Health and Economic Development from Cross-Country Perspectives

Ping Wang and Yin-Chi Wang

In this article, we provide a comprehensive overview of the role that health plays in economic development. We study cross-country differences in income and health and examine the underused value-of-life and life-year gain measures. In particular, we compare two value-of-life measures, one based on life expectancy and lifetime utility, and the other based on adult mortality and life insurance data. We find that the perception and receptiveness of life insurance are likely better in countries at more advanced stages of economic development. The value-of-life measure based on life insurance data is thus biased upward and downward for developed and developing countries, respectively. We then summarize the strand of theoretical literature and provide several modeling ingredients potentially useful for establishing an integrated analytic structure for understanding the role that health plays in the process of economic development. (JEL I15, O11, O15)

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1 INTRODUCTION

Over the past several decades, we have observed large and persistent disparities in per capita real income across countries. For example, based on our data sample of 80 countries, documented in the next section, the top 10 percent of countries had, on average, relative real income per worker about 85 percent of the U.S. level in 1960, whereas the bottom 10 percent of countries had an average of about 4.0 percent; the comparable figures became 95 percent and 2.5 percent, respectively, in 2010. That is, the ratio of the top 10 percent to the bottom 10 percent of relative income widened from 21 to 38 over 50 years. Such disparities have generated a sizable literature of development accounting, attempting to disentangle the underlying sources causing the income gaps. While the literature has offered extensive studies on potential drivers—particularly factors affecting physical, knowledge, and research capital accumulation—the roles played by health capital have been largely ignored.

Ping Wang is a research fellow at the Federal Reserve Bank of St. Louis, a professor at Washington University in St. Louis, and a research associate at the National Bureau of Economic Research. Yin-Chi Wang is an assistant professor at National Taipei University.

In this article, we provide a comprehensive overview of such roles based on individual decisionmaking. We begin by providing in Section 2 an overview of some well-known cross-country disparities in incomes and education-based measures of human capital. We then construct in Section 3 various measures that illustrate health disparities during 1960-2010. Specifically, we study cross-country differences in the following two most commonly used health measures: life expectancy at birth and adult mortality. We further examine the underused value-of-life and life-year gain measures. While some measures have been analyzed previously, the purpose of our article is to offer a deeper look using a unified framework with a broader set of cross-country data. In particular, to produce more robust findings, we group countries by their stage and speed of development because it is likely that some within-group disparities may exhibit distinct patterns.

Our data analysis enables us to establish several stylized facts. During 1960-2010, the disparity in relative real income per worker widened across countries. A higher income level made it more possible to have a better education and better health in 2010 than in 1960. Despite the overall improvement in health as measured by life expectancy, the adult mortality rate did not experience steady improvement in 1990-2000, most plausibly due to the spread of HIV. In our preferred wealth-based measure of value of life, the United States experienced a 2.5-fold increase in the value of life over the 1960-2010 50-year interval. We also find that the relative position of countries with low growth rates is deteriorating in both the relative income (falling from 32 percent to 20 percent) and relative value of life (falling from 28 percent to 20 percent), where those slow-growing countries experience a modest increase in life expectancy.

With these stylized facts in mind, we would like to call attention to the fact that, in this research area, it is "theory behind empirics." In Section 4, we thus summarize the strand of theoretical literature and provide several modeling ingredients potentially useful for establishing an integrated analytic structure for understanding the role health plays in the process of economic development. To be more clear, our discussion is organized around the following two fundamental relationships: health production and health evolution. In Section 5, we examine the role of health in economic development from various perspectives, including morbidity and productivity, health investment incentives, quality of life, the contribution of health to growth, and barriers to better health.

We acknowledge there are several dimensions of difficulty in constructing a unified framework that may suit all countries at different development stages. Thus, the reader should view our article as a "first-step organizing framework" toward analyzing the issue concerning health and economic development from cross-country perspectives—one that goes over several useful stylized facts based on cross-country data.

2 CROSS-COUNTRY INCOME AND EDUCATION DISPARITIES

To facilitate cross-country analysis, we adopt income- and year-of-schooling-based human capital data from the Penn World Table 9.0 and health data from the World Development Indicators (WDI) database. To compute relative income measures, we use the United States as the benchmark. That is, relative income of country i is the ratio of its output-based

Table 1

Difference of Life Expectancy at Birth by Country Group

	Classification by initial development stage				Classification by development speed			
Year	Low	Middle-low	Middle-high	High	Low	Stable	High	Rapid
1960	–25.409	–19.426	–10.062	–2.136	–19.804	–15.472	–8.522	–10.121
1970	–21.386	–16.355	–6.861	–1.336	–17.122	–12.322	–6.037	–5.981
1980	–19.704	–14.461	–5.928	–1.450	–15.402	–11.72	–5.351	–4.786
1990	–18.609	–12.296	–4.258	–0.673	–13.942	–10.828	–3.805	–2.955
2000	–17.816	–11.099	–3.426	0.057	–13.743	–9.819	–2.420	–1.967
2010	–14.106	–9.035	–2.863	0.434	–11.432	–7.697	–1.668	–0.806

SOURCE: PWT 9.0, WDI, and authors' calculations.

real GDP per worker to the comparable figure of the United States. In total, we have 80 countries with data since 1960.[1]

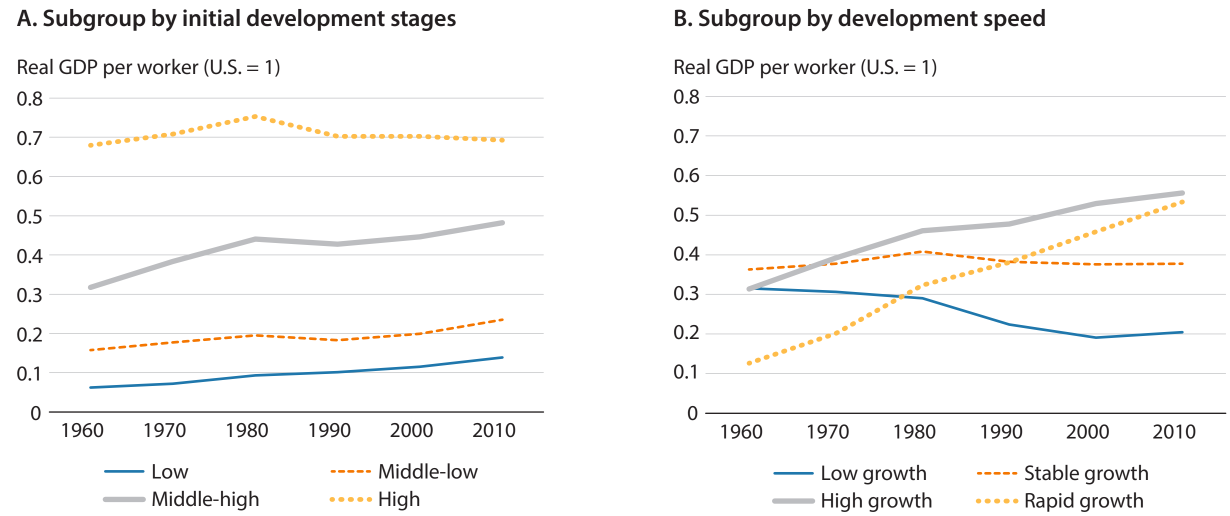
We classify countries based on both their initial development stage measured by relative income in 1960 and their development speed measured by the growth of relative income during 1960-2014. For each classification, we categorize countries into four subgroups. For the first classification, we categorize countries as initially low income if their relative income in 1960 is below 0.1; middle-low income if their relative income in 1960 is between 0.1 and 0.2; middle-high income if their relative income in 1960 is between 0.2 and 0.5; and high income if their relative income in 1960 is above 0.5. For the second classification, we categorize countries as low growth if their relative income growth is below –1 percent; stable growth if their relative income growth is between –1 percent and 0.5 percent; high growth if their relative income growth is between 0.5 percent and 2 percent; and rapid growth if their relative income growth is above 2 percent.

We then compute the mean relative income of each subgroup and report in Table 1 the number of countries in each classification. Results based on initial development stage and development speed classifications are shown in Figures 1A and 1B, respectively. We can observe from Figure 1A that the initially middle-high-income group was distinctive in narrowing its income gap between the initially high-income group. From Figure 1B, other than observing the fast increase in income of the rapid-growth group, one cannot seemingly ignore the pattern of large and widening income disparities across countries during 1960-2010.

To contrast with health capital, we also look at knowledge-based human capital using a year-of-schooling measure. We compute education disparity using the ratio of average (knowledge-based) human capital in each subgroup relative to that of the United States for every 10 years starting in 1960. The results are summarized in Figures 2A and 2B. We can observe from Figure 2A that the middle-low group improved its human capital the most during 1960-2010. We can also observe from Figure 2B that the rapid-growth group has overtaken other groups in educational attainment since 1990.

Figure 1

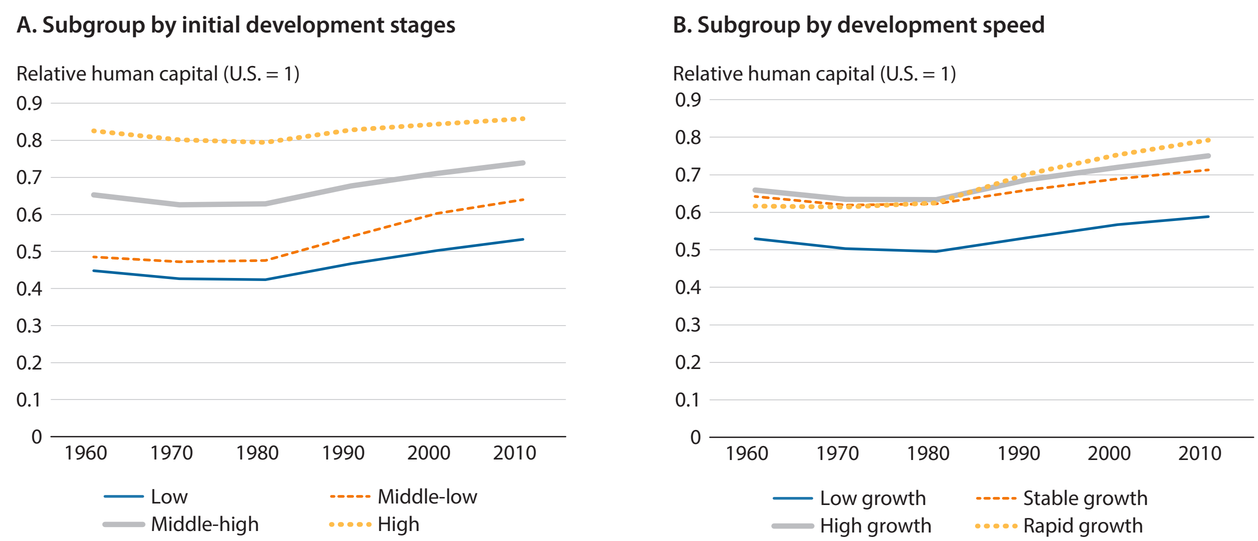
Relative Real GDP per Worker



SOURCE: Penn World Table (PWT) 9.0 and authors' calculations.

Figure 2

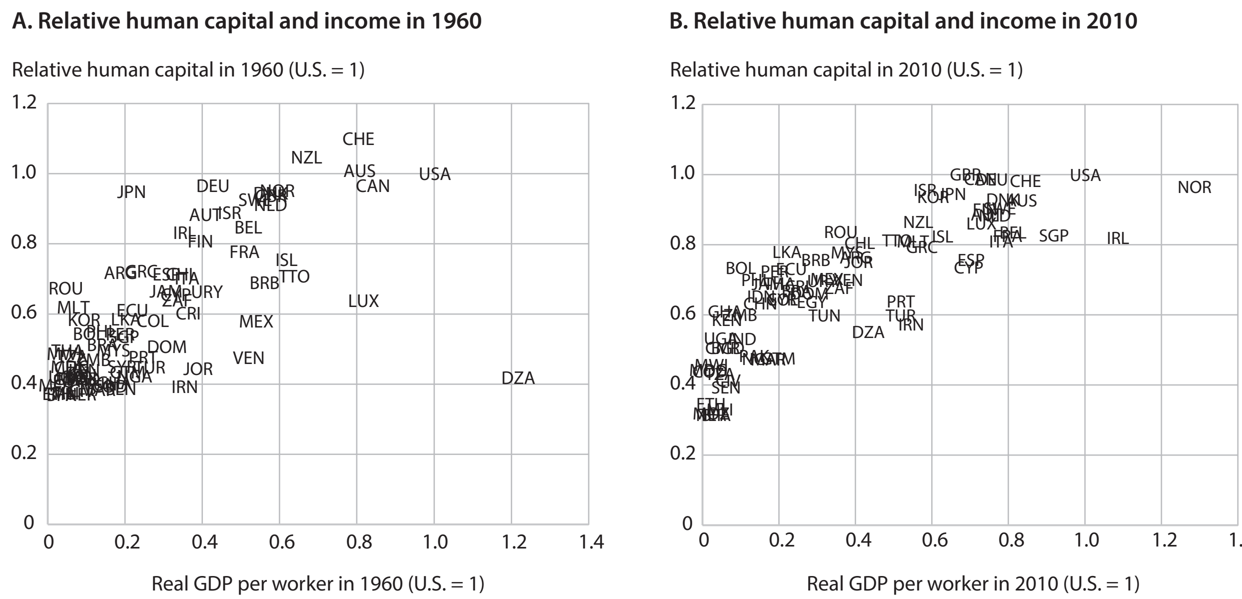
Relative Human Capital Across Country Groups



SOURCE: PWT 9.0 and authors' calculations.

Figure 3

Relative Human Capital vs. Real GDP per Worker



SOURCE: PWT 9.0 and authors' calculations.

To see the relationship between income and education, we provide a scatter plot of each country's relative income (horizontal) and relative human capital (vertical), both in the initial year of 1960 and in 2010 (Figures 3A and 3B, respectively). In comparison with the case in 1960, the positive relationship between relative income and relative human capital is tighter in 2010. This suggests that it is likely other factors played an important role, at least in earlier periods.

3 CROSS-COUNTRY HEALTH DISPARITIES

In this section, we will study cross-country disparities of various health outcome measures and the trend in such disparities. Health measures include the more commonly used life expectancy-at-birth and adult-mortality measures, as well as the underused value-of-life measure.

3.1 Life Expectancy

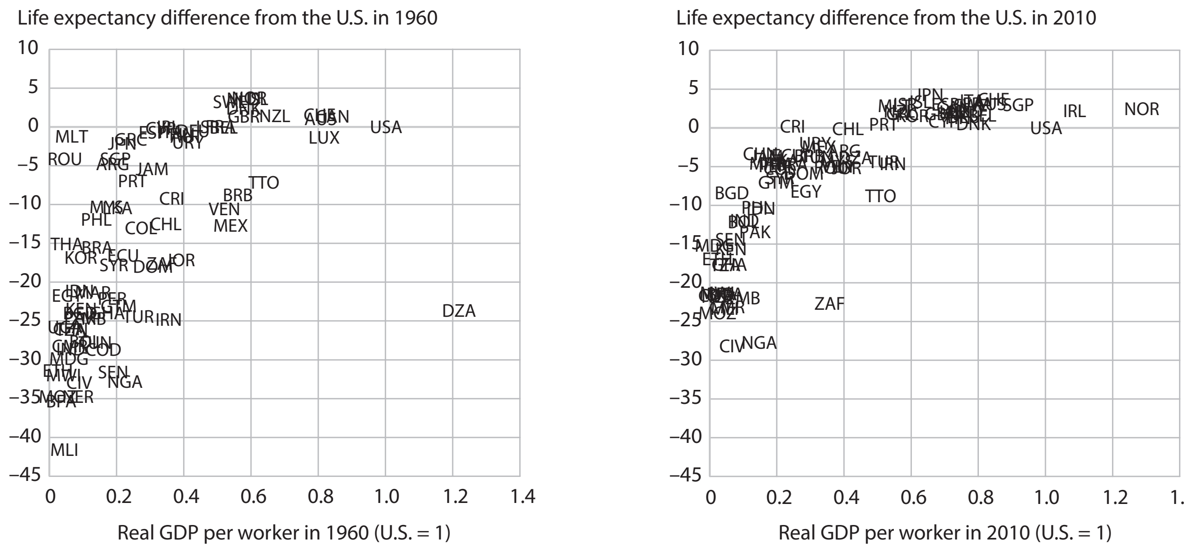
Using WDI data, we observe that in 1960 life expectancy disparities were severe: While life expectancy in advanced countries such as Iceland, the Netherlands, and Norway was 73 years, that in poor countries such as Mali was below 30 years. Moreover, despite a worldwide increase in life expectancy, there still existed large disparities in 2010, ranging from only 50 years in poor countries such as Côte d'Ivoire and Nigeria to more than 82 years in advanced countries such as Japan and Sweden.

Figure 4

Life Expectancy Difference vs. Real GDP per Worker

A. Life expectancy difference and relative income in 1960

B. Life expectancy difference and relative income in 2010



SOURCE: PWT 9.0, WDI, and authors' calculations.

To gain better insight, we compute the relative life expectancy, defined as the difference in life expectancy between those in each country and those in the United States for every 10 years starting in 1960. We then calculate the mean of each subgroup in the two classifications. The results are reported in Table 1. It is noticeable that life expectancies and, hence, health conditions of all subgroups improved greatly over the 50-year interval, but at a diminishing rate, with low-income and middle-low-income groups (columns 2 and 3) and low- and stable-growth groups (columns 6 and 7) fast improving. Such improvement suggests that health capital plays a crucial role, particularly during earlier stages of economic development.

The relationship between income and life expectancy is depicted by scatter plots of each country's relative income (horizontal) and relative life expectancy (vertical) in 1960 and 2010 (Figures 4A and 4B, respectively). As we have mentioned, life expectancy around the world improved enormously during 1960-2010. Similar to that for human capital, there is also a notable phenomenon that longer life expectancies and higher relative income levels tend to connect more closely in 2010 than they do in 1960.

3.2 Mortality

In the literature, adult mortality rate, defined as the probability of a 15-year-old dying before reaching age 60 (per 1,000 adults), is considered a good measure of health during working years and the most relevant health indicator for the level of output per worker. We

Table 2

Adult Mortality Rate Difference by Country Group

	Classification by initial development stage				Classification by development speed			
Year	Low	Middle-low	Middle-high	High	Low	Stable	High	Rapid
A. Adult mortality rate difference, per 1,000 adult males								
1960	186	136	38	–17	136	96	27	52
1970	128	93	6.3	–26	96	69	–4	0.2
1980	127	96	32	–10	98	81	20	9.3
1990	146	97	26	–16	104	96	11	2.3
2000	185	107	38	–12	137	118	10	13
2010	134	80	26	–22	108	81	–4	–5
B. Adult mortality rate difference, per 1,000 adult females								
1960	237	186	78	15	185	136	71	79
1970	185	143	45	1.4	149	105	39	32
1980	163	124	40	5.9	131	100	33	22
1990	160	107	26	1.5	120	102	18	7.8
2000	185	99	25	–6	138	111	6.3	1.5
2010	132	65	17	–13	102	76	–5	–9.4

SOURCE: PWT 9.0, WDI, and authors' calculations.

therefore take male and female adult mortality rate data from WDI, compute the mortality difference between those in each country and those in the United States, and then calculate the mean mortality rate for each subgroup for every 10 years starting in 1960. We summarize the results for males and females in Tables 2A and 2B, respectively. Different from the steadily improving pattern observed in life expectancy for low-income, middle-low-income, low-growth, and stable-growth groups, the declining trend in adult mortality was interrupted during 1990-2000, most plausibly due to the spread of HIV and AIDS-related deaths.

The relationships between income and male and female mortality rates are depicted by scatter plots of each country's relative income (horizontal) and mortality difference (vertical) in 1960 and 2010 (Figures 5A and 5B, respectively). It can be observed that the decrease in female mortality is much more prominent than that for male mortality: During the 50-year interval, the average adult female mortality is reduced by 60.42 percent, whereas the average adult male mortality is reduced by 35.68 percent. Still, the same pattern exists: The relationship between higher income and better health becomes stronger over time.

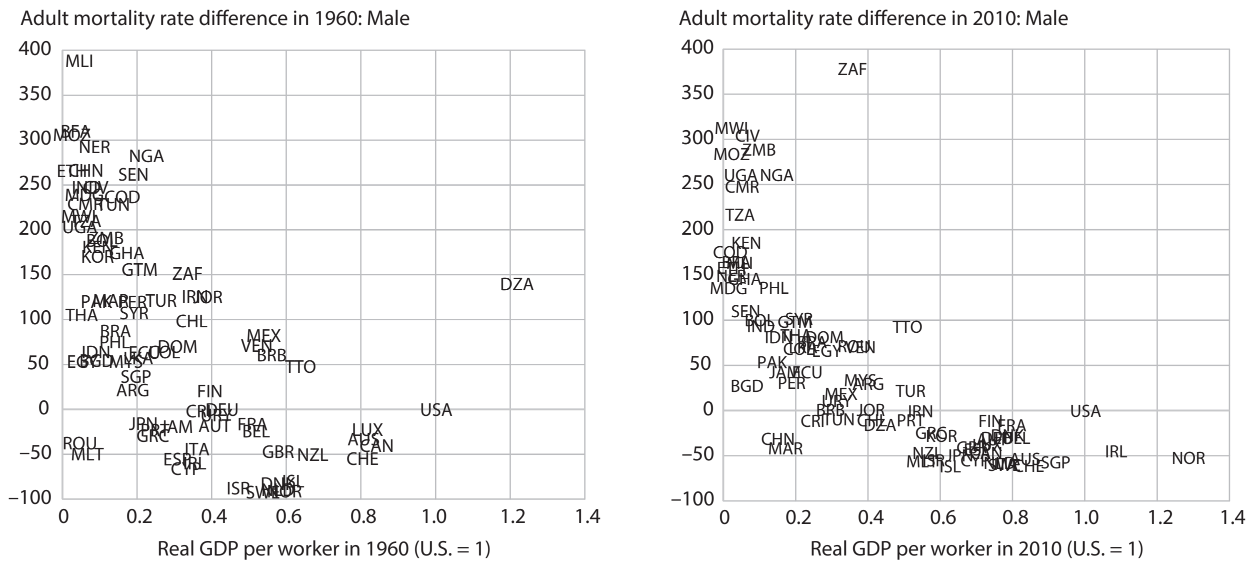
3.3 Value of Life

Value of life has been more systematically discussed since the pivotal contributions by Rosen (1988) and Ehrlich and Chuma (1990), more recently explored by Murphy and Topel (2006); Hall and Jones (2007); Jones (2016); and Chen, Wang, and Yao (2017).

Figure 5

Adult Mortality Rate Difference vs. Real GDP per Worker

A. Adult mortality rate differences, male



B. Adult mortality rate differences, female

SOURCE: PWT 9.0, WDI, and authors' calculations.

The conventional empirical measure is the value of a statistical life (VSL), which is the willingness to pay for saving a life. Such figures in the United States range from about $2 million (CPI adjusted to 2009 constant U.S. dollars) estimated by Ashenfelter and Greenstone (2004) to almost $7 million estimated by Costa and Kahn (2004). Viscusi and Aldy (2003) provide a detailed review on the VSL for the United States as well as Canada, the United Kingdom, Japan, and six additional countries, showing that the figures vary greatly across studies for any single country. As there is no systematic and consistent cross-country measure on the value of life, with reasonable simplifying assumptions we propose two cross-country measures on the value of life below. The first measure is based on a standard perpetual youth model. The second measure is based on available life insurance data. We will refer to the first measure as a model-based value of life, and the second measure as a life insurance-based value of life.

3.3.1 Model-Based Value of Life. Consider a standard continuous-time lifetime utility of an average individual with a simple flow indirect utility taking a constant intertemporal elasticity of substitution form, given by

(1)
$$v(y)=\frac{y^{1-1/\sigma}-1}{1-1/\sigma},$$

where y is per capita real income and σ is the intertemporal elasticity of substitution. Under the concept of permanent income, y is constant, measured by the average over a relevant time period.

Should mortality be chosen as the health outcome measure, one may compute a flow mortality rate μ and, given a constant time preference rate of $\rho > 0$, obtain lifetime utility under a commonly used value of $\sigma = 0.5$ as

(2)
$$V=\int_0^\infty \frac{y^{1-1/\sigma}}{1-1/\sigma}e^{-(\rho+\mu)t}dt=\frac{-y^{-1}}{\rho+\mu},$$

where t is time index and where we have omitted the –1 term because it only adds a constant when we integrate the flow indirect utility and so would not affect the result.

When life expectancy is chosen as the health outcome measure, we can no longer set $\sigma = 0.5$. This is because with negative flow indirect utility, life expectancy becomes an inferior good—the longer it is, the lower lifetime utility will be (see the discussion by Murphy and Topel, 2006). There are two ways to fix the problem: The first way is to assume the flow utility takes a natural log form (i.e., $\sigma = 1$); the second way is to consider a wealth-based value-of-life measure by assuming the flow utility takes a linear form (i.e., $\sigma = \infty$). If assuming a natural log flow utility function, one must ensure that the utility flow is positive either by adjusting the unit a la Murphy and Topel (2006) and Chen, Wang, and Yao (2017), or by adding a constant—say, one—to the log function a la Hall and Jones (2007) and Jones (2016). In the former case, $v(y) = \ln y$, where y is required to exceed the subsistence level of one. In the latter case, $v(y) = \ln(1+y)$, but such a constant distorts the relative disparity across countries: The flow utility value in poor countries is upward biased and that in rich countries is downward biased.

Table 3

Model-Based Value of Life and Gain from One Additional Life-Year for the U.S.

	Thousands of 2011 U.S. dollars					
	1960	1970	1980	1990	2000	2010
Value of life	1715.058	2189.127	2512.401	2900.608	3667.607	4273.283
Gain from one additional life-year	11.184	13.888	14.812	16.406	20.002	22.205

SOURCE: Authors' calculations.

Nonetheless, the lifetime utility in both cases is curved downward due to the property of the natural log function. We thus choose the wealth-based value-of-life measure, and the lifetime utility given life expectancy T becomes

(3) $$V = \int_0^T y \cdot e^{-\rho t} dt = \frac{y}{\rho}\left[1 - e^{-\rho T}\right].$$

Now we are prepared to define the final measure. Notice that one must convert the adult mortality rate at advanced ages to the flow mortality rate measure μ. In a cross-country study with a wide range of life expectancy outcomes, such conversion is likely sensitive to the age at which mortality is measured. The life expectancy-based measure given by equation (3) is, on the contrary, more robust for a cross-country comparison, which is why we chose it as the value-of-life measure in this study. Accordingly, gain from one additional life-year is given by

(4) $$\vartriangle V = \frac{y}{\rho}\left[e^{-\rho T} - e^{-\rho(T+1)}\right],$$

while relative value of life in country j measured against that in the United States becomes

(5) $$\frac{V_j}{V_{US}} = \frac{y_j}{y_{US}} \frac{1 - e^{-\rho T_j}}{1 - e^{-\rho T_{US}}}.$$

In our 80-country sample of income data at 10-year intervals from 1960-2010, the lowest real GDP per worker is $1,093 (2011 U.S. dollars) in Mozambique in 1960. We thus choose to express y in terms of thousands of 2011 U.S. dollars. Following the literature, the annual time preference rate ρ is set at 0.02. We first compute and report in Table 3 the value of life and gain from one additional life-year for the United States at 10-year intervals from 1960-2010. Our computed value of life for the United States ranges from $1.72 million in 1960 to $4.27 million in 2010, falling into the range of the existing computed value of life for the United States, and the value of a life-year gain is more than $20,000 since 2000. Over the 50-year interval, the value of life and the value of a life-year gain increased the most during 1960-70 and 1990-2000, mainly due to the fast increase in income levels.

To reveal cross-country health disparities, we compute the mean value of life, the mean gain from an additional life-year, and the mean relative value of life for each subgroup in the

Table 4

Model-Based Value of Life by Country Group

Year	Thousands of 2011 U.S. dollars: Classification by initial development stage: Low	Middle-low	Middle-high	High	Classification by development speed: Low	Stable	High	Rapid
1960	83.309	228.380	494.682	1136.661	482.053	584.591	520.038	206.387
1970	134.468	346.274	805.317	1530.893	619.524	801.374	840.278	431.553
1980	213.126	455.670	1077.642	1873.848	684.960	999.900	1143.189	802.844
1990	273.836	505.487	1227.043	2034.931	625.341	1094.681	1375.646	1099.705
2000	401.778	710.074	1630.365	2586.140	680.036	1368.325	1940.069	1680.754
2010	571.276	982.961	2049.406	2975.411	848.182	1597.444	2379.360	2290.207

SOURCE: Authors' calculations.

Table 5

Model-Based Gain from Additional Life-Year by Country Group

Year	Thousands of 2011 U.S. dollars: Classification by initial development stage: Low	Middle-low	Middle-high	High	Classification by development speed: Low	Stable	High	Rapid
1960	1.157	2.618	4.263	8.157	4.694	4.539	3.869	1.604
1970	1.465	3.312	6.014	10.210	5.250	5.726	5.814	2.955
1980	1.837	3.577	7.132	11.534	5.176	6.539	7.115	4.966
1990	2.086	3.495	7.285	11.567	4.179	6.551	8.002	6.332
2000	2.716	4.432	9.076	13.824	4.236	7.719	10.582	9.143
2010	3.516	5.675	10.947	15.049	5.066	8.650	12.277	11.638

SOURCE: Authors' calculations.

two classifications at 10-year intervals from 1960-2010 and report the results in Tables 4, 5, and 6, respectively. We can see from Tables 4 and 6 that the initially low-income group increases the most in its value of life because of a big improvement in life expectancy in these countries. On the contrary, the low-growth group increases the least and lags behind other groups in their value of life. As for the gain from an additional life-year, of particular notice are the fluctuations and setback experienced by only the low-growth group: The stable- and high-growth groups increase steadily in their life-year gains, and the rapid-growth group even experienced a fast increase and overtook the stable-growth group during 1990-2000.

We also illustrate in scatter plots the relationship between income and the difference in gain from an additional life-year for each country relative to that of the United States for

Table 6

Model-Based Relative Value of Life by Country Group (U.S. = 1)

	Classification by initial development stage				Classification by development speed			
Year	Low	Middle-low	Middle-high	High	Low	Stable	High	Rapid
1960	0.049	0.133	0.288	0.663	0.281	0.341	0.303	0.120
1970	0.061	0.158	0.368	0.699	0.283	0.366	0.384	0.197
1980	0.085	0.181	0.429	0.746	0.273	0.398	0.455	0.320
1990	0.094	0.174	0.423	0.702	0.216	0.377	0.474	0.379
2000	0.110	0.193	0.445	0.705	0.185	0.373	0.529	0.458
2010	0.134	0.230	0.480	0.696	0.198	0.374	0.557	0.536

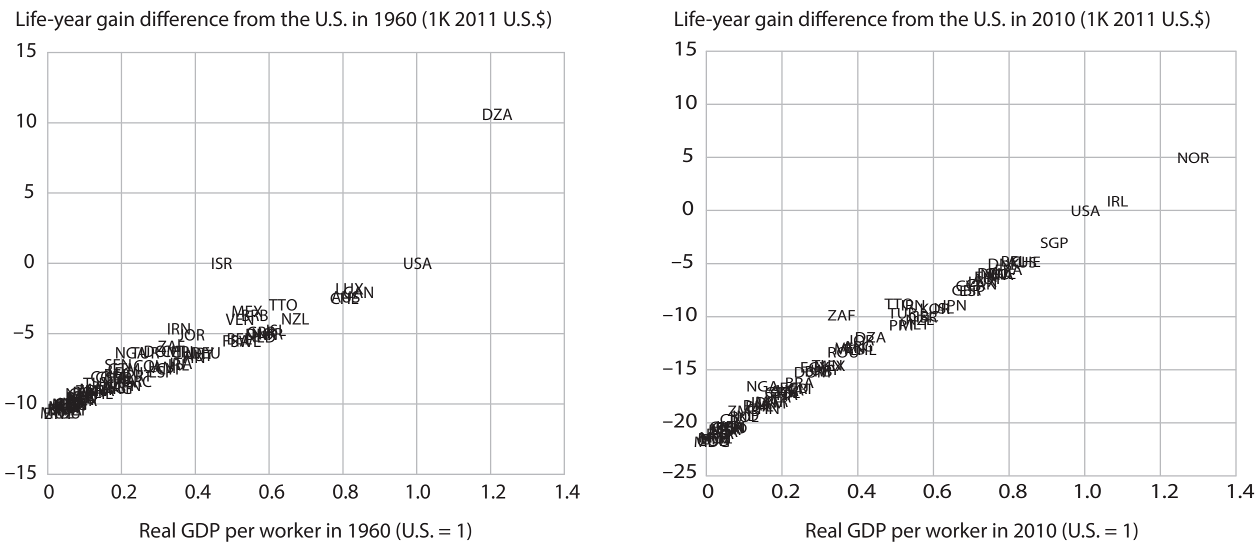
SOURCE: Authors' calculations.

Figure 6

Difference in Value of an Additional Life-Year from the U.S. vs. Real GDP per Worker

A. Life-year gain difference and relative income in 1960

B. Life-year gain difference and relative income in 2010



SOURCE: PWT 9.0 and authors' calculations.

both 1960 and 2010 (Figures 6A and 6B, respectively). A notable difference in the life-year gain can be observed for 1960-2010, as the slope becomes steeper.

3.3.2 Life Insurance-Based Value of Life. Life insurance data contain information about the willingness to pay for the loss of life. However, the data are not "clean" in the sense that they do contain other information. Life insurance data consist of cost structures of insurance companies, reflect the tightness of loanable funds markets, and mirror the development of financial markets and people's attitudes toward and acceptance of life insurance. Despite all these features, we can still gauge the value of life from these data with reasonable assumptions.

Assume actuarial fairness of the insurance market and zero markups for insurance companies. Further assume that all countries are in the same stages of economic and financial development and that people's degree of acceptance for life insurance is the same across countries. The value of life can be computed as

$$\text{Value of life} = \frac{\text{Per-person life insurance premiums}}{\text{Probability of death}}.$$

To compute the life insurance-based value of life, we take the adult mortality rates reported in Section 3.2 as the probability of death. For the data on per person life insurance premiums, we take the density data, defined as the ratio of total premiums of life insurance to total population, from the Organisation for Economic Co-operation and Development (OECD).Stat. In total, the OECD.Stat provides life insurance density data for 62 countries for 2007-17, although there are many countries with incomplete data. For better comparison with previous results, we choose to examine year 2010 and set the United States as the benchmark economy. The life insurance-based value of life per capita in the United States is $22,613 in 2010 (2010 U.S. dollars), which amounts to only 1.16 percent and 0.53 percent of the per capita and per worker model-based values of life, respectively.[2] This says that the "blurred" data on the willingness to pay life insurance severely underestimate the value of life.

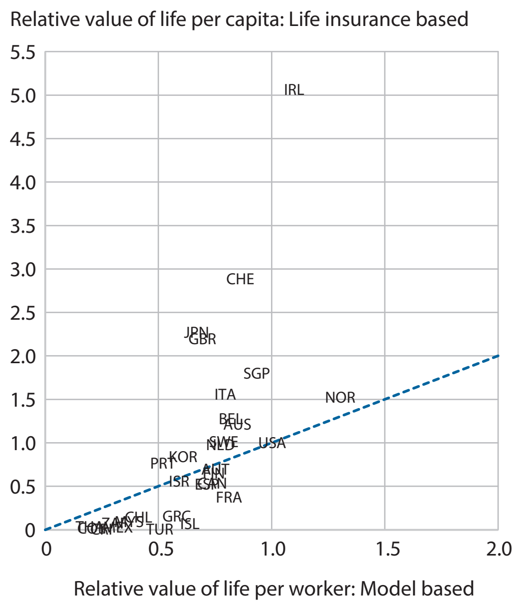
3.3.3 Comparing the Two Measures. To compare the cross-country health disparities using the two value-of-life measures, we plot in Figure 7A the per worker model-based and the per capita life insurance-based *relative* values of life against those in the United States in 2010 for 30 countries in our 1960-2010 sample.[3] In Figure 7B, for the 39 countries with available data, we plot the per worker model-based and the per capita life insurance-based relative values of life against those in the United States in 2010.

One can observe that while the two measures are positively related with a fairly high correlation coefficient of 0.6955, the life insurance-based relative value of life mostly lies below the model-based relative value of life. Combining the U.S. numbers mentioned above and the information here, we learn that measuring the value of life using life insurance data not only biases the value of life downward but also underestimates the cross-country variation. Figure 7C further contrasts the per worker and per capita model-based relative values of life to those in the United States in 2010. One can observe that the two series are highly correlated with a correlation coefficient of 0.9565, showing that per worker and per capita model-based relative values of life yield similar results when examining cross-country health disparities.

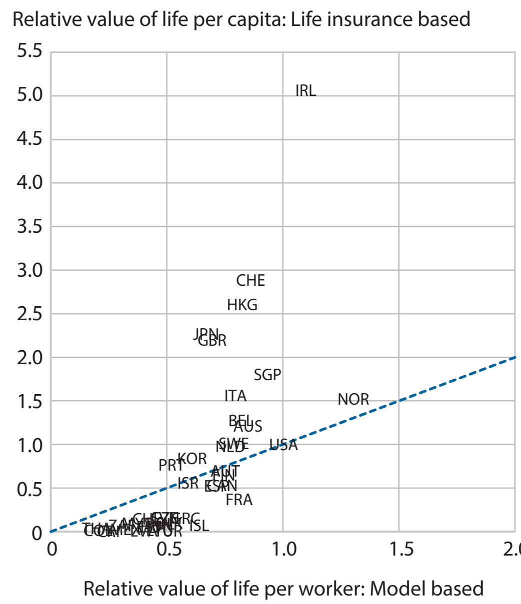
Figure 7

Relative Value of Life in 2010: Life Insurance Based vs. Model Based (U.S. = 1)

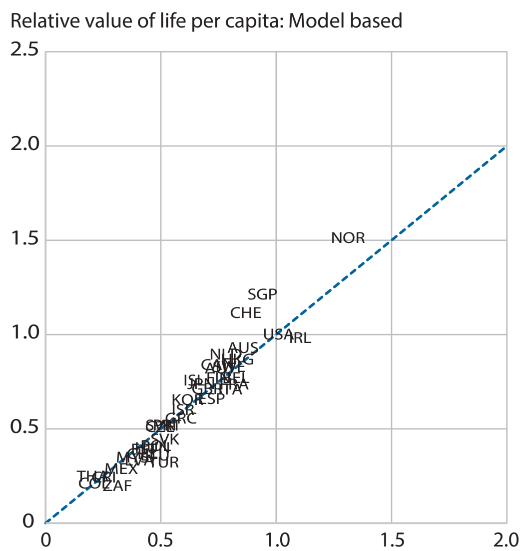
A. Relative value of life:
Insurance based vs. per worker model based, our 1960-2010 sample with available data



B. Relative value of life:
Insurance based vs. per worker model based, all available data



C. Model-based relative value of life:
Per worker vs. per capita



NOTE: The dashed blue line is the 45-degree line.
SOURCE: Authors' calculations

As mentioned before, life insurance data not only reflect people's willingness to pay, but also contain other information. We note that the greater a country's lag in financial market development and the greater the markups incurred by life insurance companies are, the higher the life insurance premium would be for the same value of life. Thus, the life insurance-based measure may be potentially biased upward in those countries. On the contrary, when people in a country have negative perceptions about and less receptiveness to life insurance (e.g., superstitions about possible bad luck in purchasing life insurance), life insurance premiums would be forced to stay low (i.e., have markdowns in exchange for bigger sales). In this scenario, the life insurance-based measure may be potentially biased downward. Should the latter effect be dominated by the former two effects, one would expect a natural downward bias when using the life insurance-based measure. Our next task is to identify the dominant effect in the context of a cross-country analysis. To proceed, we use the ratio of the life insurance-based relative value of life to the per worker model-based value of life. We then compute the correlations of this ratio with the relative real GDP per worker (relative to the United States), as well as with the per worker model-based value of life. We obtain a correlation of 0.6187 and 0.6242, respectively. The results indicate that the perception and receptiveness of life insurance are likely better in countries at more advanced stages of economic development.

Although the OECD.Stat dataset is, to our knowledge, the best internationally comparable dataset, the limited country selection misses most of the developing countries of interest, such as those in poverty traps and those rapidly growing. In short, even if a broader-based life insurance dataset were available, one must be cautious about the validity of the measure from cross-country perspectives, particularly when many less-developed countries are included in the analysis.

4 HEALTH PRODUCTION AND HEALTH CAPITAL ACCUMULATION

We now turn to the production side of health. In particular, we are interested in individual and social inputs into health production and factors affecting the process of health capital accumulation.

4.1 Health Production

Since the pivotal contribution by Grossman (1972), an individual's health expenditures z have been viewed as key inputs into one's health output x. It consists of both preventive spending, including nutrition and gym costs, and medical spending, including treatment and insurance costs. In addition to pecuniary input, time input τ is important as well, particularly exercise time. However, considering the nature of many infectious diseases, there are obvious externalities in which a society's health status should affect an individual's health production. This can be captured by the social level of health expenditures, denoted by $\bar{z}$. Moreover, public health facilities f, including clean water, a clean environment, geographic location, and medical facilities, also play critical roles, especially in developing countries. In sum, we can write the health production function as

(6) $$x = x(z, \tau; \bar{z}, f),$$

where we separate the two individual inputs from the two social inputs.

Depending on the issue examined, the pecuniary inputs of health z and time input τ can be further differentiated into inputs by oneself and inputs by parents. As the social levels of health expenditures $\bar{z}$ and public health facilities f vary greatly across countries and across income levels, the functional forms of x shall be country-specific.

4.2 Evolution of Health Capital

Given the health production function specification, we can now construct the health evolution process. Specifically, future health capital h' can be viewed as depending on current health capital h, health production that helps improve health, and health deterioration due to aging. Health deterioration can be specified as the multiple of the health deterioration rate $\delta(t)$ and current health capital. As emphasized by Chen, Wang, and Yao (2017), the health deterioration rate rises with age; that is, $\delta(t)$ is an increasing function of t over one's life cycle $[0,T]$. Moreover, any health shocks such as diseases would rise $\delta(t)$. Accordingly, the evolution of health capital is captured by

(7) $$h' = x(z, \tau; \bar{z}, f) + (1 - \delta(t))h.$$

Realistically, after reaching adulthood, an individual's health capital naturally reduces over time. That is, it is reasonable to expect $x(z,\tau;\bar{z},f) < \delta(t)h$ regardless of how many individual inputs (z,τ) have been devoted. An individual's lifetime is thus endogenized and he dies as his health capital reaches a threshold level $\underline{h}$.

Another approach of endogenizing the lifetime is to introduce the survival rate to utility function a la Murphy and Topel (2006), Hall and Jones (2007), and Jones (2016). The expected lifetime utility, taking the mortality rate into account, is

$$U = \int_0^{\infty} e^{-\rho t} u(c_t) M_t dt,$$

where c_t is consumption, and $M_t = e^{-\int_0^t \delta(x,s)ds}$ is the probability that an agent born at date 0 survives to date t. So far the literature has been focused more on the role of z in health formation, while the discussion about time input τ is relatively small and worthy of exploration.

5 THE ROLE OF HEALTH IN ECONOMIC DEVELOPMENT

We are now prepared to examine the role of health in economic development. We begin by linking health to productivity, investment incentives, and quality of life. We then discuss quantitatively the role that health plays in economic development, followed by a remark about health barriers that may be crucial for countries in the poverty trap.

5.1 Health and Productivity

Grossman (1972) stresses that in addition to education-based human capital, health capital also affects one's labor productivity. Unhealthy individuals are found to have more sick days and exert less effort at work. As a result, they have lower labor productivity and earn lower wages. This explains why an individual's earnings profile is hump-shaped over the life course: Though one's skill and experience rise, his or her health deteriorates. In short, on a per capita basis, income rises not only in physical and human capital, *k* and *s*, but also in health capital *h*:

$$y = y(k,s,h). \tag{8}$$

5.2 Health and Investment Incentives

As noted by Grossman (1972), it is widely accepted that better health leads to longer life expectancy and hence promotes saving and capital accumulation. Lorentzen, McMillan, and Wacziarg (2008) find that higher adult mortality invites more risky behavior, less saving, and less investment. Jayachandran and Lleras-Muney (2009) further point out that the improvement in health also promotes education. So education-based human capital is expected to rise with health capital. We may thus rewrite (8) as

$$y(h) = y\big(k(h), s(h), h\big), \tag{9}$$

which under proper assumption of monotonicity enables us to write current health capital as a function of current income:

$$h = h(y). \tag{10}$$

5.3 Health and Quality of Life

In the simple flow indirect utility function discussed above, we have ignored for the sake of simplicity the value of good health. As elaborated by Ehrlich and Chuma (1990); Murphy and Topel (2006); Hall and Jones (2007); and Chen, Wang, and Yao (2017), better health leads to better quality of life. Accordingly, one may modify the lifetime utility expression in (3) to

$$V = \int_0^T \Big[\ln(y) + \beta \ln\big(h(y)\big)\Big] \cdot e^{-\rho t}\, dt,$$

where $\beta > 0$. As pointed out by Chen, Wang, and Yao (2017), health has an additional effect on life expectancy and is hence a luxury good. To compute this generalized value of life is nontrivial, however. On the one hand, one must calibrate the parameter β, which is a challenge because it requires joint calibration with other model parameters using multiple targets, including expenditure shares and life expectancy. On the other hand, the health-income relationship must be derived from optimizing behavior, whose forms may involve parameters that are country-specific.

5.4 Theory Behind Empirics

To this end, we would like to point out several dimensions of difficulty in constructing a unified framework that may suit countries at very different development stages. This can be best understood by recognizing that different countries naturally have different primitives in preferences and technology. To be brief, we will list a few of greater importance.

First, preferences toward better health are likely country-specific, depending on cultural and social norms, and on public hazard that may inevitably harm private health. Second, earnings profiles over the life cycle are obviously different across countries. Third, labor income shares and elasticity of capital-labor substitutions also vary by country. Finally, the degree of complementarity between health- and education-based human capital may depend on job requirements and school/workplace peer factors, which are country-specific as well.

In summary, all such differences in primitives mentioned above have posed great challenges in calibrating a unified structural model to fit data from countries at different development stages. Such difficulties are exactly why scholars in this field tend to use reduced form-based "accounting" models for development accounting, rather than a deep structural model as proposed in this article.

5.5 Growth and Development Accounting

Weil (2007), Caselli (2005), and Wang (2012) find that health is important in understanding cross-country income differences, in addition to physical capital and education-based human capital. Typically, growth and development accounting is used to quantify the following relationship between income per worker y, efficiency A, factor inputs such as physical capital k, and human capital per worker:

$$y = Ak^{\alpha}H^{1-\alpha}.$$

Considering $H = hm$, where h is health capital relevant to production and m is education-related human capital computed from Mincerian regression, Weil (2007) uses microestimates of the effects of adult height, adult survival rate, and age of menarche on individual incomes to construct macroeconomic estimates of h. He finds that eliminating health differences among countries would reduce the variance of log GDP per worker by 9.9 percent. Using adult survival rate and birthweight, Caselli (2005) confirms Weil's result. On the contrary, with a structural model linking survival probability to health investment, Wang (2012) considers $H = h^{\beta}m^{1-\beta}$ and finds that health differences explain roughly 8 percent to 9 percent of the variance of log GDP per worker. As health affects income levels both directly through improvement in labor productivity and indirectly through the incentives of saving, education acquirement, and pure enjoyment of good health, the aforementioned results are most likely underestimating the effect of health because only the direct channel of health is measured.

As mentioned previously, there are obvious externalities, such as a natural adverse health environment, inefficiencies in the health sector, and a malfunctioning health system, in which society can affect an individual's health production. Such externalities, usually deeply rooted in a country's institutions, may create barriers for a country on its road to prosperity. In the next section we discuss how such types of institutional barriers are important in determining an economy's fate.

5.6 Barriers to Health

So far we have documented the relationship between health measures—human capital and relative income—and the contribution of health to economic development. We show that such a relationship is not as tight in earlier periods and that the contribution from development accounting is relatively modest. One may then inquire whether it is possible to tighten such a relationship and improve the contribution of health capital. Our earlier work provides a plausible answer to this inquiry.

Specifically, Wang and Wang (2016) show that health barriers are crucial for a developing country to take off successfully. Health-related institutional barriers in an economy can be so great that individuals have few opportunities to invest in their offspring, which then leads to a vicious cycle of poor health, low investment, and bad institutions. To rescue countries from such a poverty trap, Wang and Wang (2016) point out that correcting the institutions to ensure appropriate incentives is the first priority. Pulling a country out of poverty does not call for a complete or even substantial eradication of the institutional barriers: As long as the country overcomes the threshold institutional barriers, the country will be on the right track toward advancement and a better future.

6 CONCLUSION

Focusing on the role of health, we provide in this article an overview of cross-country differences in both the data and literature. We find that despite the overall improvement in income levels and health across countries over a recent 50-year interval, higher income levels and better health tend to connect more closely as time goes by. We also construct a wealth-based measure of the VSL that can be easily applied to cross-country studies. We find that the value of life in the United States increased 2.5-fold during 1960-2010 and that the relative position of countries with low growth rates deteriorated in both relative income and relative value of life.

As pointed out by Caselli (2005), there is still room for us to explore the role of health in cross-country income variations. Health problems facing rich and poor countries are different, and hence the way these health problems affect countries at dissimilar development stages may be very different as well. Therefore, to improve the current literature, researchers need to keep these differences in mind when examining how health affects an individual's choices and how the externalities arising from health influence society as a whole. As such, the reader should view our article as opening the door for valuable research in this fruitful area, rather than as closing the door with a complete quantitative analysis by calibrating a unified model to fit cross-country data. ■

NOTES

[1] There are two exceptions: Israel has data for life expectancy at birth available only up to year 1961, and Germany does not have adult mortality data in 1960, 1970, or 1980.

[2] The model-based per capita and per worker values of life in 2010 were $1,949,245 and $4,273,283 in 2011 U.S. dollars, respectively.

[3] We dropped Luxembourg throughout as it is an outlier. Luxembourg's life insurance density was $51,162 in 2010, compared with Ireland's, the country with the second-highest life insurance density, which was $7,883 in 2010.

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