Extended Abstract

The Preston curve illustrates that life expectancy (LE) increases with GDP per capita with diminishing returns at higher income[5]. This observed relationship is most commonly represented as a log-linear function: LE = a ln (GDP) + b. Over the 20th century, there has been an upward shift in the Preston curve (Preston, 1975); this effect is primarily attributed to the development and adoption of low-cost health technologies (such as immunization and oral rehydration), as well as nutrition, sanitation and female education (Bloom and Canning, 2007 and Cutler, Deaton, Lleras-Muney, 2006). Although the conventional log-linear relationship captures the overall relationship of income and mortality, its empirical form does not enable deeper analyses of achievable mortality at varying income levels.

Here we apply a statistically equivalent re-parameterization of the Preston curve characterized by two coefficients: maximum survival in high GDP countries and K_{inc} - critical income or the income needed for half of maximum survival. A modified algebraic model of the Preston curve is proposed such that in a given year (*i*) when the wealthiest countries have a maximum life expectancy ($LE_{max,i}$), the life expectancy in a country (*c*) with per capita income in parity with purchasing-power (and at constant or inflation-adjusted dollar) of $GDP_{c,i}$ is given by:

$$LE_{c,i} = \frac{LE_{\max,i} \times GDP_{c,i}}{GDP_{c,i} + K_{inc,i}}$$

This model includes two physically meaningful parameters: maximum survival and critical income, a previously undocumented parameter that represents the efficiency of levels of income in achieving half of the maximal survival. The values of these parameters over time can be extracted from global mortality data. To study the age-specific contributions to changes in life expectancy, we analyze the probability of newborns dying before age five (5q0) and the gender-specific probability of 15-year-olds reaching the age of 60 (45q15). The corresponding function for the percentage of children that survive to the age of 5 (5q0%), and for adults that survive from the age of 15 to 60 (45q15%), by gender, are:

$$5q0\%_{c,i} = \frac{5q0\%_{\max,i} \times GDP_{c,i}}{GDP_{c,i} + K_{inc,i}} \qquad \text{and} \qquad 45q15\%_{c,i} = \frac{45q15\%_{\max,i} \times GDP_{c,i}}{GDP_{c,i} + K_{inc,i}}$$

Figure 1 shows the model fit of life expectancy between 1970 and 2007. Maximal life expectancy rose from 67.8 ± 2.4 years in 1970 to 75.5 ± 1.6 years in 2007, representing an increase of 2.5 ± 0.9 months per year. This is consistent with the life expectancy increase of three months per calendar year reported for the 20th century (Oeppen and Vaupel, 2002).

Maximum survival for all age groups rose at statistically the same rate between 1970 and 2007 (figure 2a). Child survival to age 5 increased from 94.5% ± 1.8 to 98.0% ± 0.6, rising 0.8% ± 0.5 per decade; adult female survival at ages 15 to 59 years rose from 85.9% ± 0.8 to 90.1% ± 1.2 for an increase of 1.1% ± 0.5 per decade; and adult male survival at ages 15 to 59 years rose from 77.7% ± 1.0 to 82.1% ± 2.9 for a rise of 1.1% ± 0.6 per decade.

It is cheaper to increase life expectancy now than it was 40 years ago. The critical income needed to achieve half of maximal overall life expectancy declined (in constant 2005 international dollars) from $540 ± 108 in 1970 to $442 ± 84 in 2007, equivalent in 2007 to the extreme poverty line of $456 per year (or $1.25 per day). This represents an 18% decrease in cost for almost four more years of additional life expectancy.

However, critical incomes diverged dramatically for children and adults (figure 2b). The critical income for child survival fell by over half from $210 ± 44 to $88 ± 16, but more than doubled for adult male survival from $199 ± 61 to $437 ± 141, and rose over 50% for adult female survival from $208 ± 49 to $324 ± 86.

High-income countries are far less constrained by income requirements to achieve the maximum survival, whereas critical income has a more direct implication for the very poorest countries. This has led to a divergence in mortality between high- and low-income countries. Figure 3 shows the model fit for adult male survival between 1970 and 2007 deviating from a simple upward rising Preston curve. As shown, countries with

income less than $4000 per capita (under the World Bank definition of upper-middle income country) achieved higher survival rates in 1970 than in 2007 for any given income. For the 88 countries with income less than $4000 in 1970 or 2007, there was a mean increase of almost $2850 in GDP per capita with a corresponding mean increase of 5 deaths per thousand.

For adult males, removing the 10 countries with an HIV prevalence of greater than 5% in the year 2000 reduced the critical income from $740 (484-996) to $303 (188-425). Further removing the 47 countries where tobacco consumption per capita was higher than 1000 cigarettes per year reduced the critical income to $225 (53-397) compared to all nations, or not statistically different from the 1970 critical income value for adult male survival of $199 (138-260).

A preliminary first differences analysis further indicates the significant impact country specific factors can have on the critical income. For adult males in low and lower-middle income countries, a 1% increase in HIV prevalence can result in $270 increase in the critical income from 1990 to 2000. Further supporting the role of health technologies, a 10% increase in DTP vaccinations can reduce the critical income by $117. By expanding the analysis to include upper-middle and high-income countries, country specific variance in access to sanitation, years of male education, percentage of foreign direct investment and smoking prevalence all appear to have significant impact on the critical income as well.

Figure 1: Re-parameterization of the Preston curve for the years 1970 and 2007

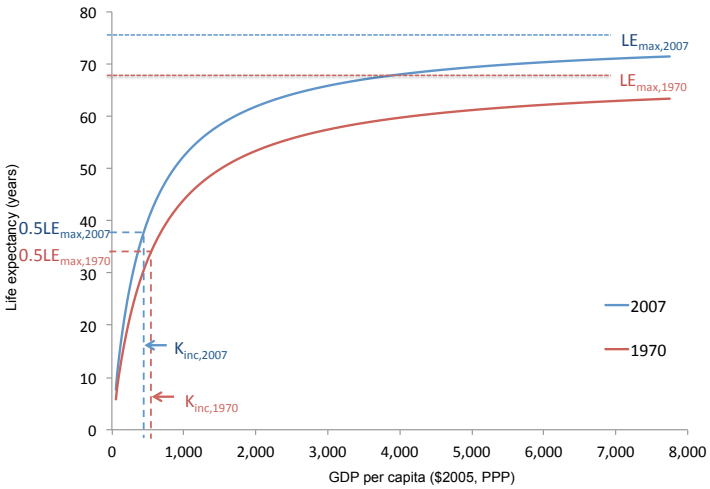

Figure 2: Child (5q0) and adult male and female (45q15) maximum survivals and critical incomes from 1970 to 2007.

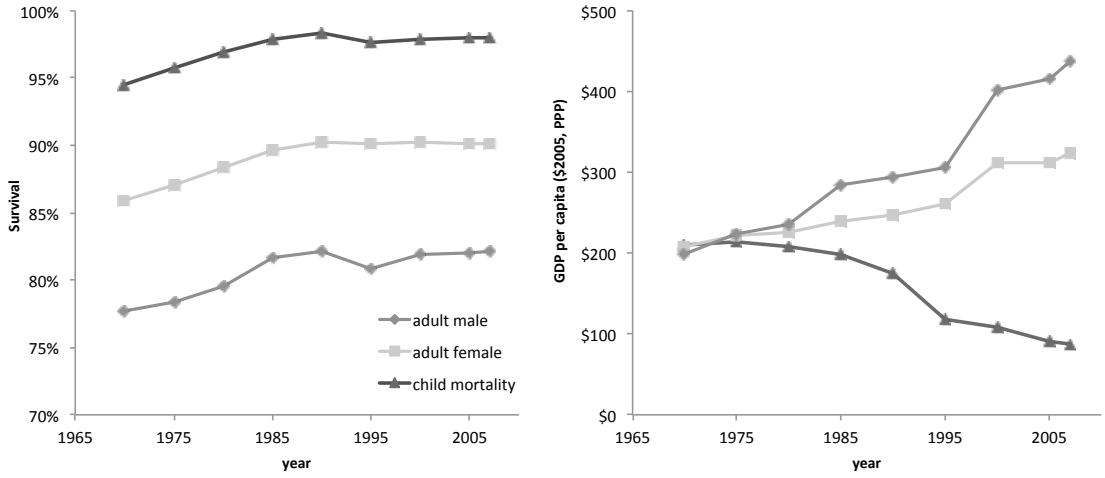

Figure 3: Impact of critical income changes on adult male (45q15) survival for the years 1970 and 2007