Determinants of Public Health Outcomes: A Macroeconomic Perspective

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June 2007

Abstract

This paper investigates the nature of the aggregate production function of health services. We build a model to analyze the determinants of social health outcomes, taking into account households choices concerning education, consumption, and health related expenditures. In the model, education has a positive external effect on health outcomes. Next, we perform an empirical analysis using a data set covering 71 countries. We find that society’s tertiary education attainment levels contribute positively to how many years an individual should expect to live, in addition to the role that basic education plays for life expectancy at the individual household level. This finding uncovers a key externality of education on the ability of society to take advantage of frontier health-related technologies.

Keywords: Education, life expectancy, health, externalities, absorptive capacity.

JEL Classification: O30, O40
1 Introduction

To the extent that income is not the sole determinant of health status across the world, one can view health as a separate component of welfare, other than income, whose determinants and implications regarding welfare growth might well be different than those relevant for economic growth.1 Thus, a central question in the debate on the determinants of international health outcomes asks whether these are a mere by-product of economic growth (see, for example, Pritchett and Summers 1996) or whether ‘exogenous’ ‘non-income’ sources are largely responsible, as argued in a series of papers by Preston (1975, 1980, 1996). In line with the latter works, Becker, Philipson and Soares (2005), Soares (2007a, 2007b), Cutler, Deaton and Lleras-Muney (2006), and Papageorgiou, Savvides, and Zachariadis (2007) argue that increases in life expectancy have largely occurred independently of increases in per capita income and are related to new medical technology and accumulation and diffusion of health knowledge. Soares (2007a, p.35) and Cutler, Deaton and Lleras-Muney (2006, p. 115) emphasize the role of education pointing out that “technologies related to individual-level inputs used in the production of health seem to be subject to the effectiveness with which individuals can use these inputs” so that “more educated individuals have higher survival advantage in diseases for which medical progress has been important” in the first case, and that “the differential use of health knowledge and technology is almost certainly an important part of the explanation” as to why “there is most likely a direct positive effect of education on health” in the second case. As long as countries are characterized by differences in educational attainment rates, one would then expect cross-country differences in health outcomes to arise as a result.

This paper examines the determinants of cross-country health outcomes with emphasis on the mechanisms through which education impacts upon life expectancy. We attempt to understand and quantify the role played by different factors in the aggregate production function of health services determining health outcomes. These include purchases of medical inputs measured by real health expenditures per capita, and public health inputs like public sanitation affecting the environment in which households make their decisions. Average health performance also depends on how well health-related knowledge is rooted in society. For instance, preventive behavior results from knowledge of risks incurred with hazardous behavior. For the individual, this is determined by own education facilitating access to appropriate health-related information. The availability of this knowledge in a country in the first place, is determined by the overall level of education for that country. Education can therefore play two different roles in the aggregate production function of health services. First, the level of education of the individual household enhances the longevity of its members. It seems reasonable for instance that education affects crucial factors such as understanding treatments or feeding children healthily. Second, the average level of education in the country improves its absorption capacity for health-related technology and ideas.

These two effects play conceptually different roles. The first one operates as a rival input benefiting household members. We expect this role of education in enhancing a household’s longevity to exhibit diminishing returns2 so that primary education attainment levels should suffice to capture it. The second

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1 Conversely, if growth in real income per capita largely determined improvements in health status then there would be no scope in studying health status and welfare growth as concepts distinct from economic growth.

2 This assumption is consistent with Haines and Avery (1982) and Merrick (1985) using individual-level data from Costa Rica and Brazil respectively, who find female education to exhibit diminishing returns in enhancing family health output.
instead determines the capacity of the health sector to take advantage of best practices. This is a high-tech sector experiencing fast technological progress. Furthermore, efficient use of new medical technologies requires understanding of scientific findings. The sophisticated character of knowledge transmission and use in this sector suggests that higher education constitutes its crucial determinant. Controlling for basic education, any additional effect resulting from higher education would then be consistent with the second role of education presented here.

Theoretical work has considered how human capital accumulation, health improvements and technological progress reinforce each other (Blackburn and Cipriani 2002, Chakraborty 2004, and Howitt 2005 among others). Here, we present a theoretical model where individuals choose their educational attainment, consumption of medical inputs, and their children’s primary education level. In this model, educational choices affect future income but also have external effects on health outcomes. We find that investment in education and in health are positively related at equilibrium, and have a reinforced impact on longevity.

We then use data from 71 countries to test the empirical validity of the theoretical model. Using initial period averages to explain end-period life expectancy and utilizing appropriate IV estimates, allows us to alleviate the inherent endogeneity problem concerning life-expectancy and education. To further address problems with capturing the direction of causality, we also consider beginning of period changes in the explanatory variables to explain end of period changes in life expectancy.

We find that primary and tertiary education have separate positive effects on life-expectancy. Our main finding is that tertiary education has at least as great an impact as primary education on health outcomes across countries. This suggests the externality role of education in facilitating adoption of best practices in health is at least as important as the role of basic education enhancing health outcomes at the household level. The paper provides evidence of a form of increasing returns in education, concerning its role in the aggregate production function of health services. This result is particularly interesting because previous work has established that primary education is the single most important determinant of income growth, while higher education has been found to have little explanatory power for this component of welfare (see Sala-i-Martin, Doppelhofer and Miller 2004). Here, tertiary education is found to be an important determinant of a second component of welfare, health status.

The next section presents the model and the theoretical results. Data are described and discussed in section 3. Section 4 describes the empirical analysis and presents the empirical results, while section 5 briefly concludes.

2 A model of education and health investment

In this section we present a model where education and health investment are chosen by individuals, and use it to analyze the relationship between education, health related expenditure, provision of public

In particular, Haines and Avery (1982, p. 43) find that "the results indicate a much greater elasticity of response of child mortality to an additional year of education for women with less education than with more education (11 percent against 2 percent", and Merrick (1985, p.6) finds that although mortality ratios fall with education attainment, "the most striking difference in mortality ratios, however, is the contrast between mothers with no formal education and other groups." In fact, Merrick (1985, p.10) suggests the role of education "may be limited to such basic steps as boiling contaminated water."
health services and life expectancy. First we set up the framework of analysis with emphasis on the individual problem. We establish sufficient conditions for the existence of a unique interior solution to the individual problem. This solution is used to predict how changes in parameters induce adjustments in higher and basic education, as well as health related private investment and therefore longevity. Next we turn to the stationary symmetric equilibrium with externalities from education on life expectancy. We derive sufficient conditions for the existence of a unique equilibrium and use the latter to predict comovements of variables of interest.

The model shows that education and longevity are strongly and positively related to each other. Their relationship is mutually reinforcing and hinges on causal links running in two directions: first, longer life expectancy boosts education by enhancing its productivity; second, improved educational attainment in the labor force increases the efficiency of health investment and therefore rises life expectancy. While the first link results from rational individual behavior, the second channel runs through external effects.

2.1 The individual problem

Suppose that individuals can live for two periods. For convenience we refer in the aftermath to the first period as youth and to the second one as adulthood. Everyone lives during the first period but survival to the second period is dictated by probability $\pi \in (0, 1)$. The survival probability is an increasing function of health-related individual inputs, $m$. We consider an isoelastic specification\(^3\)

$$\pi = \min \{zm^\mu, \bar{\pi} \} , \quad < 1$$

(1)

with $\bar{\pi} \in (0, 1)$, $z > 0$ and $m \geq 0$. Our analysis focuses on the interesting case when $\pi < \bar{\pi}$. We consider that the following is satisfied

**Parametric assumption 1** $\mu \in (0, 1)$, perceived returns on individual inputs to health are decreasing.

**Remark 1** The effectiveness, $z$, of the agent’s health investment, $m$, in enhancing her life expectancy, $\pi$, is perceived as being exogenously given. The value of $z$ will be considered as being endogenous in the next subsection, where at equilibrium it will be affected by educational externalities.

We consider the problem of a young agent of date $t$. At the beginning of the period the individual is endowed with basic education, $b_t$, chosen by her parents. In our setting fertility is exogenous and we assume that each agent has one child in the second period.\(^4\) The agent chooses her post-basic education level, $h_t$ (which hereafter we refer to simply as education). She chooses how to share her remaining income between consumption, $c_{1t}$, and purchases of health-related inputs, $m_t$. Conditional upon surviving to the second period, she chooses how to share her income between consumption, $c_{2t+1}$, and the purchase of her child’s basic education, $b_{t+1}$. These decisions are taken to maximize the expected present value of the

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\(^3\)This is the specification introduced by Chakraborty and Das (2005).

\(^4\)We abstract entirely from fertility choices and population dynamics. Since each adult has one child the population level, but not its growth rate, is an increasing function of the survival rate. This feature of the model is not the focus of the paper.
utility accruing from consumption and of the utility of providing basic education to the child, subject to two period-budget constraints and survival technology (1):

\[
\max_{m_t, h_t, b_{t+1}} \frac{1}{1 - \sigma} c_{1,t}^{1-\sigma} + \rho \pi_t \frac{1}{1 - \sigma} b_{t+1}^{1-\sigma}
\]

\[v_{t+1} \equiv c_{2,t+1}^{1-\theta} b_{t+1}^{\theta}\] (2)

\[w_t (1 - k h_t) = c_{1,t} + pm_t\] (3)

\[w_{t+1} (1 + h_t^\eta) = c_{2,t+1} + \kappa b_{t+1}\] (4)

all parameters and variables are non negative and \(\rho, \theta, \eta \in (0, 1)\).

According to the agent’s sub-period budget constraints (3)-(4) education, \(h_t\), is costly in terms of forgone first period labor income, through the effort-cost parameter \(k\). First period income is allocated to consumption (the numeraire) and to purchases of medical inputs at relative price \(p\). Second period labor income is an increasing and concave function of education. It is spent on consumption and on child’s basic education at relative price \(\kappa\).

**Remark 2** Second period sub-utility is discounted according to two factors: the subjective discount factor, \(\rho\), and the (endogenous) survival probability. Since the agent takes into account the impact of her consumption of health-related inputs, \(m_t\), on her life expectancy according to (1) she faces a problem with endogenous discounting of the type analyzed by Chakraborty (2004).

**Remark 3** We assume that the agent values her child’s basic education in the same way as she values consumption. Second period sub-utility is a function of the “consumption bundle” of two differentiated goods: \(c_{2,t+1}\) and \(b_{t+1}\).

**Remark 4** Basic education, \(b_{t+1}\), is not an investment good from the individual point of view, since it does not affect child’s income or effort-cost of education. As a result child’s basic education is valued independently of its impact on child’s income, longevity or utility. The alternative specification consists in assuming altruism, i.e., assuming that the parent cares about the indirect utility of her child. In this case the problem is recursive since parental choice of basic education takes into account its influence on child’s behavior. This alternative approach is more complex. Moreover it reflects a paternalistic approach to altruism. Our approach instead rests on a liberal view of altruism, according to which the parental has moral duty to endow her child with the basic means to freely make his own choices.

**Remark 5** We assume that \(b_t\) is entirely determined by parents at date \(t - 1\). This is a reasonable and empirically sound assumption (e.g. Dumas and Lambert, 2007). If we adopt the alternative assumption, by which each individual internalizes the effect of her educational choice on her own survival probability, the problem would become non concave in general. In fact, the feature of endogenous discounting reinforces

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5 This approach is equivalent to the one retained by Galor and Weil (2000). They define parents’ preferences over a bundle of two goods: the consumption good and potential aggregate income of offsprings. The latter is the product of the quantity of children and their per capita human capital, itself an increasing function of education supplied by parents.
complementarity between health related investment and education. Our assumption allows for this type of reinforcing interactions to take place, while ensuring the existence of a solution to the individual problem as well as of an equilibrium solution.\textsuperscript{6}

Remark 6 Education is the only form of investment and affects permanent income.\textsuperscript{7} Its marginal rate of return in terms of current potential consumption is $\eta w_{t+1}h_t^\theta/(w_tkh_t)$.

We drop time subscript where it does not lead to confusion, use (1)-(2) and substitute for $c_1$ and $c_2$ using (3) and (4), to write the problem as follows

$$\max_{h,m,b} \frac{1}{1-\sigma} \left[ w_t (1 - kh) - pm \right]^{1-\sigma} + \rho zm^\mu \frac{1}{1-\sigma} \left\{ [w_{t+1} (1 + h^n) - \kappa b]^{1-\theta} b^{1+\theta} \right\}^{1-\sigma}$$

An interior solution to this problem should satisfy the following first order conditions with respect to $m$, $h$ and $b$ respectively

$$w_tkc_1^{-\sigma} = \rho zm^\mu w_{t+1}h^{1-1}\theta \left( \frac{b}{c_2} \right)^{1-\theta} v^{-\sigma} \quad (5)$$

$$pc_1^{-\sigma} = \rho zm^{\mu-1} \frac{1}{1-\sigma} \left\{ [w_{t+1} (1 + h^n) - \kappa b]^{1-\theta} b^{1+\theta} \right\}^{1-\sigma} \quad (6)$$

$$c_2 = \frac{\theta}{1-\theta} \kappa b \quad (7)$$

System (3)-(6) solves for the five endogenous variables $c_1$, $c_2$, $m$, $h$ and $b$. We adopt the following

**Parametric assumption 2** $\sigma \in (0, 1)$, substitution effects dominate income effects.

It emerges clearly from (6) that this assumption is necessary for the existence of an interior solution for $m$, given that only in this case the marginal and absolute values of utility have the same sign.\textsuperscript{8}

From the second period budget constraint (4) we see that the rule dictated by (7) consists in spending constant shares on the two differentiated goods:

$$\frac{c_2}{w_{t+1} (1 + h^n)} = \theta \quad \text{and} \quad \frac{\kappa b}{w_{t+1} (1 + h^n)} = 1 - \theta$$

Using (7) in (2) we find that

$$v = \left( \frac{\theta}{1-\theta} \right)^\theta \kappa^\theta b \quad (8)$$

Moreover, substituting for $c_2$ in (4) from (7) we obtain

$$b = \frac{1 - \theta}{\kappa} w_{t+1} (1 + h^n) \quad (9)$$

\textsuperscript{6}Assumption 4, that is sufficient for the existence of a unique equilibrium, does in fact limit the extent of these feed-back effects between education and health-related investment.

\textsuperscript{7}This is different from Chakraborty and Das (2005) who assume that savings are possible. Previous versions of this paper included savings. The main features of the results are not affected by the introduction of savings. Results are however ambiguous in general in the latter case, as a result of problem arising from the redistribution of savings from non surviving individuals.

\textsuperscript{8}This restrictive assumption is also necessary in Chakraborty and Das (2005).
Taking into account these results we can rearrange (5) and (6) to get

\[ w_t k c_t^{1-\sigma} = \rho z m^\mu w_{t+1} \frac{\eta h_t^{\sigma-1}}{\kappa} a (1 - \theta) b^{-\sigma} \]  
\[ m_t c_t^{-\sigma} = \rho \frac{\mu}{1 - \sigma} a z m^{\mu-1} b^{1-\sigma} \]  

where we have defined \( a \equiv \theta^{\beta(1-\sigma)} (1 - \theta)^{-\beta(1-\sigma)} \kappa^{\beta(1-\sigma)} \). Combining (10) and (11) to eliminate \( c_t \), then substituting for \( b \) using (9) we can write

\[ m = \frac{\mu}{1 - \sigma \eta} w_t (1 + h^\eta) h^{1-\eta} \]  

To write \( c_t \) as function of \( h \) substitute for \( b \) and \( m \) using (9) and (12) into (11) and rearrange to get

\[ c_t = \left[ \frac{1}{\rho a z} \left( \frac{1 - \sigma}{\mu} \right)^\mu \left( \frac{k w_t}{\eta} \right)^{1-\mu} \left( \frac{1 - \theta}{\kappa} w_{t+1} \right)^{-\sigma(1-\sigma)} h^{(1-\eta)(1-\mu)} (1 + h^\eta)^{\sigma-\mu} \right] \]  

Finally using (12) and (13) into (3) we obtain the equation

\[ LSH (h) = \left[ \frac{1}{\rho a z} \left( \frac{1 - \sigma}{\mu} \right)^\mu \left( \frac{k w_t}{\eta} \right)^{1-\mu} \left( \frac{1 - \theta}{\kappa} w_{t+1} \right)^{-\sigma(1-\sigma)} h^{(1-\eta)(1-\mu)} (1 + h^\eta)^{\sigma-\mu} \right] \]  

We adopt the following

**Parametric assumption 3** \( \sigma \geq \mu \), consumption in youth is monotonically increasing in education \( (\partial c_t / \partial h) > 0 \).

This assumption is sufficient to ensure the existence of a unique solution to equation (14), since it implies that the \( LHS \) is increasing (up from zero) and concave, while the \( RHS \) is decreasing in \( h \) from \( w_t \) down to zero for \( h = 1/k \) (see figure 1).9

Performing comparative statics we can establish the following results10

**Proposition 1** Changes in parameters have the following consequences on individual’s choice

\[ \frac{dh}{dz} > 0 \Rightarrow \frac{dm}{dz} > 0, \frac{dc_1}{dz} < 0, \frac{dc_2}{dz} > 0, \frac{db}{dz} > 0 \text{ and } \frac{d\pi}{dz} > 0 \]
\[ \frac{dh}{dp} < 0 \Rightarrow \frac{dm}{dp} < 0, \frac{dc_1}{dp} > 0, \frac{dc_2}{dp} < 0, \frac{db}{dp} < 0 \text{ and } \frac{d\pi}{dp} < 0 \]
\[ \frac{dh}{dk} < 0 \Rightarrow \frac{dm}{dk} < 0, \frac{dc_1}{dk} > 0, \frac{dc_2}{dk} < 0, \frac{db}{dk} < 0 \text{ and } \frac{d\pi}{dk} < 0 \]

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9We have that \( dc_1 / dh > 0 \) if \( h^\eta / (1 + h^\eta) < \frac{1 - \sigma}{\mu} \kappa^{\sigma-\mu} \) or equivalently \( \sigma > \mu - (1 - \mu) \frac{1 - \sigma}{\eta} (1 + h^\eta) / h^\eta \). The right-hand-side of this last inequality is increasing but lower than \( \mu - (1 - \mu) \frac{1 - \sigma}{\eta} (1 + k^\eta) / k^\eta \) for \( h \leq 1/k \). Hence another sufficient assumption for \( dc_1 / dh > 0 \) is \( \sigma > \mu - (1 - \mu) \frac{1 - \sigma}{\eta} (1 + k^\eta) \) which is less restrictive than assumption 3.

10The subjective discount factor has pretty much the same effect of \( \mu \), but for a weaker impact on life expectancy.
†: These signs are ambiguous in general. Sufficient conditions for them to be negative are

i) \( \sigma > 1 - \mu \) and

\[
\left( \frac{1}{\rho a z} \frac{\mu}{\mu} \right)^{-\frac{1}{\sigma}} (1 - \sigma) \left( \frac{1 - \theta}{\kappa} w_{t+1} \right) \left( 1 - \sigma \right)^{\sigma + \mu} w_{t} \left( \sigma + \mu - 1 \right) \frac{\sigma + \mu}{\mu} \frac{\nu}{\mu} \frac{\theta}{\mu} > k \left( \sigma + \mu - 1 \right)
\]

‡: The analysis is incomplete on the impact of \( \kappa \).
For the proof see the appendix.

**Remark 7** As far as the parameters considered in proposition 1 are concerned, if only one of them differs across individuals (or countries) then we should observe positive correlations between higher education, basic education, private expenditure on health services and life expectancy.

**Remark 8** The positive correlation between \( h \) and \( \pi \) here is obtained without any direct impact of education on longevity. It is explained by the “reward to education” effect according to which longer life expectancy increases the return on education and boosts higher education. The causality runs from longer life expectancy to more investment in higher education. This precisely reflects the issue of endogeneity of higher education considered in the empirical analysis.

### 2.2 Externalities at the stationary symmetric equilibrium

We now introduce the educational externalities on health status by assuming that education affects the effect of medical inputs on longevity, i.e., parameter \( z \). From the individual point of view, medical expenditure is the more productive the greater is her own level of basic education, public health related services, and the average level of education in the economy.

The individual level of basic education, \( b_t \), enhances the individual ability in taking advantage of health services. Supply of public health services is considered as exogenous and denoted by \( s_t \). It can be interpreted as a pure public good, affecting for instance the rate at which households are subject to diseases. The average (post-basic) education level in the generation, \( \bar{h}_t \), acts as a pure externality because it improves the quality of the health service sector by, for instance, facilitating the use and diffusion of best practices.

Using a Cobb-Douglas specification and recalling (1) we can write

\[
z_t \equiv \zeta s_t^\delta b_t^\alpha w_t^\beta \Rightarrow \pi_t = \zeta s_t^\delta b_t^\alpha m_t^\beta \tag{15}\]

where \( \zeta > 0 \) is a scale parameter and \( \delta, \alpha, \beta \in (0, 1) \).

At the stationary symmetric equilibrium we have that \( \forall t \)

\[
h_t = \bar{h}_t , \ b_t = b_{t+1} \ and \ w_t = w_{t+1}
\]
Use this stationarity conditions and substitute for \( z \) in (13), then (9) to substitute for \( b \) to obtain

\[
e_1 = \left[ \frac{s^{-\delta}}{\rho \zeta} \left( \frac{1 - \sigma}{\mu} \right)^{\mu} \left( \frac{k \gamma}{\eta} \right)^{1-\mu} \left( \frac{1 - \theta}{\kappa} \right)^{-1} h (1-\eta)(1-\alpha) (1 + h^\eta)^{\sigma - \mu - \beta} \right]^{\frac{1}{\mu}}
\]

Using this expression to substitute for \( e_1 \) in the first period budget constraint (3) along with (12) for \( m \) we obtain

\[
\text{LHS} (h) \equiv \frac{s^{-\delta}}{\rho \zeta} \left( \frac{1 - \sigma}{\mu} \right)^{\mu} \left( \frac{k \gamma}{\eta} \right)^{1-\mu} \left( \frac{1 - \theta}{\kappa} \right)^{-1} h (1-\eta)(1-\alpha) (1 + h^\eta)^{\sigma - \mu - \beta} \]

\[
+ \frac{\mu k}{1 - \sigma \eta} w (1 + h^\eta) h^{1-\eta} = w (1 - kh) \equiv \text{RHS} (h)
\]

which coincides with (14) for \( \alpha = \kappa = 0 \) and \( \zeta s^\delta = z \).

There exists a unique solution of equation (16) under previous assumptions and the additional

**Parametric assumption 4** \( \alpha \leq (1 - \eta)(1 - \mu) \) and \( \beta \leq \sigma - \mu \), the external effects of education on the productivity of medical inputs are small.

Small externalities are sufficient to ensure the existence of a unique equilibrium characterized by an internal solution \( h \in (0, 1/k) \). Using (9), and (12) to substitute for \( b \) and \( m \) in (15), we can write life expectancy at the symmetric stationary equilibrium as function of the education level

\[
\pi = \zeta \left( \frac{1 - \gamma}{\kappa} \right)^{\beta} \left( \frac{\mu k}{1 - \sigma \eta \mu} \right)^{\mu} \left[ w (1 + h^\eta) \right]^{\mu + \beta} h^{\mu(1-\eta) + \alpha}
\]

**Proposition 2** The stronger are the externalities of education on life expectancy, i.e., the larger \( \alpha \) and \( \beta \), the greater are higher education, basic education, health related investment and life expectancy at equilibrium.

**Proof.** Under assumption 4 the \( \text{LHS} \) in (16) is an increasing function of \( h \), but it is relatively flat as compared to the \( \text{LHS} \) in (14) since \( dc_1/dh \) is smaller (the exponents of the terms varying with \( h \) are smaller). Since in both cases the left-hand-side starts at zero, we have that \( \text{LHS} \) lies everywhere below the \( \text{LHS} \) schedule in terms of figure 1. Given that the right-hand-sides of equations (14) and (16) coincide, the equilibrium value of \( h \) is larger than the one solving the individual problem, i.e., \( h \) solving (16) is greater than \( h \) solving (14). Finally, \( b \) and \( m \) are increasing functions of \( h \), while \( \pi \) is increasing in all of these three variables.

**Remark 9** Externalities make the link between \( h \) and \( \pi \) stronger. In the data the positive correlation between higher education and longevity should be stronger in the presence of the externality (i.e. \( \alpha > 0 \)) than in the case without externalities (i.e. the solution to the individual problem).

**Remark 10** Our theory predicts causal links between life expectancy and higher education running in both directions (i) one from greater \( \pi \) to higher \( h \) (as suggested by the result in the previous sub-section) and (ii) another one from higher \( h \) to greater \( \pi \) in the presence of externalities.
Remark 11 According to (17) life expectancy is also an increasing function of income level $w$ and of public health inputs $s$.$^{11}$

3 Data description

In this section, we describe the data set we have assembled to test our main hypotheses and take a first look at the relationship of health status with each of these health input variables. The focus of our study, a country’s health status, is measured by the average life expectancy at birth. The *World Development Indicators* (WDI) 2005 database provides data on life expectancy at birth, physicians per thousand people, real health expenditure per person$^{12}$, sanitation (defined as the percentage of the population with access to improved sanitation facilities), and GDP per capita in PPP dollars. We obtained primary and higher education attainment rates from the Barro and Lee (2001) dataset. We also use a measure of the incidence of AIDS (defined as number of cases per thousand persons) from Papageorgiou and Stoytcheva (2006) in an effort to control for the adverse effects of the AIDS epidemic on health status.

We were able to put together all the above series for 71 countries. The list of counties is shown in Table A1 in the appendix. The great majority of these series are not available frequently over time and in some cases the data are exceedingly sparse in the time dimension. Because the cross-sectional dimension of the dataset is more complete and, more importantly, because of the inherent long-run nature of the relation under study, we chose to explore empirically the cross-sectional dimension of our dataset. That is, we average the available data over the period 1995 to 2004 for life expectancy$^{13}$ and over the period 1961 to 1995 for the explanatory variables subject to availability.

4 Empirical results

4.1 Preliminary evidence

Our main hypothesis is that health inputs such us primary and higher education, physicians availability, sanitation, and health spending are related to health outcomes measured by life expectancy. Indeed, the correlations between life expectancy and higher education attainment rates equal 84 percent, while the correlation with basic education attainment rates equals 34 percent. Physicians are also strongly related with life expectancy with correlations of 87 percent. Moreover, sanitation and health expenditures have correlations with life expectancy of 70 percent and 77 percent respectively, while aids prevalence has an unconditional correlation of minus 22 percent with life expectancy. All these correlations are

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$^{11}$It can indifferently be youth potential income $w$ (exogenous) or adulthood income $w(1+h^\eta)$ (partially endogenous).

$^{12}$This is total health expenditure per capita in constant dollars. Total health expenditure is the sum of public and private health expenditures as a ratio of total population. It covers the provision of health services (preventive and curative), family planning activities, nutrition activities, and emergency aid designated for health but does not include provision of water and sanitation. In more detail: Private health expenditure includes direct household (out-of-pocket) spending, private insurance, charitable donations, and direct service payments by private corporations. Public health expenditure consists of recurrent and capital spending from government (central and local) budgets, external borrowings and grants (including donations from international agencies and nongovernmental organizations), and social (or compulsory) health insurance funds. Data are in current U.S. dollars and are converted to constant dollars by deflating using the US CPI.

$^{13}$Life expectancy data are available from 1960 to 2005.
statistically significant at the one percent level, except the latter which is statistically significant at the ten percent level. However, nearly all health inputs are strongly related to the level of real income per capita. This is especially true in the case of higher education attainment rates (80 percent), physicians availability (89 percent), and for health spending (92 percent.) Moreover, several of these inputs are highly correlated with each other raising a warning flag regarding a potential collinearity problem in the regression specifications that follow in the next subsection. Notably, the correlation between higher education attainment or enrollment rates with physicians is 87 percent. As a robustness check for the importance of higher education we will thus consider specifications both with and without the apparently highly collinear physicians variable.

4.2 Cross-section regression results

We are well aware that there is a strong theoretical argument for endogeneity between life expectancy and tertiary education. While tertiary education should be expected to affect health outcomes, it can also be argued that individual decisions on tertiary education attainment depend on expected life expectancy so that it is plausible that longer life expectancy causes higher tertiary education levels. However, for the model we consider below, we fail to reject the null that tertiary education is exogenous with a p-value of 0.21\(^\text{14}\) and the joint hypothesis that the two education measures, the physicians variable, and income are all exogenous with a p-value of 0.24. This suggests it might be reasonable to estimate the empirical model with OLS. However, given that we have just about 70 observations and that individual p-values for the null of exogeneity for each explanatory variable separately range from about 0.21 for tertiary education and physicians to 0.78 for primary enrollment rates, we choose to be conservative regarding our inference of exogeneity and also estimate the model using IV. This helps take into account possible endogeneity problems we might have been unable to detect, and also acts as a robustness check for the OLS estimates.

Towards the goal of addressing potential endogeneity problems and establishing some evidence of temporal causation we consider: (i) Using lags of higher education and the other explanatory variables\(^\text{15}\) to explain end-period averages of life expectancy. Specifically, we utilize time averages of higher education and the other explanatory variables for 1961-75 to explain average life expectancy over 1995-2004. This takes care of endogeneity if individual decisions about higher education in 1961-75 are made independently of life expectancy at birth of the next generation of individuals born between 1995 and 2004. We present results based on this specification as the "Lags" model in columns two and five in Table 1. (ii) Instrumenting the averages of tertiary education, basic education, and physicians over 1961-95 by their average value during 1961-75 to explain the average value of life expectancy over 1995-2004. In the regression of each potentially endogenous explanatory variable\(^\text{16}\) on all exogenous variables, the lag of

\(^{14}\) Treating one explanatory variable at a time as potentially endogenous and the remaining as exogenous, we also fail to reject the null that primary education attainment rates is exogenous with a p-value of 0.78. Similarly, we cannot reject the null that the physicians measure is exogenous with a p-value of 0.25. Nor, can we reject the null that initial income is exogenous with a p-value of 0.52.

\(^{15}\) We do not take lags for sanitation for which we usually have just a single observation for each country during the end of the period, per capita health spending for which we have just a handful of time series observations per country, and aids which appears only in the second half of the period under consideration.

\(^{16}\) Again, even though we fail to reject the null of exogeneity for any of these variables and jointly for all of these variables,
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Each explanatory variable is shown to be strongly significant in determining the explanatory variable’s period average, with p-values always below the one percent level of significance. Although it is not possible to test for identification, strong rejection of the null that our instruments have no impact on the potentially endogenous explanatory variable is important for the finite sample properties of the IV estimator, as explained in Wooldridge (2002, p.86) and elsewhere. We present results based on IV estimation in columns three and six in Table 1. (iii) We use log changes in the explanatory variables for the period 1961-75 to explain the log change in life expectancy for 1961-2004 in Table 2 (and for 1977-2004 in the appendix Table A2). We report results from this exercise as the "Lags" model in columns two and five of Table 2. (iv) We apply IV estimation to the variables in changes, instrumenting the log change in primary and tertiary education over 1961-95 by their 1961-75 value. Results based on this approach are reported in columns three and six of Table 2.

Overall, we assess the link between health inputs and life expectancy with the "Lags" and "IV" models described above, and the "Period Avg" model where we consider the average of the 1995-2004 period life expectancy being explained by the 1961-95 average value of the explanatory variables. We report results for the latter model in columns one and four of Table 1. All variables considered in the regression specifications are in natural logarithms so that the reported estimates are elasticities of life expectancy with respect to each explanatory variable.

We also consider log changes of the variables and present estimation results from this exercise in Table 2. In this case, all variables other than the log of the initial (1961) level of real income per capita are in log changes. For the period-averages ("Period Avg") model we consider the growth rate of life expectancy between 1961 to 2004 explained by growth rates of the explanatory variables between 1961 and 1995, with results presented in the first and fourth columns of Table 2. In the appendix Table A2, we also present estimates obtained when explaining end-of-period average life expectancy changes between 1977 and 2004, to show robustness of the main finding regarding the importance of higher education in determining future health improvements.

As noted previously, we consider specifications without and with the physicians measure in Models 1 and 2 respectively, since this is highly collinear with higher education. Finally, we note that heteroskedasticity-consistent finite sample standard errors have been used in all estimations.

In Model 1 of Table 1, we consider the impact of basic and higher education attainment rates as well as real income per capita, sanitation, health spending per capita, and AIDS per thousand population, on end-period (1995-2004) average life expectancy. We report results from Model 1 in the first three columns of Table 1. Irrespective of whether we consider the average value of the explanatory variables over the 1961-95 period, their average value at the beginning of the period, or instrument the former with the latter, higher education attainment rates consistently have a positive and strongly significant impact on life expectancy which is at least as important as the impact of primary education. The elasticity of life expectancy with respect to higher education ranges from 3.8 percent for the lags model to 5.1 percent for the instrumental variables estimation, and up to 5.5 percent for the period-averages model. The estimated elasticity of life expectancy with respect to primary education ranges from 4.4 we are being conservative in allowing for the possibility that these could be endogenous.
Table 1: Explaining 1995-2004 averages of life expectancy

<table>
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<tr>
<th>Specif. 1</th>
<th>Model 1</th>
<th>Model 1</th>
<th>Model 1</th>
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<td>Lags</td>
<td>IV</td>
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<td>Lags</td>
<td>IV</td>
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<td>0.010</td>
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<td></td>
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<td>(0.93)</td>
<td>(0.30)</td>
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<td>(-0.09)</td>
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<td>0.038***</td>
<td>0.051***</td>
<td>0.032***</td>
<td>0.022***</td>
<td>0.033***</td>
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<tr>
<td></td>
<td>(4.46)</td>
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<td>(3.83)</td>
<td>(2.94)</td>
<td>(1.79)</td>
<td>(2.86)</td>
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<tr>
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<td>(1.86)</td>
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<td>(0.74)</td>
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<td>(0.04)</td>
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<td>-0.028***</td>
<td>-0.025***</td>
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<td>—</td>
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<td>0.062***</td>
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<tr>
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<td>—</td>
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<td>(2.59)</td>
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<td>(17.6)</td>
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<td>71</td>
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Notes: * p-value less than one percent, ** p-value less than five percent, *** p-value less than ten percent. Heteroskedasticity-consistent finite sample standard errors are used in constructing t-statistics. All variables are in natural logarithms so that the reported estimates are elasticities of life expectancy with respect to each explanatory variable. For "Period Avg" models, we consider 1995-2004 averages of life expectancy being explained by 1961-95 averages for the explanatory variables. For "Lags" models, we consider again 1995-2004 averages of life expectancy being explained in this case by 1961-75 averages of the education, physicians, and income variables. Finally, for "IV" Models 1 and 2, we instrument the 1961-95 period averages of the education, income, and physicians variables using their beginning of period averages.

and 4.6 percent and marginally insignificant for the lags and IV models respectively, to 5.4 percent and marginally significant at the ten percent level for the period-averages model. Sanitation has a positive impact estimated to be significant in two of the three estimations for Model 1. The incidence of AIDS has a negative and strongly significant impact on life expectancy in all three estimations for Model 1.

We also take into account the fact that income can be a major determinant of health by including the initial period time-average value of real income per capita in the regression specifications presented in the first and second columns of Table 1, and instrumenting the former using the latter for the specification reported in the third column. Real income per capita largely determines the consumer’s purchasing power for rival inputs related to health. These would include medical expenditures but also spending on food. Controlling for the effect of income helps isolate the part of the effect of each input unrelated to income. For the specifications reported in the first three columns of Table 1, income has a positive but insignificant impact on life expectancy. Collinearity might be behind the finding of an insignificant impact of income on health status once we control for other health inputs through which income impacts upon health status. When considering income without health spending in the regression (not shown in Table 1), income comes in as a positive and significant determinant of life expectancy for all three specifications of Model 1, consistent with its role as facilitator of rival health-related inputs purchases. Similarly, whereas excluding income from the regression specifications (not shown in Table 1) renders health spending positive and significant in all three specifications of Model 1, including it renders health

17 Including income is thus in line with Fogel’s (1994) argument about the importance of nutrition in determining health.

18 As the correlation between real per capita income and real health expenditure per person is 92 percent for the countries in our sample.
spending insignificant except for the lags estimation in the second column of Table 1.

In columns four to six of Table 1, we report results for Model 2 which incorporates physicians availability in addition to the two education variables, sanitation, real per capita health spending, AIDS per thousand population, and real income per capita. To the extent that physicians help absorb and disseminate medical or health-related information across and within countries, in addition to their role as a rival health input, including it should diminish the impact otherwise captured by the measure of higher education.\textsuperscript{19} Indeed this is the case. As physicians and higher education are highly collinear, with a correlation of 87 percent (compared to 39 percent for physicians and primary education), introducing physicians dampens the impact of higher education on life expectancy. Still, this remains positive and significant, irrespective of whether we use period-averages, lags, or instrument the explanatory variables, in columns four, five, and six respectively. The impact of higher education ranges between 2.2 percent for the lags estimation to 3.3 percent for the period-averages and instrumental variables estimations. The estimated life expectancy elasticity of primary education remains positive but is now statistically insignificant throughout the three specifications of Model 2. Sanitation retains a positive and significant impact on life expectancy while health spending per capita is now estimated to have no impact on life expectancy. The latter result is the case irrespective of whether or not we include income per capita in the regression specifications. Similarly, once we include a measure for physicians, the impact of income per capita is estimated to be indistinguishable from zero irrespective of whether or not health spending is included in the estimation. On the other hand, the estimated impact of AIDS remains negative and strongly significant. Finally, physicians availability has a positive and strongly significant impact on life expectancy that remains stable between seven and six percent in columns four to six, irrespective of the methodology pursued.

Overall, we find that higher education matters significantly and is more robust than basic education, sanitation, health spending, and income. Using initial period averages to explain end-period life expectancy along with IV estimation, allows us to establish that tertiary education is a significant and robust explanatory variable of end of period health status. This approach alleviates potential endogeneity problems and provides supporting (even if merely suggestive) evidence of a causality link from tertiary education to health status (life expectancy).

Changes in variables specification

As an additional methodology to remedy potential endogeneity problems facing tertiary education as a determinant of health status, we consider log changes of the variables instead of their log levels. This serves as a robustness check for our main finding regarding the relative importance of higher education for life expectancy and for improvements in future health outcomes. When considering changes, we have

\textsuperscript{19}Physicians play a dual role: first, as a direct rival input into the health production function and second, as facilitators of health-related knowledge absorption and dissemination. Including both tertiary education and physicians in the same specification for Model 2 should thus be expected to reduce coefficient estimates for tertiary education to the extent these two variables capture the same concept. Thus, coefficient estimates for tertiary education in these specifications should be viewed as a lower bound for the importance of the knowledge externality we are focusing on in this paper. Here, we are attributing all of the impact of physicians to its direct role in the health production function, understating the overall effect of health-related knowledge. Alternatively, excluding physicians, leads to a considerable increase in magnitude for higher education estimates.
to exclude our measures of public sanitation and health spending per capita because of limited data availability over time for these health inputs. We now include changes in real income per capita over the period as a proxy of the growth rate of real health spending, given that income per capita is a reasonably good measure of purchasing power.

We report estimates from this exercise in Table 2 where we seek to explain changes in life expectancy between 1961 and 2004. The growth rate of higher education attainment levels has positive impact on end-period growth rates in life expectancy for all six specifications we consider. It takes its highest value of about six percent in the IV specification reported in column three. The growth rate of primary education has a positive effect higher than that for tertiary education and is statistically significant except for the specification in column four where it’s marginally insignificant.20 It takes its highest value of about seven percent in the IV specification reported in column three. The estimated impact of AIDS is negative as we should expect, and statistically significant in most specifications. The growth rate of physicians comes in positive and strongly significant confirming the importance of the per capita number of physicians in determining health outcomes suggested by the estimation in levels earlier.

Initial income has a negative statistically significant impact on changes in life expectancy between

\[ \text{PHYS} \]

\[ \text{constant} \]

\[ \text{Adj. } R^2 \]

\[ \text{Obs.} \]

\[ \begin{array}{cccccc}
\text{Specif} & \text{Model 1} & \text{Model 1} & \text{Model 1} & \text{Model 2} & \text{Model 2} & \text{Model 2} \\
& \text{PeriodAvg} & \text{Lags} & \text{IV} & \text{PeriodAvg} & \text{Lags} & \text{IV} \\
\text{INCOME} & -0.001^{**} & -0.001^{***} & -0.001^{*} & -0.001^{**} & -0.001^{***} & -0.001^{**} \\
& (-2.09) & (-3.03) & (-1.68) & (-2.74) & (-3.66) & (-2.39) \\
\text{EDHA} & 0.052^{***} & 0.023^{**} & 0.058^{***} & 0.033^{**} & 0.021^{***} & 0.051^{***} \\
& (3.76) & (2.75) & (3.69) & (2.18) & (2.85) & (3.48) \\
\text{EDBA} & 0.055^{**} & 0.046^{***} & 0.073^{***} & 0.038 & 0.037^{**} & 0.057^{**} \\
& (2.43) & (2.84) & (2.88) & (1.64) & (2.16) & (2.23) \\
\text{YGROWTH} & 0.035 & 0.035 & 0.042 & 0.003 & 0.0002 & 0.010 \\
& (0.99) & (1.01) & (1.46) & (0.10) & (0.01) & (0.42) \\
\text{AIDS} & -0.003^{*} & -0.002 & -0.003^{*} & -0.003^{**} & -0.002 & -0.003^{*} \\
& (1.02) & (1.04) & (1.77) & (2.92) & (1.11) & (1.93) \\
\text{PHYS} & 0.085^{***} & 0.070^{***} & 0.074^{***} \\
& (2.84) & (2.32) & (2.87) \\
\text{constant} & 0.011^{**} & 0.013^{*} & 0.008^{***} & 0.012^{***} & 0.012^{***} & 0.009^{**} \\
& (2.47) & (3.03) & (2.00) & (2.69) & (3.42) & (2.24) \\
\text{Adj. } R^2 & 0.66 & 0.66 & 0.66 & 0.63 & 0.63 & 0.63 \\
\text{Obs.} & 66 & 66 & 66 & 63 & 63 & 63 \\
\end{array} \]

Notes: * p-value less than ten percent, ** p-value less than five percent, *** p-value less than one percent. Heteroskedasticity-consistent finite sample standard errors are used in constructing t-statistics. All variables are in natural logarithms. Five countries, Bangladesh, Malawi, Mozambique, Singapore and Uganda are missing relative to the sample for Table 1. In addition, the physicians measure used in the specifications reported in columns four to six is missing for Ghana, Iceland and Sierra Leone. All variables other than the log of the initial (1961) level of real income per capita are in log changes. YGROWTH is the growth rate of real income per capita. For the "Period Avg" models, we consider the growth rate of life expectancy between 1961 and 2004 being explained by growth rates of the explanatory variables between 1961 and 1995. For the "Lags" model 1, we consider again the growth rate of life expectancy between 1961 and 2004 being explained by growth rates of the education variables between 1961 and 1975. Finally, for the "IV" Models 1 and 2, we instrument the 1961–95 period changes for the education variables using their beginning of period averages.

20 The result about the relative magnitude and statistical significance of basic education is not robust when estimating the impact of the same explanatory variables on end-of-period life expectancy changes between 1977 and 2004. In this case, the estimated coefficients for basic education fall and are statistically insignificant in all three specifications for Model 2. In contrast, the estimated coefficients for higher education are nearly unchanged and remain statistically significant across the board in explaining end-of-period life expectancy changes, suggesting that higher education is an important determinant of improvements in future health outcomes. Table A2 in the appendix reports the results of this estimation exercise.
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1961 and 2004 across the board. This is consistent with convergence in life expectancy for countries that started with low real income per capita levels in 1961. On the other hand, the growth rate of real income per capita does not seem to explain any of the gains in life expectancy. This suggests that any convergence that took place for initially low-income countries has not been the result of higher real income per capita growth, but likely due to changes in non-income determinants of public health in laggard countries. These other determinants would likely include changes in public inputs like sanitation, and perhaps medical knowledge diffusion as emphasized in Papageorgiou, Savvides, and Zachariadis (2007).

5 Conclusion

To the extent that ‘exogenous’ non-income factors are shown to be important for life expectancy across countries, the results presented in this paper suggest that there is scope for studying the determinants of welfare growth as a concept that is (closely related but) distinct from economic growth. This distinction can be important in guiding policy aimed at improving welfare in less developed countries. At the same time, the findings of this paper suggest that investing in health inputs might be important for welfare growth even if the effect of health on economic growth is small as in Weil (forthcoming), or non-existent as in Acemoglu and Johnson (2006). As acknowledged by the latter (in page 3), consistent with Becker, Philipson, and Soares (2005) “health interventions have considerably improved overall welfare” at the same time that their “estimates exclude any positive effects of life expectancy on GDP per capita.”

We have presented a model where education can have external effects on life expectancy, beyond what can be expected from the impact of basic education on the individual household’s health status. Our main empirical results are as follows: Physicians are an important determinant of life expectancy and of improvements in future health outcomes. As a side effect, introducing this variable reduces the separate impact of higher education. This should be expected to the extent that physicians are not just an other rival health input but in fact absorb and disseminate medical or health-related information across and within countries. Public health inputs such us sanitation have a positive impact on life expectancy, consistent with Soares (2007b) in relation to Brazil and with other evidence summarized in the review articles of Cutler, Deaton, and Lleras-Muney (2006) and Soares (2007a). In addition, there is some evidence of convergence in life expectancy for countries that started off with low real income per capita levels in 1961 and this does not appear to be explained by faster output growth rates of initially poor countries. This leaves open the possibility that faster technology absorption (including implementation of public health technologies related to sanitation for instance) of initially laggard countries, and other ‘exogenous’ non-income factors might actually be behind convergence in life expectancy.

Finally, higher education is an important determinant of health status and of improvements in future health outcomes. Education appears to have a dual role in determining health outcomes, with the impact of higher education at least as important as the impact of basic education in determining life

21 From Evans (1997) we know that the coefficient estimate for initial income and the implied rate of convergence will be downwardly biased here. As shown in the earlier paper, failing to account for all sources of heterogeneity across countries will have the same effect as measurement error on initial income biasing its coefficient estimate and the implied rate of convergence towards zero. Thus, we should view this evidence of convergence shown here as a lower bound and suggestive of even greater convergence rates in health status for initially poor countries.
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expectancy. The externality role of education in facilitating absorption of health-related knowledge in each recipient country appears to be no less important than the role of basic education in enhancing health outcomes. This last result is particularly interesting because growth regressions have established that primary education is the single most important determinant of income growth, while higher education is found to have little explanatory power (Sala-i-Martin, Doppelhofer and Miller 2004). Microeconomic evidence also suggests that primary education is more important than tertiary education in determining growth in income (e.g. Psacharopoulos 1994). Our findings suggest that higher education might be important for one component of welfare, health status, even if it is less important as a determinant of another component of welfare, real income per capita.

Bibliography


Weil, D. (forthcoming)“Accounting for the effect of health on economic growth” Quarterly Journal of Economics

### Appendix

#### A.1 Table A1: List of countries in the dataset

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<th>Country</th>
<th>Avg Life Expectancy</th>
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Table A1: List of countries cont.

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<tr>
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<tr>
<td>Sierra Leone</td>
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<td>Spain</td>
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<td>Sri Lanka</td>
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<tr>
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<td>Sweden</td>
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<td>Tanzania</td>
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<td>Venezuela</td>
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<tr>
<td>Zambia</td>
<td>38.4</td>
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<tr>
<td>Zimbabwe</td>
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</table>

1 This is the end of period average life expectancy from 1995 to 2004. Iceland is missing for the lags and IV models.
Table A2 (Considering end-of-period life expectancy changes)

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<thead>
<tr>
<th>Specif 3</th>
<th>Model 1</th>
<th>Model 1</th>
<th>Model 1</th>
<th>Model 2</th>
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<tr>
<td></td>
<td>Lags</td>
<td>PeriodAvg</td>
<td>Lags</td>
<td>PeriodAvg</td>
<td>Lags</td>
<td>PeriodAvg</td>
</tr>
<tr>
<td>INCOME</td>
<td>0.0002</td>
<td>(0.27)</td>
<td>0.0002</td>
<td>(0.35)</td>
<td>0.0003</td>
<td>(0.46)</td>
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<td></td>
</tr>
<tr>
<td>EDHA</td>
<td>0.050***</td>
<td>(2.84)</td>
<td>0.024**</td>
<td>(2.05)</td>
<td>0.060***</td>
<td>(2.72)</td>
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</tr>
<tr>
<td>EDBA</td>
<td>0.056**</td>
<td>(1.98)</td>
<td>0.040**</td>
<td>(2.07)</td>
<td>0.061**</td>
<td>(2.12)</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>AIDS</td>
<td>−0.004</td>
<td>(−1.62)</td>
<td>−0.003</td>
<td>(−1.14)</td>
<td>−0.004*</td>
<td>(−1.76)</td>
</tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>PHYS</td>
<td>0.099**</td>
<td>(2.42)</td>
<td>0.105***</td>
<td>(2.75)</td>
<td>0.089**</td>
<td>(2.48)</td>
</tr>
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<td></td>
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<tr>
<td>constant</td>
<td>0.001</td>
<td>(0.01)</td>
<td>0.004</td>
<td>(0.67)</td>
<td>−0.001</td>
<td>(−0.20)</td>
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</tr>
<tr>
<td>Adj. $R^2$</td>
<td>16.7</td>
<td>14.1</td>
<td>16.5</td>
<td>29.3</td>
<td>30.7</td>
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<tr>
<td>Obs.</td>
<td>66</td>
<td>66</td>
<td>66</td>
<td>63</td>
<td>63</td>
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</tbody>
</table>

Notes: Notes: * p-value less than ten percent, ** p-value less than five percent, *** p-value less than one percent. Heteroskedasticity-consistent finite sample standard errors are used in constructing t-statistics. All variables are in natural logarithms. Five countries, Bangladesh, Malawi, Mozambique, Singapore and Uganda are missing relative to the sample for Table 1. In addition, the physicians measure used in the specifications reported in columns four to six is missing for Ghana, Iceland and Sierra Leone. All variables other than the log of the initial (1961) level of real income per capita are in log changes. YGROWTH is the growth rate of real income per capita. For the *Period Avg* models, we consider the growth rate of life expectancy between 1977 and 2004 being explained by growth rates of the explanatory variables between 1961 and 1995. For the *Lags* model 1, we consider again the growth rate of life expectancy between 1977 and 2004 being explained by growth rates of the education variables between 1961 and 1975. Finally, for the *IV* Models 1 and 2, we instrument the 1961-95 period changes for the education variables using their beginning of period averages.

A.2 Technical Appendix: proof of proposition 1

**Preliminary.** Recall that

$$LHS (h) \equiv c_1 (h) + pm (h)$$

where $c_1 (h)$ and $m (h)$ are given by (13) and (12) respectively. Consider (14) and write it in implicit form as

$$F (h, x) \equiv c_1 (h) + pm (h) + w_x h - w_t = 0$$

where $x$ denotes a parameter with respect to which comparative statics exercises are performed. The we can compute

$$\frac{dh}{dx} = \frac{\partial F}{\partial x} = -\frac{\partial c_1}{\partial x} + \frac{\partial pm}{\partial x} + w_x h - \frac{\partial w_t}{\partial x}$$

Impact of $z$. An exogenous increase in $z$ shifts downward the $LHS$ schedule but leaves the $RHS$ unchanged. As a result $h$ must increase to restore individual optimality. As a consequence $\frac{dn}{dz} > 0, \frac{dp}{dz} > 0, \frac{dc_1}{dz} > 0, \frac{dp}{dz} < 0$.

Impact of $p$. An exogenous increase in $p$ shifts upward the $LHS$ schedule but leaves the $RHS$ unchanged. As a result $h$ must decrease to restore individual optimality (more so the greater is $\mu/\sigma$). As a consequence $\frac{dn}{dp} = \frac{\partial n}{\partial p} + \frac{\partial m}{\partial p} \frac{dh}{dp} < 0, \frac{dp}{dp} = \frac{\partial b}{\partial h} \frac{dh}{dp} < 0, \frac{dc_1}{dp} = \kappa \frac{\alpha}{1-\alpha} \frac{dh}{dp} < 0, \frac{dc_2}{dp} = \frac{\partial c_1}{\partial p} \frac{dh}{dp} > 0$.

Impact of $k$. An exogenous increase in $k$ shifts upward the $LHS$ schedule and downwards the $RHS$ (which pivots on its vertical intercept). As a result $h$ must decrease to restore individual optimality. As a consequence $\frac{dn}{dk} = \frac{\partial n}{\partial k} + \frac{\partial m}{\partial k} \frac{dh}{dk} = m \{ 1 - \eta (1 - \frac{h}{\tau + h}) \} \frac{dk}{dk} \frac{dh}{dk} < 0, \frac{dp}{dk} < 0, \frac{dc_2}{dk} < 0, \frac{dc_1}{dk} = -w_x \frac{dh}{dk} - k \frac{dm}{dk}$.
We have
\[ \frac{dh}{dk} = -\frac{\frac{1-\mu}{\sigma} h + p_m + w_k h}{\frac{1}{\sigma} (1-\eta) (1-\mu) + \eta (\sigma - \mu) \frac{h^n}{1+h^n} + \frac{1}{\alpha} \frac{1}{\kappa} \frac{1}{w_t+1} \left( \frac{1-\theta}{\kappa} \frac{1}{w_t+1} \right)^{\sigma-1} } \]
\[ \frac{dk}{dh} = -\frac{\frac{1-\mu}{\sigma} c_1 + pm + w_k h}{\frac{1-\mu}{\sigma} \frac{h^n}{1+h^n} + pm \left[ 1 - \eta \left( 1 - \frac{h^n}{1+h^n} \right) \right] + w_k h} \]

The impact on expenditure on education, \( w_k h \), is given by
\[ \frac{d(w_k h)}{dk} = w_k h \left( 1 + \frac{dh}{dk} \right) \]

Therefore
\[ \frac{d(kh)}{dk} < 0 \quad \text{iff} \quad \left| \frac{dk}{dh} \right| > 1 \]

which is always satisfied given that \( \left[ 1 - \eta \left( 1 - \frac{\sigma - \mu}{1-\mu} \frac{h^n}{1+h^n} \right) \right] \in (0, 1) \) and \( \left[ 1 - \eta \left( 1 - \frac{h^n}{1+h^n} \right) \right] \in (0, 1) \).

Moreover from (12) we have that
\[ \frac{dm}{dk} = 1 + \left[ 1 - \eta \left( 1 - \frac{h^n}{1+h^n} \right) \right] \frac{dk}{dh} \]

Therefore
\[ \frac{dm}{dk} < 0 \quad \text{iff} \quad \left| \frac{dk}{dh} \right| > \left[ 1 - \eta \left( 1 - \frac{h^n}{1+h^n} \right) \right]^{-1} \]

According to the computed \( \left| \frac{dk}{dh} \right| \) the last inequality is equivalent to
\[ \left[ \frac{1-\mu}{\sigma} c_1 + pm + w_k h \right] \left[ 1 - \eta \left( 1 - \frac{h^n}{1+h^n} \right) \right] + \frac{1-\mu}{\sigma} c_1 \left[ 1 - \eta \left( 1 - \frac{\sigma - \mu}{1-\mu} \frac{h^n}{1+h^n} \right) \right] + pm \left[ 1 - \eta \left( 1 - \frac{h^n}{1+h^n} \right) \right] + w_k h \]

Next substituting for \( c_1 \)
\[ \frac{1-\sigma}{\sigma} \left( \frac{1-\sigma}{\mu} \right)^\mu \frac{1}{\rho a z} \left( \frac{k}{\eta} \right)^{1-\mu} \left( \frac{1-\theta}{\kappa} \frac{1}{w_t+1} \right)^{\sigma-1} \frac{1}{\sigma} h^{\frac{1}{\sigma} (1-\eta)(1-\mu)} (1+h^\eta)^{\frac{\alpha-\mu}{\sigma}} > w_k h^{1-\eta} \]
\[ \left( \frac{1}{\rho a z} \left( \frac{p}{\mu} \right)^{\mu} \eta^{-1-\mu} \right)^{-\sigma} \left( \frac{1-\theta}{\kappa} \frac{1}{w_t+1} \right)^{-1-\sigma} \left( 1 - \sigma \right)^{\sigma+\mu} \left( k w_t \right)^{-\left( \sigma+\mu-1 \right)} \frac{1}{\sigma} (1+h^\eta)^{\frac{\alpha-\mu}{\sigma}} > h^{(1-\eta)^{\frac{\alpha-\mu}{\sigma}}} \]

Both sides of this inequality are increasing and concave in \( h \) if the following is satisfied
\[ \bullet \quad \sigma > 1 - \mu \]

The left-hand-side of the inequality starts above zero with finite slope, while the right-hand-side starts at zero with infinite slope. For low levels of \( h \), and under the assumption that \( \sigma > 1 - \mu \), we have that \( \frac{dm}{dk} < 0 \), implying \( \frac{dk}{dh} < 0 \).

A sufficient condition for this to be the case (when \( \sigma > 1 - \mu \)) is that for \( h = 1/k \) the inequality still
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holds:

$$\left( \frac{1}{\rho \alpha z} \left( \frac{p}{\mu} \right) \eta^{-(1-\mu)\sigma - \sigma} \left( 1 - \frac{\theta}{\kappa} w_{t+1} \right)^{-(1-\sigma)} (1 - \sigma)^{\sigma + \mu} w_t^{-\sigma + \mu - 1} \right) \frac{1}{1 + k^{-\eta} \frac{\sigma + \mu}{\sigma + \mu - 1}} > k^{\frac{\sigma + \mu - 1}{\sigma}}$$

a restriction on parameters configurations that is satisfied in particular for sufficiently low values of $k$.

Figure 1: The equilibrium level of education: a representation of condition (14)