CENTRE D'ETUDES
ET DE RECHERCHES
SUR LE DEVELOPPEMENT
INTERNATIONAL

SERIE ETUDES ET DOCUMENTS DU CERDI

Health capital depreciation effects on development: theory and measurement

Martine AUDIBERT, Pascale COMBES MOTEL,

Alassane DRABO

Etudes et Documents n° 10

June 2013

CERDI
65 BD. F. MITTERRAND
63000 CLERMONT FERRAND - FRANCE
TÉL. 04 73 17 74 00
FAX 04 73 17 74 28
www.cerdi.org

The authors

Martine AUDIBERT
CNRS Researcher, Clermont Université, Université d'Auvergne, CNRS, UMR 6587, Centre d'Etudes et de Recherches sur le Développement International (CERDI), F-63009 Clermont-Ferrand, France
Email: m.audibert@u-clermont1.fr

Pascale COMBES MOTEL
Professor, Clermont Université, Université d'Auvergne, CNRS, UMR 6587, Centre d'Etudes et de Recherches sur le Développement International (CERDI), F-63009 Clermont-Ferrand, France
Email: p.motel_combes@u-clermont1.fr

Alassane DRABO
Clermont Université, Université d'Auvergne, CNRS, UMR 6587, Centre d'Etudes et de Recherches sur le Développement International (CERDI), F-63009 Clermont-Ferrand, France
Email: alassanedrabo@hotmail.com

Corresponding author: m.audibert@u-clermont1.fr

La série des *Etudes et Documents* du CERDI est consultable sur le site : http://www.cerdi.org/ed

Directeur de la publication : Patrick Plane
Directeur de la rédaction : Catherine Araujo Bonjean
Responsable d'édition : Annie Cohade
ISSN : 2114 - 7957

Abstract

Relationships between health and economic prosperity or economic growth are difficult to assess. The direction of the causality is often questioned and the subject of a vigorous debate. For some authors, diseases or poor health had contributed to poor growth performances especially in low-income countries. For other authors, the effect of health on growth is relatively small, even if one considers that human capital accumulation needs also health investments. It is argued in this paper that commonly used health indicators in macroeconomic studies (e. g. life expectancy, infant mortality or prevalence rates for specific diseases such as malaria or HIV/AIDS) imperfectly represent the global health status of population. Health is rather a complex notion and includes several dimensions which concern fatal (deaths) and non-fatal issues (prevalence and severity of cases) of illness. The reported effects of health on economic growth vary accordingly with health indicators and countries included in existing analyses. The purpose of the paper is to assess the effect of health on growth. The augmented Solow model is modified so as to account for human capital depreciation. It is argued that the latter is measured by the so-called disability-adjusted life year (DALY) that was proposed by the World Bank and the WHO in 1993. Income regressions are run on 129 countries over the 2000-2004's period, where the potential endogeneity of the health indicator is dealt for. The negative effect of poor health on development is not rejected thus reinforcing the importance of achieving MDGs.

Keywords

Global Burden of Disease, DALYs, augmented Solow model, cross-country analysis

JEL Codes

E22, E24, I19, I18, O47

Acknowledgments

We have benefited from comments of participants of the INFER Annual Conference hosted by the University of Orléans, France, May 2013. Usual disclaimers apply.

1 Introduction

Sen's works on human capabilities and the emergence of AIDS have renewed the interest given to the link between health, welfare, and prosperity. At a microeconomic level, several studies found that poor health has negative effects on economic prosperity and living conditions.[1] At a macroeconomic level, the so-called Sachs Report (Commission on Macroeconomics and Health 2001, p.21-39) and that on Health and Growth (Spence & Lewis 2009) state that diseases raise barriers to economic growth and that countries have to invest in health. Several authors have considered that communicable diseases, among others, had contributed to slow down economic development of low income countries. The latter proposition is still hotly debated as some methodological issues are not satisfactorily addressed (see the comprehensive and critical review of (Packard 2009). Acemoglu & Johnson (2006), using international data from the epidemiological transition period, find that an increase in life expectancy generated by a decrease in mortality rates had a small positive effect which grows over the post epidemiological transition. The latter was not enough important to compensate for increases in population. Consequently, life expectancy increases do not lead to a significant increase in per capita economic growth. This study makes reminiscent previous results with regard to malaria eradication (Barlow 1967) and to economic effects of AIDS as well (Over 1992).

There are at least three reasons that could explain difficulties to assess health impacts at the macroeconomic level. First, links between health and development or growth are complex and health effect could also be channelled into education levels, the environment, lack of sound economic policies and cultural behaviours as well. When, due to missing adequate indicators, these channels are not accounted for in the model, the estimated health effect will be biased or hidden by unobserved heterogeneity (Jack & Lewis 2009; Strauss & Thomas 2007; Thomas 2009). Second, health is subject to measurement errors either due to poor measurement facilities such as lack of good equipment and materials for setting appropriate diagnosis, low human resource training, deficient registration, measurement variability over the day (e.g. blood pressure) or the year (e. g. malaria indicators). Third, health status is a rather complex notion that includes several dimensions. Existing health indicators address one specific dimension of health and therefore using one or the other is not equivalent.

Partly due to these difficulties of measuring multiple dimensions of health and therefore global health, macroeconomic effects of health have been more still studied using health indicators such as life expectancy at birth, infant mortality rates, or nutritional status measures. Existing results can be questioned by addressing specifically the choice of health indicators that either measure health outcomes or the effects of specific diseases. We argue in this paper that a global health status indicator such as DALY can be a relevant indicator in assessing the effect of health on development. Moreover, using DALY in macro studies of the effect status on development may be supported by growth theory

[1] The literature on links between health and economic well-being or prosperity at microeconomic level is abundant. See (Strauss & Thomas 2007) for an exhaustive literature review.

The rest of the paper is organized as follows. Section 2 is devoted to reviews the empirical literature on the link between health outcomes and economic performances. The empirical setting and the results are presented in section 3. Section 4 concludes.

2 Relationship between health and development

If at a micro-level, empirical studies found that poor health has an economic effect through several channels e.g. (Audibert 2010), this effect is less obvious at a macro-level. The Preston's curb establishes an upward shifting relationship between mortality and national income per capita between 1900 and 1960 (Preston 1975; Bloom & Canning 2007). This correlation however gives no pieces information on the sense of the causality. Moreover, it can be seen from existing studies that the effect of health indicators on development is not clearly established. We focus here on studies putting forward health outcomes and specific diseases.[2]

2.1.1 Health outcomes

Health outcomes are related to the health status of an individual or a given population. Indicators of health outcomes at the macroeconomic level are life expectancy at birth and infant mortality rates (Strauss & Thomas 2007). Those indicators are considered reflecting the general health status of populations and supposed to be positively associated with economic growth. Results found with health outcomes are less clear-cut than those established with health inputs (see footnote 3). For instance, (Bloom et al. 2004) show that life expectancy has a positive, sizable, and statistically significant effect on aggregate output even when experience of the workforce is controlled for. Using cross-national and sub-national data, (Lorentzen et al. 2008) argue that high adult mortality rates reduce economic growth by shortening time horizons since they favour riskier behaviours, higher fertility rates, and lower investments in physical capital. (Sala-i-Martin et al. 2004) departing from numerous potential explanatory variables in cross-country growth regressions, implement a model selection criterion. The set of explanatory variables which emerges from the analysis includes various human capital variables such as life expectancy at birth. (Acemoglu & Johnson 2006) are however less conclusive with results indicating that increases in life expectancy have no significant effect on output per capita.[3] While (Bhargava et al. 2001) showed that effects of Adult Survival Rates on economic growth rates are significant for low income countries and negligible for high income countries.

It is true that life expectancy is higher and infant mortality lower in richer countries than in poorer countries. The correlation between life expectancy at birth and GDP per capita is not systematic as life expectancy is lower (or higher) than expected given GDP per capita in countries like Southern Africa, Gabon or Indonesia (for examples, see (Strauss & Thomas 2007)). Per capita incomes have diverged over time while life expectancy and infant mortality have converged (Deaton 2006; Jack & Lewis 2009). Life expectancy and infant mortality appear to be inadequate indicators of the population's

[2] Several studies find a significant effect of better nutrition i.e. health inputs on health and development. Results are convergent either from a microeconomic point of view (Strauss 1986; Behrman & Rosenzweig 2004), or a macro point of view (Weil 2007) as well as from a theoretical point of view (Fogel 1994).
[3] Even though (Bloom et al. 2009) disagree with their results, Acemoglu and Johnson still maintained their position in their 2009 paper (Acemoglu & Johnson 2009).

health in high income countries and for several upper middle income countries where life expectancy is high and infant mortality is very low or low. For low and lower middle income countries, those indicators are more adequate due to their poor levels. For that reason, studying the relationships between health and economic development or growth in cross-country studies using infant mortality or life expectancy at birth is not really appropriate and allows to calling for more elaborate data on health indicators (Bhargava et al. 2001).

2.1.2 Specific diseases

As underlined by (Jack & Lewis 2009), the effect of a population's health status on national income varies accordingly with the health indicator used. In countries where AIDS prevalence is high, life expectancy is determined by AIDS mortality. One may thus wonder whether specific diseases or epidemics have an effect. For instance, the emergence of HIV/AIDS and its high prevalence (more than 15%) in several southern African countries (Botswana, Lesotho, Namibia, South Africa, Swaziland, Zambia, and Zimbabwe, UNAIDS), have motivated studies focusing on their economic effects. (McDonald & Roberts 2006) find that the elasticity of economic growth to HIV/AIDS prevalence in Africa is -0.59. But, little evidence of a correlation between HIV/AIDS and GDP per capita was found (Strauss & Thomas 2007).

With the renewed interest for malaria, several authors (e.g. J. D. Sachs & Malaney 2002) have investigated its effect on African countries growth. (Carstensen & Gundlach 2006) find that malaria prevalence causes quantitatively important negative effects on income even after controlling for institutional quality. (Cole & Neumayer 2006) also find a negative impact of malaria on growth, but through the total factor productivity. Wiping out malaria from sub-Saharan Africa could increase that continent's per capita growth rate by as much as 2.6% a year (Gallup & J. D. Sachs 2001).

But, those indicators neither take into account other dimensions of health, such as invalidity, handicap or social consequences, nor multidimensional characteristics of health. Health status is multi-dimensional and it may be argued that a global health status indicator is relevant in studies devoted to the effect of health on development

2.1.3 A global health indicator

The main thesis of this paper is that macroeconomic effects of the global health status are accurately caught by the Disability-Adjusted Life Year (DALY) per capita calculated by the World Health Organization (WHO). This indicator is proposed by the World Bank and WHO since 1993. Its represents "a one lost year of healthy life and extends the concept of potential years of life lost due to premature death to include equivalent years of healthy life lost by virtue of being in states of poor health or disability […].The sum of these DALYs across the population represents the burden of disease and can be thought of as a measurement of the gap between current health status and an ideal health situation where the entire population lives to an advanced age, free of disease and disability" (World Health Organization 2008).[4] "DALYs were calculated initially for

[4] The DALYs for each health condition are the sum of the years of life lost (YLL) due to premature mortality and the years lost due to disability (YLD) for incident cases of the health condition. YLL are calculated from the number of deaths at each age multiplied by a global standard life expectancy for each age. YLD is the number of incident cases in a particular period × average duration of the disease × weight

about one hundred causes and diseases and over the whole world and were not updated since 2000. From 2000 to 2005 however, DALYs are also available on a regional basis. DALYs are commonly used in cost-effectiveness analyses but, to the best of our knowledge, have never been used in macroeconomic analyses since DALYs at the country level are only available for 2002 and 2004.

Any indicator, including DALYs, is amenable to criticism with a particular emphasis on weighting (namely age and disease severity) and discounting (Anand & Hanson 1997). A large revision has been however implemented, mainly by the Institute of Health Metrics, which is in charge DALYs calculations updates and improvements (Lopez et al. 2006; Murray et al. 2012). This does not prevent however this indicator from being a serious candidate for representing population global health status, deriving from illness consequences which are taken into consideration in a single indicator.

3 Empirical framework

Though choosing DALY may be justified by its ability to concentrate different aspects of health status, it should be firmly rooted in a theoretical framework. This paper builds on the idea of health being a capital. In other words, people are endowed an initial stock which can depreciate through time with age but which can also be the subject of investments (Grossman 1972).[5] We argue here that DALY can be considered as a measure of human capital erosion. Our empirical framework thus borrows its theoretical foundations in augmented Solow growth models. We derive first the empirical specification (section 3.1). Then we put a particular emphasis on endogeneity issues (section 3.2)

3.1 Theoretical background: the augmented Solow model

3.1.1 Model and main assumption

Our theoretical framework derives from a light modification of the augmented Solow model and using the same notations as provided in (Mankiw et al. 1992).

The aggregate production function is defined as:

$$Y(t) = K(t)^{\alpha} H(t)^{\beta} \big(A(t)L(t)\big)^{1-\alpha-\beta} \text{ with } \alpha > 0, \beta > 0 \text{ and } \alpha + \beta < 1 \qquad (1)$$

Where Y stands for GDP, K is the stock of material capital, H is the stock of human capital, L is labour and A the stock of knowledge. L and A grow at exogenous rates n and x respectively. $\hat{y}$, $\hat{k}$ and $\hat{h}$ are measured per effective units of labour:

$$\hat{y}(t) = \hat{k}(t)^{\alpha} \hat{h}(t)^{\beta} \text{ and } \hat{k}(t) \equiv K(t)/A(t)L(t)\, ;\, \hat{y}(t) \equiv Y(t)/A(t)L(t) \text{ and } \hat{h}(t) \equiv H(t)/A(t)L(t)$$

Empirical investigations within the augmented Solow model framework have put emphasis on education in human capital. Later, the health component of human capital

factor. The weight factor reflects the severity of the disease on a scale from 0 (perfect health) to 1 (death). For additional information, see WHO, http://www.who.int/healthinfo/global_burden_disease/metrics_daly/en/.

[5] see (Mwabu 2007) for a literature review on the concept of health capital.

was also taken into account (e.g. McDonald & Roberts 2002). The authors rightly gave importance to the multiple components of human capital and thus raised the problem of measuring and econometrically assessing the effect of human capital on growth. From our point of view, the question of human capital depreciation also deserves attention. Indeed, in augmented Solow models *à la* MRW one assumes that the dynamics of material and human capital have the same general characteristics *i.e.* all sorts of capital depreciate at the same rates. We argue in this paper that there are no theoretical reasons to do so. (Grossman 1972) for instance showed that the demand for health depends on human capital depreciation. Moreover, one may argue that human capital depreciates at different rates between countries for several reasons. First, health status channels environmental degradation effects on growth. Local pollution may dramatically impact health in developing countries. Moreover, malaria still remains an important health issue in developing countries. Several studies have indeed shown that the detrimental effects of malaria on growth (Barlow 1967). Others have evidenced for instance that malaria prevalence affect educational achievements and thus productivity. Health driven human capital depreciation may be the result of poor environmental policies (Thuilliez et al. 2010; J. D. Sachs & Malaney 2002). Second, genuine savings or inclusive wealth measures put emphasis on human capital investments (e.g. Hamilton & Clemens 1999). It may thus be interesting to investigate whether these investments are not undermined by drastic health driven human capital erosion.

We thus assume the following capital dynamics:

$$\dot{\hat{k}} = s_k\ \hat{y}\ - (\varepsilon_k + n + x)\hat{k}$$

And,

$$\dot{\hat{h}} = s_h\ \hat{y}\ - (\varepsilon_h + n + x)\hat{h}$$

s_k and s_h denote investment rates in material and human capital respectively. ε_k is the rate of decay on material capital units; ε_h is the rate of decay on human capital. Under this assumption, it can be established that the economy converges towards a steady-state where the value of output $\hat{y}^*$ measured in effective labour units:

$$\ln \hat{y}^* = \frac{\alpha}{1-\alpha-\beta}\ln s_k + \frac{\beta}{1-\alpha-\beta}\ln s_h - \frac{\alpha}{1-\alpha-\beta}\ln(\varepsilon_k + n + x) - \frac{\beta}{1-\alpha-\beta}\ln(\varepsilon_h + n + x)$$

This equation shows that the erosion affecting human capital has a different effect on output than erosion affecting material capital. This erosion may be of greater magnitude since it is determined by β which is usually assumed to be greater than α. Not taking human capital erosion ε_h into account may thus generate an omitted variable bias. The former equation with respect to income per capita is the following:

$$\ln y(t) = \mathrm{A}(0) + xt + \frac{\alpha}{1-\alpha-\beta}\ln s_k + \frac{\beta}{1-\alpha-\beta}\ln s_h - \frac{\alpha}{1-\alpha-\beta}\ln(\varepsilon_k + n + x) - \frac{\beta}{1-\alpha-\beta}\ln(\varepsilon_h + n + x) \quad (5)$$

With y, k and h are measured per units of labour. As in (Mankiw et al. 1992) $A(0)$ and x are supposed to be the same for all countries.

3.1.2 Empirical specification

As explained before, it is argued here that DALYs provides a measurement of human capital erosion, which is health capital depreciation. Since, as explained below, DALYs are only available on the 2000 to 2004 period, our empirical model is thus:

$$\ln y_i = B + \frac{\alpha}{1-\alpha-\beta}\ln s_{k_i} + \frac{\beta}{1-\alpha-\beta}\ln s_{h_i} - \frac{\alpha}{1-\alpha-\beta}\ln(\varepsilon_k + n_i + x) - \frac{\beta}{1-\alpha-\beta}\ln\left(\varepsilon_{h_i} + n_i + x\right) + v_i$$

Where i denotes a country; v_i is the error term and B is a term where all constant terms collapse. In order to as general as possible, we define the function g. This function is a transformation of DALYs allowing having a proper proxy for ε_h:

$$\ln y_i = \mathrm{A}(0) + xt + \frac{\alpha}{1-\alpha-\beta}\ln s_{k_i} + \frac{\beta}{1-\alpha-\beta}\ln s_{h_i} - \frac{\alpha}{1-\alpha-\beta}\ln(n_i + 0.05) - \frac{\beta}{1-\alpha-\beta}\ln(g(DALY_i) + n_i + 0.02) + v_i$$

with $\varepsilon_k + x = 0.05$ and $x = 0.02$

The latter equation may be simplified after linearizing logs around 1:

$$\ln y_i = B + \frac{\alpha}{1-\alpha-\beta}\ln s_{k_i} + \frac{\beta}{1-\alpha-\beta}\ln s_{h_i} - \frac{\alpha+\beta}{1-\alpha-\beta}n_i - \frac{\beta}{1-\alpha-\beta}g(DALY_i) + v_i$$

3.2 Empirical analysis

3.2.1 Data and variables

3.2.1.1 DALY measurement

DALYs are available on the 2000-2004' period for many WHO member states (see countries' list in Table 4). DALYs at the country level are not available on the whole period. DALYs are available for each WHO country (*country DALY*) in 2002 and 2004; and from 2000 to 2002 and 2004 at a regional level according to the WHO's classification (*regional DALY*). In order to have comparable periods, we have several opportunities for DALYs measurement.

First, we can use country DALYs in 2002 or in 2004 (*DALY 2002*; *DALY 2004*) assuming that the figures are representative of health status over the period under study. Second, we can also use the average country DALY value, calculated with the 2002 and 2004 data (*DALY 2002-2004*). Third, we calculate a *corrected DALY*. Under the hypothesis that the gap between the DALY of a country and the DALY of the WHO region is constant on the 2000-2004's period, the regional DALY is weighted by the ratio of the 2004 country level DALY over the 2004 regional DALY. It allows generating DALY at the country level over the whole period and then generates the average value for DALYs. More precisely:

$$Corrected\ Daly\ in\ t = Regional\ DALY\ in\ t \times \frac{Country\ DALY\ in\ 2004}{Regional\ DALY\ in\ 2004}$$

with $t = 2000, 2001, 2002, 2004$

The causes of the disease burden differ according to income levels. This characteristic is taken into account while calculating DALYs with respect to communicable diseases (*Communicable DALY*) and to non-communicable diseases (*Non Communicable DALY*) as well. Finally as malaria and HIV/AIDS constitutes a large part of the disease burden in low income countries, and are two of the main diseases in the world (World Health Organization 2008), DALYs with respect to malaria (*Malaria DALY*) and HIV (*HIV DALY*) will be also considered in the econometric analysis.

Figure 1, Figure 2 and Figure 2 in Appendix B, present the relationships between different DALY indicators and traditional health outcomes measures (Life expectancy and Infant Mortality Rate) as well as GDP per capita. Three remarks can be done. First, the association between the DALYs and the traditional health indicators is tight, but more for low life expectancy and high infant mortality. Second, the association appears much less tight when Malaria DALYs is considered. Third, the relation between the DALYs and GDP per capita appears to be nonlinear.

3.2.1.2 Left-hand side and control variables

The left-hand side variable is y_i which is the average value of income per capita on the 2000 to 2004 period. We consider a vector of control variables **X**, which are assumed from the theoretical model. They are averaged over the 2000 to 2004 period. Annual growth rates of population (*Population growth rate*) and investment ratio to GDP (*Investment ratio to GDP*) have respectively a negative and positive effect on growth. In addition to the global health indicator, the average years of schooling is used as other human capital variables are included (*Education*)

Summary statistics are reported in Table 2 and Table 3 in Appendix A.

3.2.2 Econometric specification

Our regression of interest is:

$$\ln y_i = B + \frac{\alpha}{1-\alpha-\beta}\ln s_{k_i} + \frac{\beta}{1-\alpha-\beta}\ln s_{h_i} - \frac{\alpha+\beta}{1-\alpha-\beta}n_i - \frac{\beta}{1-\alpha-\beta}g(DALY_i) + v_i$$

For the sake of simplicity, $g(DALY_i)$ is simplified into $DALY_i$, our econometric model is thus:

$$\ln y_i = a^y - h^y DALY_i + \mathbf{X}'_i c^y + v_i \qquad \text{with } h^y > 0 \qquad (1)$$

Where v_i is the error term; y_i is GDP per capita (or per worker) and $\mathbf{X}_i$ a vector of covariates determined by our theoretical background which are theoretically relevant in the determination of output. If unobserved determinants of GDP per capita are negatively correlated with health burden i.e. $\text{cov}(DALY_i, v_i) < 0$ which can be featured by the following equation:

$$v_i = \alpha - \beta DALY_i + \varepsilon_i \text{ with } \beta > 0$$

Then running OLS provides estimates of Equation 2 below instead of Equation 1:

$$\log y_i = (a^y + \alpha) - (h^y + \beta)DALY_i + c^y\mathbf{X}_i + \varepsilon_i \quad (2)$$

The effect of health burden on GDP per capita is thus overestimated with OLS. This bias may however be contradicted by measurement errors on DALYs which generate an attenuation bias.

3.2.3 Endogeneity bias

It is difficult to find an instrument for health status in cross country regressions (e.g. (Weil 2007)) and identify a causal effect of health on income. We try to address this endogeneity of health status considering each of the DALYs measures (*Communicable DALY*, *Non Communicable DALY, Malaria DALY*, *HIV DALY*).

The effect of DALYs due to communicable, non-communicable and HIV/AIDS on economic development are not estimated for two reasons. First, we did not find valid and relevant instruments. We used the number of physicians per 1,000 inhabitants in 1960, health expenditures per capita in 1960, and tuberculosis and smoking prevalence for *Communicable DALY*, *Non Communicable DALY*. Second, first stage regressions did not provide satisfying results. Moreover one may suspect that they can have a direct effect on development. Lagged HIV/AIDS prevalence, considered as a relevant instrument for *HIV DALY* (McDonald & Roberts 2006), is not available on the period considered.

We thus restrict our analysis to *Malaria DALY* for which we consider two instruments. The first is proposed by Sachs (*Malaria ecology*). We calculate the second as described below (*Malaria Environment*).

Malaria ecology is developed by (Kiszewski et al. 2004) and first used in cross-country regressions by (J. D. Sachs 2003). *Malaria ecology* is built upon climatic factors (rainfall and temperature) and specific biological properties of each regionally dominant malaria vector which only reflects the forces of biological evolution and is thus independent from present health interventions and economic conditions. Moreover germs likely to be affected by economic conditions or public health interventions (like mosquito abundance, for example) do not enter the calculation of the index.

Malaria Environment is a dummy related to the geographical risk of malaria. It is a variable indicating the favorable geographical region for the development of mosquitos. This dummy takes the value 1 if the country simultaneously satisfies the following conditions, and 0 otherwise (Van Lieshout et al. 2004; Tanser et al. 2003):

- For each of the five years, the rainfall of at least three months was above 80 mm.

- The yearly average temperature ranked between 22°C and 32°C.

3.3 Econometric results

Our results stress that health status is an important predictor of economic development on a large sample of poor and rich countries. Efficient-GMM estimations are presented in Table 1 below. The quality of the instruments is either validated by the Shea R^2, or the statistic of Fisher presented in the first column.

The first and third columns report estimates for the first step regression. The second and fourth columns present the results for the two stage least squares. *Malaria DALY* is found to have a negative and statistically significant effect on economic growth. The marginal effect of *Malaria DALY* on growth is significant whatever the sample used. This result is robust to variants of samples.[6] These results are in conformity with our theoretical framework apart from the population growth on the whole sample.

Table 1. Two-step GMM estimation of economic effects of Malaria DALYs per capita

	Whole Sample		Developing Countries Sample	
	(1)	(2)	(3)	(4)
Independent variables	Malaria DALY	Log GDP per capita	Malaria DALY	Log GDP per capita
Malaria DALY		-21.360**		-19.477***
		(2.10)		(2.80)
Malaria Ecology	0.002***		0.002***	
	(7.64)		(7.23)	
Population growth rate	0.003***	0.516***	0.005***	0.062
	(3.13)	(4.51)	(2.78)	(0.57)
Log Investment ratio to GDP	-0.012***	0.422	-0.014***	0.446
	(3.26)	(0.96)	(3.59)	(1.32)
Log Education	-0.007***	1.039***	-0.007***	0.418***
	(4.04)	(5.06)	(3.08)	(2.69)
Africa dummy	0.005	-1.532***	0.002	-0.268
	(1.12)	(5.55)	(0.39)	(0.98)
Asia dummy	-0.009***	-1.985***	-0.011**	-1.182***
	(3.69)	(5.80)	(2.62)	(4.32)
Latin America dummy	-0.009***	-1.153***	-0.013***	0.106
	(5.28)	(3.91)	(3.63)	(0.34)
Constant	0.044***	6.498***	0.050***	6.071***
	(3.74)	(4.61)	(3.99)	(5.67)
Number of countries	129	129	91	91
R^2	0.837	0.656	0.838	0.650
Shea R2	0.446		0.443	
Fisher F statistic		58.323		52.343
Fisher P. value	0.0000		0.0000	

***significant at 1%, **significant at 5%, *significant at 10%. Robust t-statistics in parentheses.

3.4 Robustness analyses

Our previous results may still be questioned. Because we used only one instrument, it is not possible to test for exclusion hypothesis of our instrument. To deal with that, we use our second instrument, *Malaria Environment*, in addition to *Malaria Ecology*. The results obtained are presented in Table 2. The Hansen over-identification test confirms the good quality of the two instruments with regard to exclusion hypothesis. The results are similar to those obtained in Table *1*, namely, *Malaria DALY* remains an important determinant of economic growth.

[6] Regressions on a sample of developing countries without BRICS countries produce similar results.

Table 2. Two-step GMM estimation of economic effects of Malaria DALYs per capita (two instrumental variables)

	Whole Sample		Developing Countries Sample	
	(1)	(2)	(3)	(4)
	Malaria Daly	Log GDP per capita	Malaria Daly	Log GDP per capita
Malaria Daly		-20.720**		-19.570***
		(2.05)		(2.83)
Malaria Ecology	0.002***		0.002***	
	(6.62)		(6.42)	
Malaria Environment	-0.001		-0.001	
	(0.45)		(0.17)	
Population growth rate	0.003***	0.513***	0.005***	0.063
	(3.09)	(4.48)	(2.82)	(0.58)
Log Investment ratio to GDP	-0.012***	0.431	-0.014***	0.444
	(3.24)	(0.98)	(3.56)	(1.32)
Log Education	-0.007***	1.046***	-0.007***	0.417***
	(4.02)	(5.09)	(3.05)	(2.69)
Africa dummy	0.005	-1.544***	0.002	-0.267
	(1.08)	(5.64)	(0.35)	(0.98)
Asia dummy	-0.009***	-1.979***	-0.011**	-1.184***
	(3.45)	(5.78)	(2.60)	(4.33)
Latin America dummy	-0.008***	-1.146***	-0.012***	0.104
	(3.50)	(3.88)	(3.30)	(0.33)
Constant	0.044***	6.462***	0.050***	6.077***
	(3.71)	(4.60)	(3.95)	(5.70)
Number of countries	129	129	91	91
R_square	0.837	0.655	0.838	0.650
Shea R2		0.447		0.443
Fisher F. Statistic	28.211		25.667	
Fisher P. value	0.0000		0.0000	
Hansen OID p-value		0.219		0.515

***significant at 1%, **significant at 5%, *significant at 10%. Robust t-statistics in parentheses

Despite the pertinence of the TSLS method used in this paper, other extensions need to be explored in order to assess the robustness of the results.

Firstly, longer time coverage should be welcome so as to implement panel data techniques which catch individual and time invariant unobservable characteristics.

Second, even though the control variables appear suitable and the information delivered to explain income variability are useful, the relevance of our estimates may be questioned by omitted variable bias. It could consequently be interesting to extend this article by following the methodology developed by (Altonji et al. 2005) and already used in the literature (Nunn & Wantchekon 2009). It consists in measuring the strength of the likely bias which may arise from omitted variables. The idea behind the test is that "selection on unobservable is like selection on observables" (Altonji et al. 2011, p.2).

Third, simultaneity between income and health status also need further exploration in this work. In order to deal with simultaneity between income and health status, a two steps procedure could be applied following (Brückner 2011). The first step consists in implementing a regression of health status (*Malaria DALY*) while generating exogenous variability in the per capita GDP measured by the residuals. There is by construction a simultaneity bias between health status and GDP per capita. The second step calculates the TSLS estimated DALY by using these residuals as instrument of the health indicator.

It is not flawed by simultaneity bias by construction since the response of health status to GDP per capita is partialled out in the first step. Moreover, (Brückner 2011) proves the consistency of parameters estimates.

4 Concluding remarks

This article fuels the debate on the relationship between health outcomes and economic performance. The evidence of statistical association between health and economic development is not clear-cut in the literature. Some reasons have been put forward, which put emphasis either on the non-linearity of the relationship or the need to elaborate more on health status measurement (Bhargava et al, 2001).

Paying a particular attention to the measurement of health status allows contributing theoretically and empirically to the growth literature. In augmented Solow models *à la* MRW, all sorts of capital are supposed to depreciate at the same rates. We argue in this paper that there are no theoretical reasons to do so. The MRW framework is thus extended such as to separate human capital from material capital erosion. Furthermore, our main thesis is that DALYs (Disability Adjusted Life Years) are good predictors of human capital erosion in an augmented Solow growth model. DALYs, proposed by the World Bank and WHO since 1993, measure the gap between current health status and an ideal health situation where the entire population lives to an advanced age, free of disease and disability.

Our results highlight and confirm the role of poor health in the economic development as measurement by DALYs. We did not find evidence of a significant effect of the global disease burden on development. This is perhaps not a surprising result since (i) relevant instruments for several DALY measures are not available, (ii) DALYs are available on a rather short period of time and (iii) consequently panel estimation techniques cannot be implemented. Nevertheless, Malaria seems to be a real barrier to development. This result contributes to the debate pertaining to the role of malaria in development and confirms the results found at the micro-level which put lights on malaria being a barrier to knowledge learning at school, or undermining productivity. Malaria thus contributes to human capital erosion and hence has a detrimental effect on growth. This result is a reminder of the usefulness of targeting malaria eradication as identified by goal 6 of the Millennium Development Goals.

5 References

Acemoglu, D. & Johnson, S., 2009. Chapter 4 - Disease and Development: The Effect of Life Expectancy on Economic Growth. In M. Spence & M. A. Lewis, éd. *Health and Growth*. Commission on Growth and Development. World Bank Publications. Available at: https://openknowledge.worldbank.org/handle/10986/2633.

Acemoglu, D. & Johnson, S., 2006. *Disease and Development: The Effect of Life Expectancy on Economic Growth*, National Bureau of Economic Research. Available at: http://www.nber.org/papers/w12269 [Consulté le février 8, 2013].

Altonji, J.G. et al., 2011. Methods for Using Selection on Observed Variables to Address Selection on Unobserved Variables. Available at: http://www.economics.harvard.edu/faculty/altonji/files/ou52511_iza.pdf.

Altonji, J.G., Elder, T.E. & Taber, C.R., 2005. Selection on Observed and Unobserved Variables: Assessing the Effectiveness of Catholic Schools. *Journal of Political Economy*, 113(1), p.151–184.

Anand, S. & Hanson, K., 1997. Disability-adjusted life years: a critical review. *Journal of Health Economics*, 16(6), p.685–702.

Audibert, M., 2010. Endemic Diseases and Agricultural Productivity: Challenges and Policy Response. *Journal of African Economies*, 19(Supplement 3), p.iii110–iii165.

Barlow, R., 1967. The Economic Effects of Malaria Eradication. *The American Economic Review*, 57(2), p.130–148.

Behrman, J.R. & Rosenzweig, M.R., 2004. Returns to Birthweight. *The Review of Economics and Statistics*, 86(2), p.586–601.

Bhargava, A. et al., 2001. Modeling the effects of health on economic growth. *Journal of Health Economics*, 20(3), p.423–440.

Bloom, D.E. & Canning, D., 2007. Commentary: The Preston Curve 30 years on: still sparking fires. *International Journal of Epidemiology*, 36(3), p.498–499.

Bloom, D.E., Canning, D. & Fink, G., 2009. *Disease and Development Revisited*, National Bureau of Economic Research. Available at: http://www.nber.org/papers/w15137 [Consulté le avril 19, 2013].

Bloom, D.E., Canning, D. & Sevilla, J., 2004. The Effect of Health on Economic Growth: A Production Function Approach. *World Development*, 32(1), p.1–13.

Brückner, M., 2011. On the simultaneity problem in the aid and growth debate. *Journal of Applied Econometrics*. Available at: http://onlinelibrary.wiley.com.sicd.clermont-universite.fr/doi/10.1002/jae.1259/full [Consulté le mai 25, 2012].

Carstensen, K. & Gundlach, E., 2006. The Primacy of Institutions Reconsidered: Direct Income Effects of Malaria Prevalence. *The World Bank Economic Review*, 20(3), p.309–339.

Cole, M.A. & Neumayer, E., 2006. The impact of poor health on total factor productivity. *Journal of Development Studies*, 42(6), p.918–938.

Commission on Macroeconomics and Health, 2001. *Macroeconomics and Health: Investing in Health for Economic Development : Report*, Geneva: World Health Organization.

Deaton, A., 2006. *Global Patterns of Income and Health: Facts, Interpretations, and Policies*, National Bureau of Economic Research. Available at: http://www.nber.org/papers/w12735 [Consulté le avril 19, 2013].

Fogel, R.W., 1994. *Economic Growth, Population Theory, and Physiology: The Bearing of Long-Term Processes on the Making of Economic Policy*, National Bureau of Economic Research. Available at: http://www.nber.org/papers/w4638 [Consulté le avril 22, 2013].

Gallup, J.L. & Sachs, J.D., 2001. The economic burden of malaria. *The American Journal of Tropical Medicine and Hygiene*, 64(1 suppl), p.85–96.

Grossman, M., 1972. On the Concept of Health Capital and the Demand for Health. *The Journal of Political Economy*, 80(2), p.223–255.

Hamilton, K. & Clemens, M., 1999. Genuine Savings Rates in Developing Countries. *The World Bank Economic Review*, 13(2), p.333–356.

Jack, W. & Lewis, M.A., 2009. *Health Investments and Economic Growth: Macroeconomic Evidence and Microeconomic Foundations*, Rochester, NY: Social Science Research Network. Available at: http://papers.ssrn.com/abstract=1368628 [Consulté le avril 19, 2013].

Kiszewski, A. et al., 2004. A Global Index Representing the Stability of Malaria Transmission. *The American Journal of Tropical Medicine and Hygiene*, 70(5), p.486498.

Van Lieshout, M. et al., 2004. Climate change and malaria: analysis of the SRES climate and socio-economic scenarios. *Global Environmental Change*, 14(1), p.8799.

Lopez, A.D. et al., 2006. *Global Burden of Disease and Risk Factors*, Washington D.C.: World Bank and Oxford University Press. Available at: https://openknowledge.worldbank.org/handle/10986/7039 [Consulté le avril 19, 2013].

Lorentzen, P., McMillan, J. & Wacziarg, R., 2008. Death and development. *Journal of Economic Growth*, 13(2), p.81124.

Mankiw, N.G., Romer, D. & Weil, D.N., 1992. A Contribution to the Empirics of Economic Growth. *The Quarterly Journal of Economics*, 107(2), p.407437.

McDonald, S. & Roberts, J., 2006. AIDS and economic growth: A human capital approach. *Journal of Development Economics*, 80(1), p.228250.

McDonald, S. & Roberts, J., 2002. Growth and multiple forms of human capital in an augmented Solow model: a panel data investigation. *Economics Letters*, 74(2), p.271276.

Murray, C.J.L. et al., 2012. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *The Lancet*, 380(9859), p.21972223.

Mwabu, G., 2007. Chapter 53 Health Economics for Low-Income Countries. In T. P. Schultz & J. A. Strauss, éd. *Handbook of Development Economics*. Elsevier, p. 33053374. Available at: http://www.sciencedirect.com/science/article/pii/S1573447107040533 [Consulté le août 26, 2011].

Nunn, N. & Wantchekon, L., 2009. The Slave Trade and the Origins of Mistrust in Africa. *National Bureau of Economic Research Working Paper Series*, No. 14783. Available at: http://www.nber.org/papers/w14783.

Over, M., 1992. *The macroeconomic impact of AIDS in Sub-Saharan Africa*, Washington D.C.: The World Bank - Population and Human Resources Department.

Packard, R.M., 2009. « Roll Back Malaria, Roll in Development »? Reassessing the Economic Burden of Malaria. *Population and Development Review*, 35(1), p.53–87.

Preston, S.H., 1975. The Changing Relation between Mortality and level of Economic Development. *Population Studies*, 29(2), p.231248.

Sachs, J.D., 2003. Institutions Don't Rule: Direct Effects of Geography on Per Capita Income. *National Bureau of Economic Research Working Paper Series*, No. 9490. Available at: http://www.nber.org/papers/w9490.

Sachs, J.D. & Malaney, P., 2002. The economic and social burden of malaria. *Nature*, 415(6872), p.680685.

Sala-i-Martin, X., Doppelhofer, G. & Miller, R.I., 2004. Determinants of Long-Term Growth: A Bayesian Averaging of Classical Estimates (BACE) Approach. *The American Economic Review*, 94(4), p.813835.

Spence, M. & Lewis, M.A. éd., 2009. *Health and Growth*, World Bank Publications. Available at: https://openknowledge.worldbank.org/handle/10986/2633.

Strauss, J.A., 1986. Does Better Nutrition Raise Farm Productivity? *Journal of Political Economy*, 94(2), p.297320.

Strauss, J.A. & Thomas, D., 2007. Chapter 54 Health over the Life Course. In T. P. Schultz & J. A. Strauss, éd. *Handbook of Development Economics*. Elsevier, p. 33753474. Available at:

http://www.sciencedirect.com/science/article/pii/S1573447107040545 [Consulté le avril 19, 2013].

Tanser, F.C., Sharp, B. & Le Sueur, D., 2003. Potential effect of climate change on malaria transmission in Africa. *The Lancet*, 362(9398), p.1792‑1798.

Thomas, D., 2009. The causal effect of health on social and economic prosperity: Methods and findings. In AERC Health, Economic Growth and Poverty Reduction in Africa Framework Workshop. Accra. Available at: http://www.aercafrica.org/documents/health_framework_papers/ThomasD_Causal.pdf [Consulté le avril 19, 2013].

Thuilliez, J. et al., 2010. Malaria and primary education in Mali: A longitudinal study in the village of Donéguébougou. *Social Science & Medicine*, 71(2), p.324‑334.

Weil, D.N., 2007. Accounting for the Effect of Health on Economic Growth. *The Quarterly Journal of Economics*, 122(3), p.1265 ‑1306.

World Health Organization, 2008. *The global burden of disease: 2004 update*, Geneva: World Health Organization. Available at: http://www.who.int/healthinfo/global_burden_disease/2004_report_update/en/.

6 Appendix

6.1 Appendix A: Tables

Table 2. Variables characteristics and sources

	mean	min	max	Coef of Var.	Std error	Source
Corrected DALYs	0,27	0,10	0,83	0,65	0,17	WHO
DALY 2002-2004	0,27	0,10	0,89	0,66	0,18	WHO
DALY in 2002	0,28	0,10	0,95	0,68	0,19	WHO
DALY in 2004	0,26	0,10	0,82	0,64	0,17	WHO
Malaria DALY	0,01	0,00	0,09	1,95	0,02	WHO
Malaria Ecology	3,86	0,00	31,55	1,77	6,85	Sachs 2003
Investment ratio to GDP	0,21	0,08	0,57	0,33	0,07	WDI
Population growth rate	1,38	-1,10	7,07	0,86	1,20	WDI
Education	100,77	36,53	144,52	0,17	16,75	Barro & Lee

Table 3. Correlation between the main variables

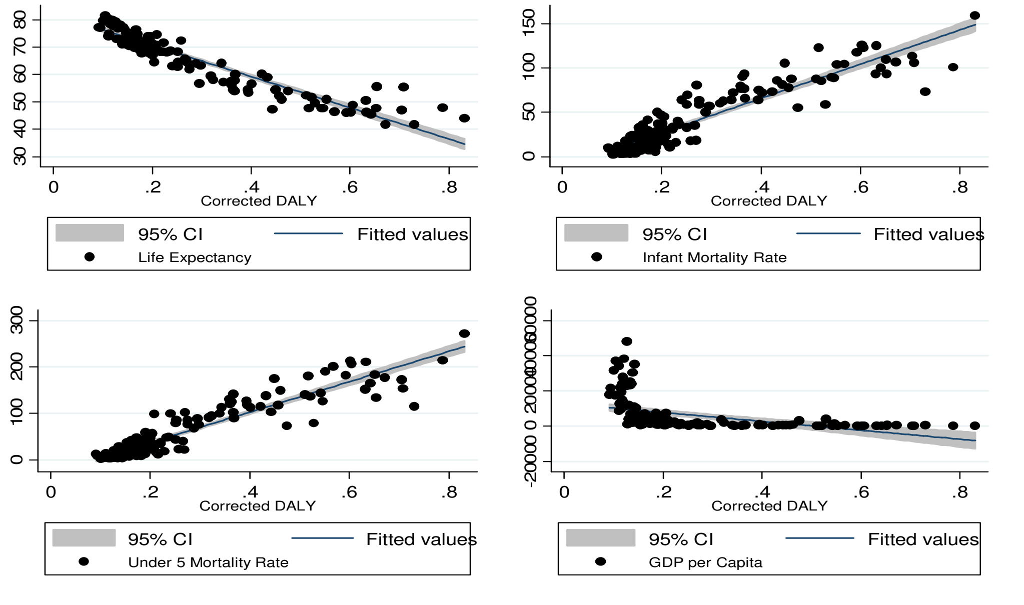
	GDP Growth	Corrected DALYs	DALY 2002-2004	DALY in 2002	DALY in 2004	Malaria DALY
Corrected DALYs	0,005	1,00				
DALY 2002-2004	0,03	0,99*	1,00			
DALY in 2002	0,03	0,97*	0,99*	1,00		
DALY in 2004	0,03	1,00*	0,99*	0,97*	1,00	
Malaria DALY	0,03	0,84*	0,83*	0,80*	0,84*	1

Table 4. List of countries

Developed Countries	Developing Countries		
	Africa	**Asia**	**Latin America**
Australia	Algeria	Armenia	Argentina
Austria	Benin	Bangladesh	Belize
Belgium	Botswana	Cambodia	Bolivia
Brunei Darussalam	Burundi	China	Brazil
Cyprus	Cameroon	India	Chile
Czech Republic	Central African Republic	Indonesia	Colombia
Denmark	Congo. Rep.	Iran. Islamic Rep.	Costa Rica
Estonia	Cote d'Ivoire	Jordan	Cuba
Finland	Egypt. Arab Rep.	Kazakhstan	Dominican Republic
France	Gabon	Kyrgyz Republic	Ecuador
Germany	Gambia. The	Lao PDR	El Salvador
Greece	Ghana	Malaysia	Guatemala
Hungary	Kenya	Mongolia	Guyana
Iceland	Lesotho	Nepal	Honduras
Ireland	Liberia	Pakistan	Mexico
Israel	Libya	Philippines	Nicaragua
Italy	Malawi	Russian Federation	Panama
Japan	Mali	Sri Lanka	Paraguay
Korea. Rep.	Mauritania	Syrian Arab Republic	Peru
Kuwait	Mauritius	Tajikistan	Uruguay
Luxembourg	Morocco	Thailand	Venezuela. RB
Netherlands	Mozambique	Vietnam	
New Zealand	Namibia	Yemen. Rep.	
Norway	Niger		
Portugal	Rwanda	**Europe**	**Other**
Qatar	Senegal	Albania	Fiji
Saudi Arabia	Sierra Leone	Bulgaria	Papua New Guinea
Singapore	South Africa	Croatia	
Slovak Republic	Sudan	Latvia	
Slovenia	Swaziland	Lithuania	
Spain	Tanzania	Poland	
Sweden	Togo	Romania	
Switzerland	Tunisia	Turkey	
United Arab Emirates	Uganda	Ukraine	
United Kingdom	Zambia		
Canada	Zimbabwe		
Trinidad and Tobago			
United States			

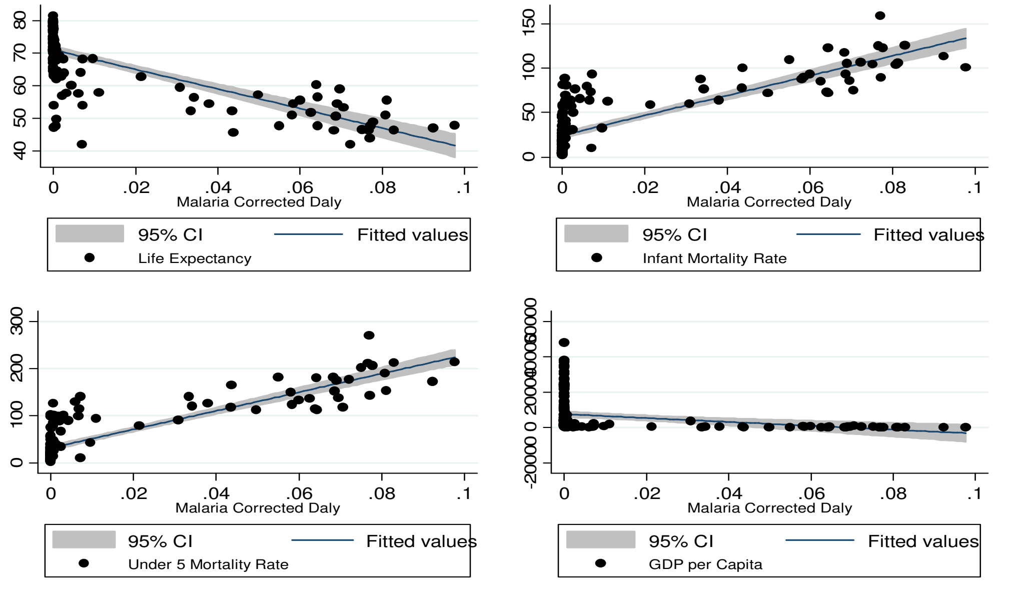
6.2 Appendix B: Figures

Figure 1. Relationship between Corrected DALY, traditional health indicators and GDP per capita.



Source: Authors' construction with data from World Bank and WHO.

Figure 2. Relationship between Malaria Corrected DALY, traditional health indicators and GDP per capita.



Source: Authors' construction with data from World Bank and WHO.