perspective.

2. Estimates from Growth Accounting and "a la Barro" Regressions, Methodological Aspects

In Tables A1 and A2, penultimate column in the Appendix shows how the results reported by the literature are quite consistent regardless of the methodology used. However, we must be careful here when interpreting the coefficients. In some models, the growth rate is used as endogenous variable, and the variation in health status as exogenous variable. The fact of using both variables of interest in differences enables us to interpret the coefficients obtained. As stated by Bloom, Canning, and Sevilla (2001, 2004), in this case, it may be useful to consider the long-term effects such that the coefficient obtained can be interpreted as the effect on the long-term income of a marginal change in health status. Additionally, in cases where the level of income is used as endogenous variable, the interest exogenous variable is also expressed in levels. As a consequence of that, the interpretation of coefficients is the same.

Another problem arises when the growth rate is used as endogenous variable, and the level of health status as an exogenous variable in the regression. Because the latter is expressed in levels and the former in first differences, it is not possible to compare the estimated coefficients as they are when both variables are calculated in levels. One way to overcome this problem is to compute the health effect on the long-term *per capita* income based on the marginal effects obtained those first difference-on-level regressions, as follows.

Assuming a constant growth rate, the income of country *i* in period *t* is given by:

$$Y_{it} = (1 + \gamma_0)^n Y_0 \,, \tag{1}$$

where Y_0 is the income level in the initial period, γ_0 the constant growth rate prior to the marginal change in health status, and n is the number of periods between the initial and the current period.

Thus, the effect on long-term income will be:

$$\Delta Y_{LP} = \frac{(1+\gamma_1)^n - (1+\gamma_0)^n}{(1+\gamma_0)^n}, \tag{2}$$

where γ_1 will be the new growth rate once the health status is modified.

To calculate the variation in long-term income in (2), we consider how this income varies over a time period n due to a change in growth rate γ in turn due to a change in health status, i.e. γ_1. Then, we apply Equation (2) to the results obtained in the regressions that consider level of health status as the exogenous variable. For the sake of simplicity, we assume the initial growth rate (γ_0) is the average growth rate in our sample or 2% *per annum*.

We report the variation in the growth rate attributed to a change in health status in the penultimate column of Tables A1 and A2 for a number of earlier regressions in the literature, where the number of periods (n) is the number of years covered by each study. Finally, we calculate the corresponding marginal effects of health on long-term income in the last column of Tables A1 and A2.

For instance, in Barro (1998), where the marginal effect on growth rate is 4%, we estimate γ_1 as follows:

$$\gamma_1 = \gamma_0(1+0.04) = 0.02*(1+0.04) = 0.0208.$$

From Equation (2), and considering the database time period used by the author, we obtain the average long-term income increase predicted in that paper:

$$\Delta Y_{LP} = \frac{(1+\gamma_1)^n - (1+\gamma_0)^n}{(1+\gamma_0)^n} = \frac{(1+0.0208)^{30} - (1+0.02)^{30}}{(1+0.02)^{30}} = 2.3798 \simeq 2.4\%.$$

3. Regression Models

After presenting the theoretical framework of each of the approaches, and considering the main contributions using each of the empirical strategy, we now proceed to introduce our econometric models. We will first present the growth accounting model, and then present our model of the "a la Barro" approach.

3.1 The Growth Accounting Model

As we have mentioned, growth accounting identifies how different factors contribute to the variation of production. The portion where the product range is not from changes in the factors is called TFP. The assumptions we make about the TFP will characterize the model that we will estimate.

The production function we used for estimation is based on the proposals by Bloom, Canning, and Sevilla (2001, 2004) and Bloom and Canning (2005). Thus, the production function that we assume is defined as:

$$Y = A\,K^{\alpha}\,(L\,e^{\phi_s S+\theta_h H})^{\beta}, \tag{3}$$

where A is the TFP, K the aggregate capital, L the number of workers, s the education level, and h the health status.

The growth accounting approaches proposed for conducting estimates work with both the level of aggregate output and the expression in *per capita* terms. However, the "a la Barro" approach is based on finding the determinants of the growth rate of *per capita* output. In this regard, in order to compare the two approaches, we find it useful to express the production function, as in Equation (3), in *per capita* terms. Dividing both sides by L we have:

$$Ypc = A\,K^{\alpha}\,L^{\beta-1}(e^{\phi_s S+\phi_h H})^{\beta}, \tag{4}$$

where Ypc represents *per capita* output.

Taking logarithms of the production function, we can express the product of country i at time t as:

$$ypc_{it} = a_{it} + \alpha\,k_{it} + (\beta-1)\,l_{it} + \beta\,(\phi_s S_{it} + \theta_h H_{it}), \tag{5}$$

where lowercase letter variables represent the logarithms of the uppercase letter variables of Equation (4).

Differentiating Equation (5), we have:

$$\Delta ypc_{it} = \Delta a_{it} + \alpha\, \Delta k_{it} + (\beta - 1)\, \Delta l_{it} + \beta\left(\phi_s\, \Delta S_{it} + \Theta_h \Delta H_{it}\right). \quad (6)$$

A key to the model to be estimated is the way we model the TFP. In this paper, we used the modeling strategy of the TFP raised by Bloom, Canning, and Sevilla (2001, 2004) and Bloom and Canning (2005). As mentioned, these authors propose to model TFP as a diffusion process between countries, but with possibilities of long-term differences in TFP after diffusion was complete. Formally, we have:

$$\Delta a_{it} = \lambda\left(a_{it}^{*} - a_{i,t-1}\right) + \varepsilon_{it}. \quad (7)$$

Equation (7) indicates that the variation of TFP of country i will be a proportion of its distance from its steady-state TFP a_{it}^{*} plus a random term. This TFP equilibrium depends, in turn, on the characteristics of the country and the world technology frontier:

$$a_{it}^{*} = \delta\, x_{it} + a_t, \quad (8)$$

where x_{it} represents a set of determinants of TFP in each country, while a_t represents temporary dummy variables that indicate the current state of the world TFP.

From Equation (5), established in t-1, we define TFP in the previous period as:

$$a_{it-1} = ypc_{i,t-1} - \alpha k_{i,t-1} - (\beta - 1) l_{i,t-1} - \beta(\phi_s \Delta s_{i,t-1} + \theta_h \Delta H_{i,t-1}). \quad (9)$$

Substituting Equations (8) and (9) in (7), and substituting the result in (6), we arrive at the final equation of growth accounting to be estimated, that is:

$$\Delta ypc_{i,t} = \alpha\, \Delta k_{it} + (\beta - 1)\Delta l_{it} + \beta(\phi_s\, \Delta S_{it} + \Theta_h \Delta H_{it}) + \lambda\big(a_t + \delta\, x_{it} + \alpha\, k_{it-1} + (\beta - 1)\, l_{i,t-1} + \beta(\phi_s\, S_{it-1} + \phi_h\, H_{it-1}) - ypc_{i,t-1}\big) + \varepsilon_{it}. \quad (10)$$

Equation (10) shows that the *per capita* output growth can be divided into three components. The first is the variation of inputs, that is, physical capital, labor and human capital composed of education and health. The second is a term that measures the degree to which the distance of TFP of each country over its steady-state value shrinks, λ being the speed of convergence. Finally, the term ε_{it} represents the random error.

In Subsection 3.2, we introduced the model to estimate, according to the "a la Barro" methodology, and the results are shown in Section 4.

3.2 The "a la Barro" Approach Estimation Model

As mentioned above, the "a la Barro" estimation model consists in the regression of the growth rate against a set of variables, among which we include indicators relating to health status. Typically, in the growth regressions, and particularly in the "a la Barro" regression in addition to the variable of interest (in our case the health indicator) the model specification includes other variables that are determinants of the endogenous variable, and the omission of which would bias the estimation. These variables are known as "control variables".

In the last two decades, there has been a proliferation in work regarding determinants of economic growth, so there are countless variables that can be used as control variables in our estimation. In our case, we have chosen a number of variables mainly based on the contributions of Barro (1998) and Carlos Dabús and Yanina Laumann (2006).

These variables are the level of education, the investment as a percentage of GDP, the public expenditure as percentage of GDP, trade openness, an indicator of the political system, an indicator of enforcement of property rights, the variation of level prices and the initial GDP for any country *i* at time *t*.

It is necessary to mention that in the cross-country analysis, current income coincides with initial income. In the case of panel data analysis, we may consider either the initial income level or the level of current income. In our case, following Duraisamy and Mahal (2005), we chose to use the initial income level.

Our endogenous variable, in order to make it comparable with the growth accounting model, is the variation of the logarithm of real GDP *per capita*. Thus, our model can be stated as follows:

$$\Delta ypc_{it} = \alpha + \beta_1 h_{it} + \beta_2 S_{it} + \beta_3 IGDP_{it} + \beta_4 PEGDP_{it} + \beta_5 OPEN_{it} + \beta_6 POLSYS_{it} + \beta_7 PROP_{it} + \beta_8 LPDESV_{it} + \beta_9 inigdp_{it} + \varepsilon_{it}, \quad (11)$$

where h represents the logarithm of the health status, s represents the logarithm of education, *IGDP* represents the share of investment in GDP, *PEGDP* represents public expenditure participation in GDP, *OPEN* is the indicator of the degree of trade openness of the economy, *POLSYS* is the indicator of the political system, *PROP* is the indicator of the compliance with property rights, *LPDESV* is the deviation of consumer prices index (included as proxy of economic instability) and $inigdp$ is the logarithm of initial GDP for each country.

According to the availability of data for all selected variables, we build a panel of 91 countries spanning data every 5 years for the period 1960-2005. Table A3 in the Appendix shows the source and the calculation of each variable while Table A4 indicates the countries considered for the estimation.

4. Results

In this section, we present the results of growth accounting and the "a la Barro" regressions. In all estimation results, tables in this paper show, in parentheses, the *p*-value of individual significance tests and are denoted with * and ** where the exogenous variables are significant at the 5% and 10%, respectively. We use Stata 11.

4.1 Results of Estimates of the Growth Accounting Model

In this section, we present the results of the estimation of the growth accounting model (Equation (10)). As mentioned earlier, we used temporary dummies to approximate the variation of TFP over time. As a determinant of TFP in each country, at each moment of time, we used three variables: openness, political system, and level of compliance with property rights.

Table 1 presents the summary of results of the estimation of the growth accounting equation. We can see the results of the regression using different panel estimators. Column 1 presents the results of the model assuming that its intercept term is the same for all countries, that is, the pool model. The second column supposes a constant intercept for each country (fixed effects model), while the third column presents the results of the random effects model, which assumes that each country has a different intercept, which is randomly distributed. Finally, in the last column we presented the Panel Standard Corrected Error (PSCE) model, which corrects the regression residuals for the presence of autocorrelation and heteroskedasticity.

Regardless of the estimation technique used, we observe that the health status, represented by life expectancy at birth, has a positive and significant effect on output growth. Regarding education, it is not significant in explaining changes in income while, as expected, changes in physical capital are significant in explaining changes in the product. In relation to labor, considering the fact that GDP variation is expressed in *per capita* terms, the coefficient of the variable is negative, unlike what would happen if we considered the variation of aggregate output. This is because when the labor force increases, it generates a positive effect on income but less than proportional, so that the *per capita* income will fall.

Table 1 Growth Accounting Model

Variable	Pool model	Fixed effects	Random effects	PCSE
Capital	0.062* (0.000)	0.144* (0.000)	0.061* (0.000)	0.052* (0.001)
Labor	-0.497* (0.000)	-0.328* (0.020)	-0.485* (0.000)	-0.432* (0.003)
Education	0.023 (0.122)	0.003 (0.848)	0.019 (0.200)	0.017 (0.278)
Health	0.009* (0.003)	0.003 (0.283)	0.009* (0.003)	0.008** (0.064)
Openness	0.0005* (0.000)	0.00007 (0.743)	0.0005* (0.000)	0.0004* (0.001)
Political system	0.0002 (0.780)	-0.003* (0.003)	0.00006 (0.945)	-0.00002 (0.983)
Property rights	-0.001 (0.802)	0.018 (0.084)	-0.0001 (0.983)	-0.00006 (0.994)
Constant	0.055 (0.450)	2.477 (0.000)	0.080 (0.308)	0.098 (0.292)
Observations	819			

Source: Own elaboration.

Which is the "best" estimator? In Table 2 we can see that both the individual significance tests of the fixed effects, and the Trevor S. Breusch and Adrian R. Pagan (1980) tests indicated the existence of fixed and random effects. Therefore, we can rule out the pool model. At the same time, the Jerry Hausman (1978) test showed that there are significant differences in the estimated coefficients under fixed and random effects estimators, so that in this case it is recommendable to use fixed effects estimation.

The modified Wald test proposed by William Greene (2000) indicates the presence of heteroskedasticity, while the Jeffrey Wooldridge (2002) test indicates the presence of serial correlation. However, the Wooldridge test has a drawback, which is related to the tendency to reject the null hypothesis even when this is true under the presence of random effects. The test of Anil Bera, Walter Sosa-Escudero, and Mann Yoon (2001) is valid even under the existence of random effects, and confirms the presence of serial correlation. As a consequence we perform the PCSE model correcting for the presence of heteroskedasticity and autocorrelation.

Thus, our appropriate model in this first approximation is given by the PCSE model, which includes the correction for heteroskedasticity and autocorrelation. This model shows the existence of a significant positive effect of health (represented by life expectancy at birth) on economic growth.

Table 2 Test in the Growth Accounting Model

Test	Null hypothesis	Statistic value	*p*-value	Result
Fixed effects significance	Fixed effects are not significant	11.86	0.000	Fixed effects are significant
Random effects existence (Breusch and Pagan test)	There are no random effects	7.50	0.006	There are random effects
Difference between fixed and random effects (Hausman test)	The estimated coefficients are similar	478.50	0.000	There are differences in the estimated coefficients
Panel data heteroskedasticity (Wald test)	Homoscedasticity	5215.68	0.000	Heteroskedasticity
Autocorrelation in panel data (Wooldridge test)	No autocorrelation	74.133	0.000	Serial correlation
Autocorrelation in panel data (Bera, Sosa-Escudero, and Yoon test)	No autocorrelation	16.70	0.000	Serial correlation

Source: Own elaboration.

As stated by Bloom and Canning (2005), the relationship between human capital and growth in the growth accounting models has historically encountered bicausality problems, in the sense that higher income can lead to better health indicators, as well as better education indicators. This situation can generate biased and inconsistent estimators. This problem can be solved, as the authors suggested, by employing an instrument, i.e. a variable that meets two requirements, first that it must be correlated with human capital variables, and second, that it must not be correlated with the error term.

We instrument the variables of health and education using their lagged values of changes in both variables. These variables satisfy the characteristics required to be an instrument: they are correlated with variations in the human capital variables, and are uncorrelated with the error term. Table 3 shows the results of the model instrumenting human capital variables.

For both estimations, we see that health has a positive and significant effect on the growth rate of *per capita* output. The Hausman test indicates that it is convenient to use the fixed effects model, as there are significant differences in the estimated coefficients under both methods. Thus, our final preferred model is instrumental variables, fixed effects model. It indicates that there is a positive and significant effect of health status on economic growth, with a marginal effect of 0.026. This implies that a marginal increase in life expectancy at birth by 1 year raises the level of long-term income by 2.6%.

Table 3 Model Using Instrumental Variables

Variable	Fixed effects	Random effects
Capital	0.116* (0.000)	0.166* (0.000)
Labor	-0.423* (0.014)	-0.675* (0.000)
Education	-0.006 (0.962)	0.052 (0.243)
Health	0.026* (0.008)	0.022* (0.000)
Openness	0.0005 (0.118)	0.0006* (0.000)
Political system	-0.004* (0.001)	0.001 (0.250)
Property rights	0.018 (0.112)	0.005 (0.459)
Constant	1.950 (0.008)	0.045 (0.559)
Observations	728	
Hausman test (difference between fixed and random effects)	Statistic value: 208.28 *p*-value: 0.000	

Source: Own elaboration.

Thus, the estimated growth accounting model shows that there is a positive and significant effect of health on economic growth, confirming the prediction of the economic theory and earlier papers.

4.2 Results of the "a la Barro" Approach

Table 4 shows the results of our "a la Barro" regression (Equation (11)). Overall, health has a positive and significant effect on economic growth. At the same time, investment, as a share of GDP, also has a positive and significant effect on economic growth regardless of the estimation techniques used. Public spending, as a share of GDP, and the variation in price levels (as proxy of economic instability), also have significant effects on growth, although in this case this is negative. Openness, institutional variables, and the logarithm of initial *per capita* income, are not significant in explaining economic growth.

Table 5 exhibits a battery of statistical tests where the Hausman test, shows it is more appropriate to adopt a fixed effects model against a random effects model. However, the Wald and Bera, Sosa-Escudero, and Yoon tests detect the presence of heteroscedasticity and serial correlation. Thus, we must remedy for these problems using the PCSE model, which is our final model. It tells us that health has a positive and significant effect on economic growth with a marginal value of 0.108. Applying Equation (2) to compute the effect of health on the level of long-term income, we get that a marginal increase in life expectancy at birth by 1 year raises the level of long-term income by 8.3%.

Table 4 The "a la Barro" Model

Variable	Pool model	Fixed effects	Random effects	PCSE
Health	0.129* (0.007)	-0.001 (0.989)	0.115* (0.020)	0.108** (0.069)
Education	-0.003 (0.260)	-0.015* (0.002)	-0.004 (0.182)	-0.003 (0.291)
Investment/GDP	0.004* (0.000)	0.006* (0.000)	0.005* (0.000)	0.005* (0.000)
Public expenditure/GDP	-0.003* (0.001)	-0.010* (0.000)	-0.003* (0.000)	-0.003* (0.002)
Openness	-0.0001 (0.275)	-0.0007* (0.003)	-0.0001 (0.204)	-0.0001 (0.097)
Political system	-0.00001 (0.984)	-0.001 (0.149)	-0.0001 (0.831)	-0.0003 (0.763)
Property rights	-0.001 (0.866)	0.027* (0.004)	0.0001 (0.987)	0.0007 (0.922)
Variation in prices level	-0.000001 (0.002)	-0.0000007 (0.130)	-0.000001* (0.03)	-0.000001** (0.054)
Initial GDP per capita	0.001 (0.825)	5.853 (0.785)	0.004 (0.492)	0.004 (0.591)
Constant	-0.503 (0.004)	-45.59 (0.786)	-0.467 (0.010)	-0.442 (0.041)
Observations	819			

Source: Own elaboration.

Table 5 Test in "a la Barro" Model

Test	Null hypothesis	Statistic value	*p*-value	Result
Fixed effects significance	Fixed effects are not significant	2.49	0.000	Fixed effects are significant
Random effects existence (Breusch and Pagan test)	There are no random effects	11.66	0.0006	There are random effects
Difference between fixed and random effects (Hausman test)	The estimated coefficients are similar	31.07	0.000	There are differences in the estimated coefficients
Panel data heteroskedasticity (Wald test)	Homoskedasticity	19098.83	0.000	Heteroskedasticity
Serial correlation in panel data (Wooldridge test)	No serial correlation	5.608	0.020	Serial correlation
Serial correlation in panel data (Bera, Sosa-Escudero, and Yoon test)	No serial correlation	35.22	0.000	Serial correlation

Source: Own elaboration.

4.3 Summary of Results

Throughout the different sections of this paper, we have developed two different empirical strategies to measure the relationship between health and economic growth: growth accounting and "a la Barro" regressions. Using both techniques, we found that health has a positive and significant effect on economic growth. In this section, we examined the robustness of the results. Our results will be robust if they don't change if we use alternative estimation techniques and/or different variables concerning education and health.

In relation to the estimation techniques, in the case of the growth accounting model, we used different estimation techniques including instrumental variables, in addition to corrections for serial correlation and heteroskedasticity. In the case of the "a la Barro" regression model, we also used different estimation techniques and introduced heteroskedasticity and serial correlation corrections along with the PCSE estimator. In all cases, the results are consistent with respect to the significant effect of health on economic growth.

Another issue that may affect the validity of our estimates is the time series properties of our panel data (Felipa de Mello-Sampayo and Sofia de Sousa-Vale 2014), in particular if the variables used in estimating are expressed in levels. Table A5 in the Appendix shows the results of the Levin-Lin-Chu test (Andrew Levin, Chien-Fu Lin, and Chia-Sang James Chu 2002), the most used in the literature to detect the existence of unit roots in panel data. As we reject the null hypothesis the series are stationary, avoiding the existence of spurious regressions.

With regard to the variables used, Tables A6 and A7 in the Appendix display the regression output considering alternative physical capital, health and education variables. The latter two are the infant mortality rate, and the average years of secondary education and they turn out to be robust.

In conclusion, regardless of the methodologies (growth accounting and "a la Barro" regressions) of the preferred estimation techniques, and of the physical and human capital variables used, we found that there is a positive, significant and robust effect of health on economic growth. Table 6 summarizes our main results and puts it in a comparative perspective highlighting the long-run effect of health on income produced by either increases the life expectancy at birth increases by 1 year or decreases in the infant mortality rate by 1%.

Table 6 Summary and Comparison of Results-Robust Estimators

Model	Estimation technique	Marginal effect of health on long-term income-life expectancy at birth	Marginal effect of health on long-term income-infant mortality rate
Growth accounting	Instrumental variables, fixed effects	2.6%	0.1%
"a la Barro"	PCSE, fixed effects	8.3%	1.8%

Source: Own elaboration.

5. Conclusions

In this paper we analyzed and quantified the empirical effect of the health status in long-run economic growth using a database including 91 countries over the period 1960-2005. We measured the health status using life expectancy at birth and for the sake of robustness another variable which is the infant mortality rate, defined as the number of deaths of infants under one year old per 1,000 live births.

Our main contribution was twofold. First, we applied two different estimation techniques – growth accounting and conditional convergence panel regressions – to a homogeneous dataset in order to estimate the marginal impact of health in long-run *per capita* income: How much additional *per capita* income does a 1% improvement in the population health status cause? Second, we simulated and quantified the size of that marginal impact in a selection of earlier papers in the literature, as detailed in Table A1.

Irrespective of the estimation technique adopted and correcting for potential endogeneity we found a robust effect of health on long-run economic growth, controlling for other popular determinants in the literature such as education, institutions, trade openness, property rights, inflation and country income at the sample initial year (1960). A marginal change in the health status, proxied by life expectancy at birth (10.8% in our preferred estimated equation), increases long-run *per capita* income by 8.3% in the case of "a la Barro" regressions and by 2.6% when the growth accounting technique is employed. These marginal effects are in line with our simulations on earlier contributions to the literature (Tables A1 and A2).

These findings call for more effective, preventive and growth-enhancing health public policies, in particular in developing countries where life expectancy at birth is lower and infant mortality rates higher than in developed countries, conducive to improving health conditions. Healthier populations are more creative, more able to invest in education, more productive, more adaptive to changes in the socio-economic environment and therefore contribute to raising productivity and long-run income.

We suspect the marginal effect of extending life expectancy at birth or reducing infant mortality in those poorer countries where the former is around 50 years and the latter between 70 and 100 infants deaths per 1000 live births under 1 year old may be stronger than in those countries enjoying longer life expectancy or survival rates and evidencing less infants dead under one year-old. Further research may investigate this non-linear effect of health on economic growth.

Another possible extension of our paper may consist of conducting a study splitting our sample by group of countries according their level of development to investigate the differential long-term effect of health and education on income. This would in a way allow us to identify differential public policies aimed to improve the health status and cause higher *per capita* income.

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Appendix

Table A1 Comparative Results of the Effect of Health on Growth - Growth Accounting Approach

Authors	Health status variable	Growth variable	Period	Countries	Marginal effect of health on growth	Marginal effect of health in long-term income[1]
Knowles and Owen (1995)	80 minus life expectancy at birth	Per worker GDP growth rate	1960-1985	Broad group of countries	-	Significant and robust[2]
Bloom, Canning, and Sevilla (2001, 2004)	Change in life expectancy at birth	Per worker GDP growth rate	1960-1990	Broad group of countries	-	4.0%
Heshmati (2001)	Health care expenditure	Per worker GDP growth rate	1970-1992	OECD countries	17.5%	7.83%
McDonald and Roberts (2002)	80 minus life expectancy at birth	Per worker GDP	1965-1989	Broad group of countries	-	Significant and robust[3]
Rivera and Currais (2004)	Total public health expenditure	GDP growth rate per inhabitant in working age	1973-1993	17 Spanish regions	13%	5.18%
Bloom and Canning (2005)	Change in adult survival rate	Per capita GDP growth rate	1960-2005	Broad group of countries	-	3.1%

Source: Own elaboration.

Table A2 Comparative Results of the Effect of Health on Growth - "a la Barro" Regressions Approach

Authors	Health status variable	Growth variable	Period	Countries	Marginal effect of health on growth	Marginal effect of health in long-term income
Barro (1998)	Life expectancy at birth	Per capita GDP growth rate	1960-1990	Broad group of countries (100 countries)	4%	2.4%
Bhargava et al. (2001)	Adult survival rate lagged one period	Per capita GDP growth rate	1965-1990	Low-income broad group of countries	19%	9.7%
Gyimah-Brempong and Wilson (2004)	Adult survival rate lagged one period	Per capita GDP Growth rate	10 years (Africa) and 35 years (OECD)	Sub-Saharan Africa and OECD countries	11.1% (Africa) and 2.18% (OECD)	4.37% (Africa) and 1.5% (OECD)
Duraisamy and Mahal (2005)	Initial life expectancy at birth	Per capita GDP growth rate	1980-1998	Indian states	6%	2.1%
Jamison, Lau, and Wang (2005)	Male adult survival rate	Per capita GDP growth rate	1965-1990	Broad group of countries	3.5%	1.9%
Bloom et al. (2010)	Life expectancy at birth	Per capita GDP growth rate	1960-2000	Broad group of countries	10.6%	4.8%

Source: Own elaboration.

[1] For an explanation about the calculation of the coefficients and their interpretation see Section 2.
[2] The fact of employing a different variable from the one usually employed in the literature does not allow a comparison of the values with the estimated parameters in the rest of the literature.
[3] In this case, the same explanation introduced in Footnote 2 is applied.

Table A3 Definition and Source of the Variables

Symbol	Variable	Definition /calculus	Source
Y	Per capita GDP	Expressed in purchasing power parity (PPP) adjusted by the Laspeyres index, and expressed in constant dollars of 2005.	The Center for International Data (2013), Penn World Table (PWT)[4]
K	Capital	We use the perpetual inventory method for the calculation. Capital in 1960 (i.e., the initial period) is defined as the ratio of investment/GDP multiplied by GDP in the initial period, and divided by 0.07 (the depreciation rate which we assume). Then in the following periods, capital will be the current capital minus depreciation plus investment.	PWT
L	Labor force	We assume that the ratio between the employed population and the active population remains constant over time. Thus, we use the total population as a proxy of the working population.	PWT
S	Education	Two education variables. The main variable we use is the average total years of education and the alternative variable is the average total years of secondary education.	Barro and John Lee (1994, 2010)
H	Health	Two health variables. The main variable we use is the life expectancy at birth and the alternative variable is the infant mortality rate (number of deaths of children under one year of age, per thousand live births registered).	United Nations[5]
IGDP	Investment/GDP	Proportion of investment in relation to GDP.	PWT
PEGDP	Public expenditure/GDP	Proportion of public expenditure in relation to GDP.	PWT
OPEN	Openness	Coefficient of openness (exports + imports in relation to GDP).	PWT
POLSYS	Political system	Difference between a democracy index that includes various institutional aspects, and an autocracy index that also takes into account various institutional aspects.	Keith Jaggers, Ted Gurr, and Ted Marshall (2005)
PROP	Respect for property rights	Indicator of the degree of respect for property rights.	Juan Ginarte and Walter Park (1997) and Park (2008)
LPDESV	Variability of the level of prices	Standard deviation of the level of consumer price index.	PWT

Source: Own elaboration.

Table A4 List of Countries, Classified According to Income Level (2005)

Low and middle-low income	High and middle-high income
Algeria	Argentina
Bangladesh	Australia
Benin	Austria
Bolivia	Belgium
Brazil	Botswana
Burundi	Canada
Cameroon	Chile
Central African Republic	Cyprus
China	Costa Rica
Colombia	Denmark
Dominican Republic	Finland
Ecuador	France
Egypt	Gabon
El Salvador	Greece
Fiji	Iceland
Ghana	Ireland
Guatemala	Israel
Haiti	Italy

[4] **The Center for International Data.** 2013. Penn World Table. http://cid.econ.ucdavis.edu/pwt.html (accessed December 13, 2013).
[5] **United Nations.** 2013. Social Indicators. https://unstats.un.org/unsd/demographic/products/socind/ (accessed December 13, 2013).

Honduras	Japan
India	Luxembourg
Indonesia	Malaysia
Iran	Mauritius
Ivory Coast	Mexico
Jamaica	Netherlands
Jordan	New Zealand
Kenya	Norway
Malawi	Panama
Mali	Portugal
Morocco	Republic of Korea
Mauritania	Romania
Mozambique	Singapore
Nepal	Spain
Nicaragua	Sweden
Niger	Switzerland
Pakistan	South Africa
Papua New Guinea	Trinidad and Tobago
Paraguay	Turkey
Peru	United Kingdom
Philippines	United States
Republic of Congo	Uruguay
Rwanda	Venezuela
Senegal	
Syria	
Sri Lanka	
Thailand	
Tanzania	
Togo	
Uganda	
Zambia	
Zimbabwe	

Source: Own elaboration according to World Bank database (2013)[6].

Table A5 Levin-Lin-Chu Unit Root Test - Significant Variables

Variable	Without trend		With trend		Result
	p-value	Statistic value	*p*-value	Statistic value	
S (average total years of education)	-17.459	0.000	-20.346	0.000	Series are stationary
H (life expectancy at birth)	-8.504	0.000	-32.471	0.000	Series are stationary
IGDP	-22.954	0.000	-19.660	0.000	Series are stationary
PEGDP	-19.036	0.000	-24.791	0.000	Series are stationary
OPEN	1.832	0.966	-10.642	0.000	Series are stationary
POLSYS	-4.945	0.000	-12.206	0.000	Series are stationary
PROP	1.432	0.924	-8.619	0.000	Series are trend stationary
LPDESV	-38.909	0.000	-33.892	0.000	Series are stationary

Source: Own elaboration.

Table A6 Robustness in the Growth Accounting Model - Instrumented Model, Fixed Effects

Variable	Fixed effects	Capital sensitivity	Education sensitivity	Health sensitivity
Capital	0.116* (0.000)	0.123* (0.000)	0.116* (0.000)	0.125* (0.000)
Labor	-0.423* (0.014)	-0.425* (0.014)	-0.429* (0.012)	-0.190 (0.224)
Education	-0.006 (0.962)	-0.004 (0.974)	0.107 (0.301)	-0.092 (0.489)

6 **World Bank.** 2013. World Bank Open Data. http://data.worldbank.org/ (accessed December 13, 2013).

Health	0.026* (0.008)	0.026* (0.009)	0.025* (0.012)	0.001[7] (0.591)
Openness	0.0005 (0.118)	0.0005 (0.121)	0.0005 (0.118)	0.0002 (0.400)
Political system	-0.003* (0.001)	-0.004* (0.001)	-0.004* (0.001)	-0.001* (0.005)
Property rights	0.018 (0.112)	0.018 (0.110)	0.019** (0.081)	0.014 (0.192)
Constant	1.950 (0.008)	1.940 (0.008)	2.164 (0.001)	2.782 (0.559)
Observations		728		

Source: Own elaboration.

Table A7 Robustness in "a la Barro" Model - PCSE Estimation Corrected by the Presence of Autocorrelation and Heteroskedasticity

Variable	PCSE	Education sensitivity	Health sensitivity
Health	0.102** (0.088)	0.119* (0.03)	0.020** (0.086)
Education	-0.003 (0.288)	-0.017* (0.015)	-0.003 (0.275)
Investment/GDP	0.005* (0.000)	0.005* (0.000)	0.005* (0.000)
Public expenditure/GDP	-0.004* (0.000)	-0.004* (0.001)	-0.004* (0.000)
Openness	-0.0001 (0.110)	-0.0001 (0.126)	-0.0002** (0.069)
Political system	-0.0003 (0.750)	-0.0002 (0.849)	-0.0004 (0.691)
Property rights	0.001 (0.842)	0.007 (0.408)	-0.002 (0.743)
Variation in prices level	0.005 (0.541)	0.006 (0.439)	0.005 (0.505)
Initial GDP per capita	-0.423 (0.053)	-0.507 (0.011)	0.086 (0.433)
Observations		819	

Source: Own elaboration.

[7] Considering that the infant mortality rate varies in the opposite direction to the life expectancy at birth, we express the estimated coefficient with the opposite sign in order to facilitate the comparison of results.

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