Disease and Development: The Effect of Life Expectancy on Economic Growth*

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Abstract

What is the effect of increasing life expectancy on economic growth? To answer this question, we exploit *the international epidemiological transition*, the wave of international health innovations and improvements that began in the 1940s. We obtain estimates of mortality by disease before the 1940s from the League of Nations and national public health sources. Using these data, we construct an instrument for changes in life expectancy, referred to as *predicted mortality*, which is based on the pre-intervention distribution of mortality from various diseases around the world and dates of global interventions. We document that predicted mortality has a large and robust effect on changes in life expectancy starting in 1940, but no effect on changes in life expectancy *before* the interventions. The instrumented changes in life expectancy have a large effect on population; a 1% increase in life expectancy leads to an increase in population of about 1.5%. Life expectancy has a much smaller effect on total GDP both initially and over a 40-year horizon, however. Consequently, there is no evidence that the large exogenous increase in life expectancy led to a significant increase in per capita economic growth. These results confirm that global efforts to combat poor health conditions in less developed countries can be highly effective, but also shed doubt on claims that unfavorable health conditions are the root cause of the poverty of some nations.

Keywords: disease environment, economic development, economic growth, health, international epidemiological transition, life expectancy, mortality.

JEL Numbers: I10, O40, J11.

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1 Introduction

Improving health around the world today is an important social objective, which has obvious direct payoffs in terms of longer and better lives for millions.[1] There is also a growing consensus that improving health can have equally large indirect payoffs through accelerating economic growth.[2] For example, Gallup and Sachs (2001, p. 91) argue that wiping out malaria in sub-Saharan Africa could increase that continent's per capita growth rate by as much as 2.6% a year, and a recent report by the World Health Organization (2001) states:

> "in today's world, poor health has particularly pernicious effects on economic development in sub-Saharan Africa, South Asia, and pockets of high disease and intense poverty elsewhere" (p. 24) and
>
> "...extending the coverage of crucial health services... to the world's poor could save millions of lives each year, reduce poverty, spur economic development and promote global security" (p. i).

The evidence supporting this recent consensus is not yet conclusive, however. Although cross-country regression studies show a strong correlation between measures of health (for example, life expectancy or infant mortality) and both the level of economic development and recent economic growth, these studies have not established a causal effect of health and disease environments on economic growth. Since countries suffering from short life expectancy and ill-health are also disadvantaged in other ways (and often this is the reason for their poor health outcomes), such macro studies may be capturing the negative effects of these other, often omitted, disadvantages. While a range of micro studies demonstrate the importance of health for individual productivity, as discussed below, these studies do not resolve the question of whether health differences are at the root of the large income differences we observe today and whether improvements in health will increase economic growth substantially.

This paper investigates the effect of life expectancy at birth—as a general measure of the health of the population—on economic growth. We exploit the large improvements in life expectancy, especially among the relatively poor nations, driven by international health interventions, more effective public health measures, and the introduction of new chemicals and drugs starting in the 1940s.[3] This episode, which we refer to as the *international epidemiological transition*, led to an unprecedented improvement in life expectancy in a large number

[1] See Becker, Phillipson and Soares (2005) and Deaton (2003 and 2004) for recent analyses.

[2] See, among others, Bloom and Sachs (1998), Gallup and Sachs (2001), World Health Organization (2001), Alleyne and Cohen (2002), Bloom and Canning (2005), and Lorentzon, Wacziarg, and McMillan (2005).

[3] There were some effective medical and public health innovations prior to 1940. But the positive effects from these innovations were concentrated in richer countries.

of countries.[4] Figure 1 shows this by plotting life expectancy in countries that were initially (circa 1940) poor, middle income, and rich. It illustrates that while in the 1930s life expectancy was low in many poor and middle-income countries, this transition brought their levels of life expectancy close to those prevailing in richer parts of the world.[5] As a consequence of these developments, health conditions in many parts of the less-developed world today, though still in dire need of improvement, are significantly better than the corresponding health conditions were in the West at the same stage of development.[6]

The international epidemiological transition provides us with an empirical strategy to isolate potentially-exogenous changes in health conditions. The effects of the international epidemiological transition on a country's life expectancy were related to the extent to which its population was initially (circa 1940) affected by various specific diseases, for example, tuberculosis, malaria, and pneumonia, and to the timing of the various health interventions.

The early data on mortality by disease are available from standard international sources, though they have not been widely used in the economics literature. These data allow us to create an instrument for changes in life expectancy based on the pre-intervention distribution of mortality from various diseases around the world and the dates of global intervention (e.g., discovery and mass production of penicillin and streptomycin, or the discovery and widespread use of DDT against mosquito vectors). The only source of variation in this instrument, which we refer to as *predicted mortality*, comes from the interaction of baseline cross-country disease prevalence with global intervention dates for specific diseases. We document that there were large declines in disease-specific mortality following these global interventions. More im-

[4]The term epidemiological transition was coined by demographers and refers to the process of falling mortality rates after about 1850, associated with the switch from infectious to degenerative disease as the major cause of death (Omran, 1971). Some authors prefer the term "health transition," as this includes the changing nature of ill health more generally (e.g., Riley, 2001). Our focus is on the rapid decline in mortality (and improvement in health) in poorer countries after 1940, most of which was driven by the fast spread of new technologies and practices around the world (hence the adjective "international"). The seminal works on this episode include Stolnitz (1955), Omran (1971), and Preston (1975a).

[5]This figure is for illustration purposes and should be interpreted with caution, since convergence is not generally invariant to nonlinear transformations. Our empirical strategy below does not exploit this convergence pattern; instead, it relies on potentially-exogenous changes in life expectancy.

In these figures and throughout the paper, the initially rich countries are those with income per capita in 1940 above the level of Argentina (the richest Latin American country at that time, according to Maddison's data, in our base sample). These are, in ascending order, Belgium, Netherlands, Sweden, Denmark, Canada, Germany, Australia, New Zealand, Switzerland, the United Kingdom and the United States. The initially poor countries are those with income per capita below that of Portugal, which was the poorest European nation in our base sample. These are, in ascending order: China, Bangladesh, India, Pakistan, Myanmar, Thailand, El Salvador, Honduras, Indonesia, Brazil, Sri Lanka, Malaysia, Nicaragua, Korea, Ecuador, and the Philippines. Because of data quality issues, African nations are not included in our base sample, but they are used in robustness checks in Section 7. See Appendix Table A1 for a list of initially rich, middle-income and poor countries.

[6]For example, life expectancy at birth in India in 1999 was 60 compared to 40 in Britain in 1820, when income per capita was approximately the same level as in India today (Maddison, 2001, p. 30). From Maddison (2001, p. 264), income per capita in Britain in 1820 was $1707, while it stood at $1746 in India in 1998 (all figures in 1990 international dollars).

portantly, we show that the predicted mortality instrument has a large and robust effect on changes in life expectancy starting in 1940, but has *no* effect on changes in life expectancy *prior* to this date (i.e., before the key interventions).

The instrumented changes in life expectancy have a fairly large effect on population; a 1% increase in life expectancy is related to an approximately 1.3-1.8% increase in population. The magnitude of this estimate indicates that the decline in fertility rates was insufficient to compensate for increased life expectancy, a result which we directly confirm by looking at the relationship between life expectancy and total births.

On the other hand, we find no statistically significant effect on total GDP (though our two standard error confidence intervals do include economically significant effects). More importantly, relative growth rates for GDP per capita (and GDP per working age population) show some decline in countries experiencing large increases in life expectancy. In fact, our estimates exclude any positive effects of life expectancy on GDP per capita within a 40-year horizon. This is consistent with the overall pattern in Figure 2, which, in contrast to Figure 1, shows no convergence in income per capita between initially poor, middle-income and rich countries. Similarly, we find no evidence of an increase in human capital investments associated with improvements in life expectancy.

The most natural interpretation of our results comes from neoclassical growth theory. The first-order effect of increased life expectancy is to increase population, which initially reduces capital-to-labor and land-to-labor ratios, thus depressing income per capita. This initial decline is later compensated by higher output as more people enter the labor force. This compensation can be complete and may even exceed the initial level of income per capita if there are significant productivity benefits from longer life expectancy. Yet, the compensation may also be incomplete if the benefits from higher life expectancy are limited and if some factors of production, for example land, are supplied inelastically. A smaller initial effect on GDP than the longer-run effect is also consistent with the neoclassical growth model when the accumulation of capital is slow.

The role of changes in capital-labor ratios in the above discussion also suggests that we should expect less negative (or more positive) effects on income per capita in economies that have higher investment rates. We investigate this by estimating models that allow for interactions between life expectancy and initial GDP per capita or initial investment rates (for which the data are less reliable), and find some support for this hypothesis.

Our findings do not imply that improved health has not been a great benefit to less-developed nations during the postwar era. On the contrary, they suggest that global efforts can significantly improve health conditions in less developed countries, and they may be able to do so without large long-run costs in terms of income per capita. The accounting approach of Becker, Philipson and Soares (2005), which incorporates information on longevity and health

as well as standards of living, would then suggest that these interventions have considerably improved "overall welfare" in these countries. What these interventions have not done, and in fact *were not* intended to do, is to increase output per capita in these countries.

Furthermore, our results, though suggestive, may not directly apply to the present date because of the different nature of diseases now prevalent in poor countries, in particular, because of HIV/AIDS. Many of the diseases brought under greater control during the international epidemiological transition were primarily killers of children.[7] In contrast, arguably the most serious health problem in the poorest parts of the world today, HIV/AIDS, affects those at the peak of their labor productivity. Preventing HIV/AIDS could conceivably have different effects from those we estimate here.

It is also important to note that the micro estimates have established beyond reasonable doubt that improved health leads to better individual economic outcomes.[8] Nevertheless, these estimates do not directly answer the question of how important differences in disease environments and health conditions are in accounting for cross-country income disparities, and are difficult to compare with our results, because they do not incorporate *general equilibrium effects* (in addition, there still remains a great deal of uncertainty about the precise size of the relevant effects). The most important general equilibrium effect arises because of diminishing returns to effective units of labor (for example, because land and/or physical capital are supplied inelastically). In the presence of such diminishing returns, micro estimates will exaggerate the aggregate productivity benefits from improved health, especially when health improvements are accompanied by population increases. This may be an important concern since existing estimates of production functions, theory and also our our results suggest that there are indeed diminishing returns to labor.[9]

Our paper is most closely related to two recent contributions, Weil (2005) and Young (2005). Weil calibrates the effects of health using a range of micro estimates, and finds that

[7]The exception is tuberculosis. The age profile of deaths from tuberculosis pre-1940 was closer to that of AIDS today—with a heavy burden on young adults. The greatest impact of the remaining diseases were on children, but not necessarily on infants (e.g., endemic malaria typically has highest fatality rates for children between ages 1 and 5). Our analysis of the (somewhat less reliable) data on infant mortality shows no evidence of a differential effect of the international epidemiological transition on infant mortality or survival rates (these results are not reported to save space).

[8]See Strauss and Thomas (1998) for an excellent survey of the research until the late 1990s. For some of the more recent research, see Behrman and Rosenzweig (2004), Bleakley (2002, 2004), Miguel and Kremer (2004), and Schultz (2002).

[9]Another general equilibrium effect arises when healthier individuals have higher earnings partly because they are successful in competing against less healthy individuals in the labor market (for example, for scarce high-paying jobs); when such competition effects are present, all individuals becoming healthier would have smaller effects than those implied by the micro estimates. See Persico, Postlewaite and Silverman (2004) for evidence suggesting that the major effect of height on economic outcomes may be through a "competitive advantage" in adolescence.

these effects could be quite important in the aggregate (see also Bloom and Canning, 2005).[10] The major difference between Weil's approach and ours is that the conceptual exercise in his paper is concerned with the effects of improved health holding population constant. In contrast, our estimates look at the general equilibrium effects of improved health from the most important health transition of the 20th century, which takes the form of both improved health and increased life expectancy (and thus population). Young evaluates the effect of the recent HIV/AIDS epidemic in Africa. Using micro estimates and calibration of the neoclassical growth model, he shows that the decline in population resulting from HIV/AIDS may increase income per capita despite significant disruptions and human suffering caused by the disease.[11]

In addition, our work is related to the literature on the demographic transition both in the West and in the rest of the world, including the seminal contribution of McKeown (1976) and studies by Arriaga and Davis (1969), Preston (1975a, 1980), Caldwell (1986), Kelley (1988), Fogel (1986, 2004), and Deaton (2003, 2004). More recent work by Cutler and Miller (2005) finds that the introduction of clean water accounts for about half of the decline in US mortality in the early 20th century (see also Cutler and Miller, 2006).

The rest of the paper is organized as follows. In the next section, we present a simple model to illustrate the factors that determine the effect of increased life expectancy on economic growth. Section 3 describes the health interventions and the data on disease mortality rates and life expectancy that we constructed from a variety of primary sources. Section 4 presents our estimating framework and the ordinary least square (OLS) relationship between life expectancy and a range of outcomes. Section 5 discusses the construction of our instrument and shows the first-stage relationships, robustness checks, falsification exercises, and other supporting evidence. Section 6 presents the main results. Section 7 presents a number of robustness checks and additional results, and Section 8 concludes. Appendices A and B provide information on data sources, data construction and the diseases used in this study. Appendix C, which provides further details and some additional results, is available upon request.

2 Motivating Theory

To frame the empirical analysis, we first derive the medium-run and long-run implications of increased life expectancy in the closed-economy neoclassical (Solow) growth model. All labor and land are supplied inelastically. We represent all of health in terms of life expectancy.[12]

[10] Weil's baseline estimate uses the return to the age of menarche from Knaul's (2000) work on Mexico as a general indicator of "overall return to health". Using Behrman and Rosenzweig's (2004) estimates from returns to birthweight differences in monozygotic twins, he finds smaller effects.

[11] For more pessimistic views on the economic consequences of HIV/AIDS, see Arndt and Lewis (2000), Bell, Devarajan, and Gersbach (2003) and Kalemli-Ozcan (2006).

[12] Life expectancy here and throughout the paper is interpreted as a proxy (index) for the overall health of the population. In practice, the decline in mortality from infectious disease and the corresponding increase

Economy i has the constant returns to scale aggregate production function

$$Y_{it} = (A_{it}H_{it})^{\alpha} K_{it}^{\beta} L_{it}^{1-\alpha-\beta}, \tag{1}$$

where $\alpha + \beta \leq 1$, K_{it} denotes capital, L_{it} denotes the supply of land, and H_{it} is the effective units of labor given by

$$H_{it} = h_{it}N_{it},$$

where N_{it} is total population (and hence employment), while h_{it} is human capital per person.

Without loss of any generality, we normalize $L_{it} = L_i = 1$ for all i and t. Let us also first assume that $A_{it} = A_i$ for all i and t. Capital depreciates at the rate δ and the savings/investment rate of country i is constant and equal to s_i, which implies:

$$K_{it+1} = s_i Y_{it} + (1 - \delta) K_{it}.$$

Suppose that there exists $\bar{t} < \infty$ such that for all $t \geq \bar{t}$, human capital per person and population are constant, i.e.,

$$h_{it} = h_i \text{ and } N_{it} = N_i \text{ for all } t \geq \bar{t}.$$

This implies that there exists a steady state, with $K_{it} = K_i$, satisfying

$$K_i = \frac{s_i}{\delta} Y_i.$$

Substituting into (1) and taking logs we obtain a simple relationship between income per capita, the savings rate, human capital, technology, and population:

$$\begin{aligned} y_i &\equiv \log\left(\frac{Y_i}{N_i}\right) \\ &= \frac{\alpha}{1-\beta}\log A_i + \frac{\alpha}{1-\beta}\log h_i + \frac{\beta}{1-\beta}\log s_i - \frac{\beta}{1-\beta}\log\delta - \frac{1-\alpha-\beta}{1-\beta}\log N_i. \end{aligned} \tag{2}$$

This equation shows that income per capita is affected positively by technology, A_i, human capital, h_i, and the investment rate, s_i, and negatively by population, N_i.

For industrialized economies where land plays a small role in production (because only a small fraction of output is produced in agriculture), we can reasonably presume $1 - \alpha - \beta \simeq 0$

in life expectancy resulting from the international epidemiological transition have been closely associated with increased overall health and reduced morbidity (in particular, fewer incidences of illness from infectious disease, including less incapacity from tuberculosis, malaria, pneumonia, and lower incidence of illness in childhood). For example, before 1958 there were 817,000 cases of malaria in Venezuela, but after DDT spraying and other eradication efforts, there were only 800 cases. In Taiwan, there were about 1 million cases of malaria in 1954; a similar anti-malaria campaign was so effective that by 1969 there were only 9 cases. Most of these cases of malaria in both countries were associated with sickness and morbidity, not necessarily mortality (Lancaster, 1990, Chapter 15). See also Riley (1993 and 2001) on the relationship between mortality and health in the 19th-century Britain.

and population drops out of equation (2). Nevertheless, for many less-developed countries, where agriculture is still important, we should expect $1-\alpha-\beta>0$ and the direct effect of an increase in population may be to reduce income per capita even in the steady state (i.e., even once the capital stock has adjusted to the increase in population).[13]

Greater life expectancy will first lead to greater population (both directly and also potentially indirectly by increasing total births), so we posit:

$$N_{it}=\bar{N}_i X_{it}^{\lambda}, \tag{3}$$

where X_{it} is life expectancy in country i at time t. Better health and longer life spans may also increase productivity through a variety of channels, including more rapid human capital accumulation or direct positive effects on (total factor) productivity.[14] To capture the beneficial effects of these variables on productivity emphasized in the literature, let us assume the following isoelastic relationships:

$$A_{it}=\bar{A}_i X_{it}^{\gamma} \text{ and } h_{it}=\bar{h}_i X_{it}^{\eta}, \tag{4}$$

where $\bar{A}_i$ and $\bar{h}_i$ are some baseline differences across countries.

To focus on long run (steady-state) relationships, suppose that $X_{it}=X_i$ (at least for $t\geq\bar{t}$ for some $\bar{t}<\infty$), so that there exists a steady state relationship:

$$\begin{aligned} y_i &= \frac{\alpha}{1-\beta}\log\bar{A}_i+\frac{\alpha}{1-\beta}\log\bar{h}_i+\frac{\beta}{1-\beta}\log s_i-\frac{\beta}{1-\beta}\log\delta \\ &\quad -\frac{1-\alpha-\beta}{1-\beta}\log\bar{N}_i+\frac{1}{1-\beta}\left(\alpha\left(\gamma+\eta\right)-\left(1-\alpha-\beta\right)\lambda\right)x_i \end{aligned} \tag{5}$$

where $x_i\equiv\log X_i$ is log life expectancy and recall that $y_i\equiv\log\left(Y_i/N_i\right)$.

An increase in life expectancy therefore leads to a significant increase in long-run income per capita when there are limited diminishing returns (i.e., $1-\alpha-\beta$ is small) and when life expectancy creates a substantial externality on technology (high γ) and/or encourages significant increases in human capital (high η). On the contrary, when γ and η are small and $1-\alpha-\beta$ is large, an increase in life expectancy can reduce income per capita even in the steady state.

[13] See Galor and Weil (2000), Hansen and Prescott (2002), and Galor (2005) for models in which at different stages of development the relationship between population and income may change because of a change in the composition of output or technology. In these models, during an early Malthusian phase, land plays an important role as a factor of production and there are strong diminishing returns to capital. Later in the development process, the role of land diminishes, allowing per capita income growth. Hansen and Prescott (2002), for example, assume a Cobb-Douglas production function during the Malthusian phase with a share of land equal to 0.3.

[14] On the potential effects of life expectancy and health on productivity, see Bloom and Sachs (1998). On their effects on human capital accumulation, see, among others, Kalemli-Ozcan, Ryder, and Weil (2000), Kalemli-Ozcan (2002) or Soares (2005), which point out that when people live longer, they will have greater incentives to invest in human capital.

Equation (5) applies to the "long run" once the capital stock has adjusted to the increase in population. It is also interesting to look at what happens to output in the "medium run" where the capital stock is constant (or before it has fully adjusted). This medium-run scenario would be particularly relevant to countries that have low savings rates and can only attract limited foreign capital. To illustrate this point, consider the extreme case where the capital stock is fixed at some value $\bar{K}_i$. Then:

$$\frac{Y_i}{N_i} = \bar{K}_i^{\beta} \left(A_i h_i\right)^{\alpha} N_i^{-(1-\alpha)}$$

or substituting for (4) and (3), we have:

$$\begin{aligned} y_i \equiv\ & \beta \log \bar{K}_i + \alpha \log \bar{A}_i + \alpha \log \bar{h}_i + \\ & - (1-\alpha) \log \bar{N}_i + (\alpha (\gamma + \eta) - (1-\alpha) \lambda) x_i. \end{aligned} \tag{6}$$

Comparing this equation to equation (5), we see that the medium-run effect of an increase in life expectancy is more negative (or less positive). This is intuitive: the response to an increase in N_i before the capital stock adjusts to its new steady-state level will be a reduction in the capital-labor ratio, further reducing income per capita.

Our empirical strategy below is to estimate equations similar to (5) and (6), and compare the estimates to the parameters in these equations.

It is also evident that how quickly an economy approaches the long-run equilibrium depends on its savings and investment rate. Therefore, this framework also suggests that we should investigate the impact of the interaction between life expectancy and the investment rate on the evolution of income per capita.

3 Background and Data

3.1 International Epidemiological Transition

Early improvements in public health began in Western Europe, the United States and a few other places from the mid-nineteenth century.[15] Initially progress was through empirically observing what worked, but soon came major breakthroughs connected with the germ theory of disease. By 1900, tropical medicine had also made impressive progress, most notably with Ronald Ross's demonstration that mosquitoes transmitted malaria and with practical advances against yellow fever in the Caribbean.

Nevertheless, through 1940 most of the progress in improving mortality was confined to relatively rich countries, with some—but more limited—impact in Southern and Eastern Eu-

[15] Cutler, Deaton, Lleras-Murray (2006, pp. 11-12) also point out that new drugs, primarily antibiotics and sulphonamide drugs, had an important impact on US mortality between the 1930s and 1960.

rope. In most of the Americas, Africa, and Asia, there were even more limited improvements.[16] In part, this was because there were few effective drugs against major killers, so most of the measures were relatively expensive public works (e.g., to drain swamps). Colonial authorities showed little enthusiasm for such expenditure.

The situation changed dramatically from around 1940 mainly because of four factors. First, there was a wave of global drug innovations. Many of these products offered cures effective against major killers in developing countries. The most important was the discovery and subsequent mass production of penicillin, which provided an effective treatment against a range of bacterial infections (National Academy of Sciences, 1970, Easterlin, 1999). Penicillin, which was only used in small quantities even in the most developed countries through the mid-1940s (Conybeare, 1948, p. 66), became widely available by the early 1950s (see, e.g., Valentine and Shooter, 1954).[17] Further antibiotic development quickly followed, most notably with the discovery of streptomycin, which was effective against tuberculosis. Between 1940 and 1950, the major bacterial killers became treatable and, in most cases, curable. Diseases that could now be treated, for most people without serious side effects, included pneumonia, dysentery, cholera, and venereal diseases. Antibiotics also reduced deaths indirectly caused by (and attributed to) viruses, such as influenza, which often kill by weakening the immune system and allowing secondary bacterial infections to develop. Also important during the same period was the development of new vaccines, for example, against yellow fever.[18]

The second reason for the dramatic improvement in health was the discovery of DDT (Dichlorodiphenyl trichloroethylene), which allowed a major breakthrough in attempts to control one of the major killers of children in less-developed regions of the world, malaria.[19] Desowitz describes the impact of DDT as follows:

[16] During the 1920s and 1930s, there were measures to reduce mortality from smallpox and cholera in Indonesia, smallpox and plague in the Philippines, malaria in India, malaria and respiratory and diarrheal diseases in the British Guyana (see, for example, Preston 1980, Mandle 1970). Gwatkin (1980, p. 616) states: "But such increases [in life expectancy] were modest compared with those that came later, for soon after World War II annual gains in life expectancy averaging over a year were recorded for periods of up to a decade in such diverse places as Taiwan, Malaysia, Sri Lanka, Mauritius, Jamaica, and Mexico".

[17] Fleming isolated penicillin in the 1930s but could not produce it in any significant quantity; Florey and Chain made the breakthroughs essential for using penicillin as a drug and they shared the Nobel prize with Fleming in 1945 (see, e.g., Chain, 1980). The first large-scale use of penicillin was in 1943, by Allied armies in North Africa. Andrew Moyer's patent in 1948 is often regarded as a major step in its mass production. The invention of penicillin led to a wave of discovery of other antibiotics, including streptomycin, chloromycetin, aureomycin, and terramycin (The National Academy, 1970, p. 147). Waksman discovered streptomycin in 1944 and was awarded the Nobel Prize in 1952 (see, Keers, 1978, for details and also on the importance of streptomycin).

[18] The yellow fever vaccine was invented by Max Theiler in 1930 and became widely available in the 1940s. Theiler was awarded a Nobel Prize in 1951. A great deal more vaccine invention followed in the 1950s and 1960s (e.g., against small pox and measles), but antibiotics already provided usually effective treatment against those diseases.

[19] DDT was first synthesized in 1874, but the discovery of its insecticide properties was much later—in 1939, by Paul H. Müller; he received a patent for the insecticide in 1940, and was awarded a Nobel Prize in 1948 (Alilio et al, 2004, p. 270).

> "There was nothing quite like [DDT] before and has been nothing quite like it since. Here was a chemical that could be sprayed on the walls of a house and for up to six months later any insect that alighted or rested on that wall would die. It was virtually without toxicity to humans. And, for the icing on the chemical cake, it was dirt-cheap to manufacture" (1991, pp. 62-63).

Aggressive use of inexpensive DDT led to the rapid eradication of malaria in Taiwan, much of the Caribbean, the Balkans, parts of northern Africa, northern Australia, large parts of South Pacific, and all but eradicated malaria in Sri Lanka and India (see, e.g., Davis, 1956).

The third pillar of the improvements in public health was the establishment of the World Health Organization (WHO), which greatly facilitated the spread of medical and public health technology to poorer countries.[20] From the 1950s, the WHO, together with other UN-related bodies, most significantly, UNICEF, was the driving force behind the public health (e.g., anti-malaria campaigns) and immunization drives (e.g., against smallpox).[21] The US military also played a significant role in developing treatments for diseases like cholera and spreading the use of DDT and penicillin.[22]

The fourth factor was a change in international values. As Preston (1975a) emphasizes, after the 1930s:

> "Universal values assured that health breakthroughs in any country would spread rapidly to all others where the means for implementation existed" (p. 243).

The consequence of the combination of these four factors was a dramatic improvement in life expectancy in much of the world, especially in the lesser developed parts of the globe, starting in the 1940s. Most of the key changes were available in almost all countries by 1950. As a result, by the late 1940s and early 1950s, there were significant improvements in health conditions and life expectancy in Central America, South Asia, and parts of Eastern and Southern Europe compared to richer countries.[23]

[20] It is notable that Brazil and China, both poor countries at the time, took the initiative in pushing for the formation of the WHO (WHO, 1998). A central goal of the organization was to diffuse medical practices and technology to poorer countries. Between the world wars, the League of Nations was responsible for international disease interventions and worked with other European organizations, for example, against typhus in Eastern Europe (see also Office International d'Hygiene Publique, 1933). However, in contrast with the WHO, the League of Nations showed less interest in and had limited resources for combating diseases in less-developed countries, and focused on monitoring epidemics that might spread to the West.

[21] Lee et al (1996) report: "[Founded in 1946]... Unicef was given the task of utilising its resources 'for child health purposes generally'. When the WHO came on to the scene two years later it was accepted that coordination on health matters was needed. This led to the creation of the WHO/Unicef joint committee on health policy, with the WHO, importantly, designated as the lead health organisation."

[22] Captain Phillips of the U.S. Navy was involved in developing intravenous rehydration methods in Cairo after 1946 and Taipei after 1955 (Savarino, 2002); he was also the first to try oral glucose saline on two cholera patients (Bhattacharya, 1994).

[23] Davis (1956) was probably the first to write about this in the economics literature. He stressed that "these

3.2 Coding Diseases

Central to our empirical strategy is to construct cross-country mortality rates for various diseases before the 1940s. For this purpose, we have collected comparable data on 15 of the most important infectious diseases across a wide range of countries. In all cases, the primary data source is national health statistics, as collected and republished by the League of Nations (until 1940) and the World Health Organization and the United Nations (after 1945). We have tried several different ways of constructing these data, all of which produce similar results.

We confirm the validity of these numbers using the qualitative and quantitative evidence in Lancaster (1990, especially, Chapter 48), the maps and discussion of Cliff, Haggett, and Smallman-Raynor (2004) and the maps of disease incidence published by the American Geographical Society (1951a, b, c, and d) immediately after World War II. Appendix A provides details on sources and construction. Further details are contained in Appendix C. Information on the etiology and epidemiology of each disease is obtained from the comprehensive recent surveys in Kiple (1993) and other sources (see Appendix B). To the extent possible, we have also checked our data against those reported in Preston and Nelson (1974).

The other building block for our approach is *global intervention* dates for each specific disease, that is, dates of significant events potentially reducing mortality around the world from the disease in question. These events are described below (and in Appendix B) and the relevant dates were obtained from WHO Epidemiological Reports, as well as National Academy of Sciences (1970), Preston (1975a), Kiple (1993), Easterlin (1999), and Hoff and Smith (2000).

The 15 diseases we focus on are tuberculosis, malaria, pneumonia, influenza, cholera, typhoid, smallpox, whooping cough, measles, diphtheria, scarlet fever, yellow fever, plague, typhus fever, and dysentery. The most important killers in this list are tuberculosis, malaria, and pneumonia, which we discuss in this section. Information about the remaining diseases is summarized in Appendix B.

Tuberculosis was probably the largest single cause of death around the world in 1940. It is primarily caused by *Mycobacterium tuberculosis*, transmitted through the air. Vaccination had been available from the 1920s, but the breakthrough cure was the 1944 invention of streptomycin.[24] The drug spread quickly and has remained important. Following the above discussion of the invention and introduction of penicillin and streptomycin, we code the intervention against tuberculosis in the 1940s.

areas do not need to become economically developed to reduce their death rates drastically" (p. 305) and that this pattern in the relatively poor parts of the world had no precedent in richer countries. See Stolnitz (1955) and Preston (1975a) for early discussions of this large decline in mortality in the demography literature.

[24]Previously tuberculosis could be treated by surgery, but even in the UK resources for this were limited and not available to many patients (Conybeare, 1948, p. 61). One discussant of Conybeare (1948) made the point, based on data from the UK's Statisical Reviews, that comparing 1939 with 1931-35, "in the general population tuberculosis had not recently been a decreasing risk at all." This was on the eve of the dramatic impact of streptomycin (Keers, 1978).

Malaria is caused by four types of parasites, transmitted by the bite of an infected female *Anopheles* mosquito. Control of mosquito vectors had been underway since the late nineteenth century, but became much more effective with the discovery that DDT was an effective insecticide (see Expert Committee on Malaria, 1947, pp. 26-28). The use of DDT became widespread in the late 1940s (particularly following a successful demonstration in Greece) and was intensified following the 1955-57 WHO decision to campaign systematically to eradicate malaria (see Bradley, 1992, WHO, 2004).[25] In our baseline instrument, the intervention against malaria is taken to be the extensive use of DDT during the 1940s (chloroquine was also invented during the 1940s and quickly replaced mepacrine as the antimalarial drug of choice, until chloroquine-resistant parasites developed). In our alternative instrument, we code it as taking place in the 1950s because of the WHO campaign to eradicate malaria.

Pneumonia is caused by a variety of infectious agents and toxins, including various bacterial and viral pathogens. Frequently, it appears as a secondary bacterial infection that causes death. The primary causes are often tuberculosis, influenza, and more recently AIDS. Antibiotics, for example penicillin, proved highly effective against bacterial pneumonia in the 1940s (although by now resistant strains have developed).[26] Also, from the 1940s there were partially effective vaccines against pneumonia. In our baseline instrument, the intervention against pneumonia takes place in the 1940s.

3.3 Life Expectancy, Population, and GDP Data

Data on life expectancy at birth, total births, and infant mortality are obtained from historical UN data (various issues of the Demographic Yearbook) and League of Nations reports.[27]

Since we need population and GDP data before World War II, we use the data compiled by Maddison (2003). Postwar demographic data are from UN data sources (see Appendix A).

Our base sample consists of 59 countries, from Western Europe, Oceania, the Americas, and Asia. East European and Russia are excluded from the base sample (because of concerns about the quality of their GDP data), but are included in robustness checks.[28] Because of the

[25] While it is generally accepted that DDT played a major role in the dramatic declines in malaria prevalence, there is some controversy in the demography literature about whether broader public health interventions of the 1940s were also essential (see, e.g., Langford, 1996).

Following the WHO campaign, it became apparent that some mosquitos could develop resistance to insecticides. However, the view from the WHO was that spraying with DDT remained effective, if used properly. E. J. Pampana (1954), chief of the Malaria Section of the WHO, called for a change in strategy, but still centered around residual-insecticide spraying.

[26] Sulphonamides were also used against pneumonia, but were soon superceded by penicillin (Conybeare 1948, p. 65, National Academy of Sciences, 1970, pp. 144-146). In any case, these drugs were not widely available, even in the UK, until the very end of the 1930s (Conybeare, 1948).

[27] All of these data are rough estimates. For example, life expectancy is calculated by combining data on age-specific death rates at a point in time, but often approximations are made using standard life tables. Preston (1975a) previously used some of the pre-war data for the 1930s. See Appendices A and C for more details.

[28] The only communist country in our sample is China. Excluding China has no effect on any of our results.

poorer quality of the available data, Africa is not in our baseline sample, but results including Africa are reported in Section 7 and are very similar to the baseline estimates.

We focus on the period 1940 to 1980 as our base sample, with observations for 1940, 1950, 1960, 1970 and 1980. We look at pre-1940 changes in our falsification exercises. Post-1980 is excluded because the emergence of AIDS appears to have led to a divergence in life expectancy between some poor countries and the richer nations.[29] Nevertheless, we report additional robustness checks by extending our sample through 2000 (particularly as this allows us to look at longer potential lags in the impact of health on economic outcomes).

Table 1 provides basic descriptive statistics on the key variables (see also the raw data in Appendix Table A1). The first column is for the whole world, while the second column refers to our base sample. A comparison of these two columns indicates that, despite the absence of Africa from our base sample, averages of life expectancy, population, GDP and GDP per capita are similar between the whole world and our sample. The next three columns show numbers separately for the three groups of countries used in Figures 1 and 2—initially rich, middle-income, and poor countries (measured in terms of GDP per capita in 1940). These columns show the same patterns as Figures 1 and 2: there is a large convergence in life expectancy among the three groups of countries between 1940 and 1980, but no convergence in GDP per capita. The three columns also give information on predicted mortality, which will be our instrument for life expectancy.

4 Estimation Framework and OLS Estimates

4.1 Estimation Framework

Our empirical approach is to estimate equations similar to equations (5) and (6) above. We interpret these equations as providing the conditional expectation function for our variables of interest. Thus, adding an error term, our estimating equation becomes

$$y_{it+k} = \pi x_{it} + \zeta_i + \mu_t + \mathbf{Z}'_{it}\boldsymbol{\beta} + \varepsilon_{it+k} \tag{7}$$

where y is log income per capita, ζ_i is a fixed effect capturing potential technology differences and other time-invariant omitted effects, μ_t incorporates time-varying factors common across all countries, $\mathbf{Z}$ is a vector of other controls, and x is log life expectancy at birth as defined above. The coefficient π is the parameter of interest.[30] Including a full set of country fixed

[29] In addition, malaria reappeared in the 1970s and 1980s because of reduced international efforts, the international ban on the use of DDT, and the emergence of insecticide resistant mosquitoes and drug-resistant strains of malaria. Tuberculosis has also returned as a secondary infection associated with AIDS.

[30] Given equations (5) and (6) above and the regression models used in the existing literature, we use log life expectancy on the right hand side throughout. The results are very similar if we use the level of life expectancy instead (results available upon request).

effects, the ζ_i's, is important, since many country-specific factors will simultaneously affect health and economic outcomes; fixed effects at least remove the time-invariant components of these factors.[31]

Notice also that in equation (7) the left-hand side variable has timing potentially different from the right-hand side variables. This allows us to investigate potential differences between medium-run and long-run effects. In particular, for $k > 0$, this equation would estimate the effect of life expectancy differences at time t on future (date $t+k$) income per capita differences.

Before investigating the effect of life expectancy on income per capita, we look at its effects on population, total births, and total income. The equations for these outcome variables are identical to (7), with the only difference being the dependent variable.

The most serious challenges in estimating the causal effect of life expectancy on income per capita or population are potential omitted variable bias and reverse causality. In particular, in equation (7), typically the (population) covariance term $\text{Cov}(x_{it}, \varepsilon_{it+k})$ is not equal to 0, because even conditional on fixed effects, health could be endogenous to economics.

Our empirical strategy is to exploit the potentially-exogenous source of variation in life expectancy because of global interventions. More specifically, our first-stage relationship is

$$x_{it} = \psi M_{it}^I + \tilde{\zeta}_i + \tilde{\mu}_t + \mathbf{Z}_{it}'\tilde{\boldsymbol{\beta}} + u_{it} \tag{8}$$

where M_{it}^I is *predicted mortality*, which will be discussed below. The key exclusion restriction is $\text{Cov}(M_{it}^I, \varepsilon_{it+k}) = 0$.

Notice that equation (7) does not allow for mean-reverting dynamics in the outcome variables. A more general model is:

$$y_{it+k} = \rho y_{it-1} + \pi x_{it} + \zeta_i + \mu_t + \mathbf{Z}_{it}'\boldsymbol{\beta} + \varepsilon_{it+k}^m. \tag{9}$$

Though conceptually attractive, this equation is considerably harder to estimate because of the simultaneous presence of fixed effects and a lagged dependent variable (see, e.g., Wooldridge, 2002, Chapter 11). This, and the fact that even if the data generating process were given

[31] Many authors estimate growth regressions of the following form:

$$g_{it} = \tilde{\alpha} y_{it-1} + \pi x_{it-1} + \mathbf{Z}_{it}'\boldsymbol{\beta} + \varepsilon_{it}$$

where y_{it-1} is log income per capita, g_{it} is growth between $t-1$ and t, and x_{it-1} log life expectancy at birth or some other measure of health. Since $g_{it} \simeq \Delta y_{it}$, this is equivalent to

$$y_{it} = (1+\tilde{\alpha}) y_{it-1} + \pi x_{it-1} + \mathbf{Z}_{it}'\boldsymbol{\beta} + \varepsilon_{it}$$

This way of rewriting the above equation highlights that growth regressions are analogous to the levels regressions like (7) or (9). But since typical growth regressions do not include country fixed effects, the correlation of x_{it-1} with other potential determinants of income per capita is likely to lead to biased estimates. Our approach partially circumvents this problem by including country fixed effects and thus removing the time-invariant component of such correlation. In Section 7, we also estimate equation (9), which by the same argument here, is equivalent to a growth regression with fixed effects.

by (9), instrumental-variables estimate of (7) would lead to consistent estimates of π as long as $\text{Cov}(M_{it}^I, \varepsilon_{it+k}) = 0$, motivates our initial focus on (7). Nevertheless, for completeness, we report estimates from (9) in subsection 7.2.

Finally, we also estimate a more demanding specification of the form:

$$y_{it+k} = \pi x_{it} + \zeta_i + \mu_t + \sum_{t=1940}^{1980} \lambda_t y_{i,1930} + \mathbf{Z}'_{it}\boldsymbol{\beta} + \varepsilon^d_{it+k}, \tag{10}$$

where $y_{i,1930}$ denotes the 1930 ("initial") value of the dependent variable (e.g., log population, log GDP, etc.), and the summation term represents a full set of interaction between this initial value and time dummies. This specification controls flexibly for mean-reversion, and is also useful as a check against differential trends in the dependent variable.

4.2 OLS Estimates

Tables 2 and 3 report OLS regressions for the main variables of interest. These results are useful both to show the (conditional) correlations in the data and for comparison to the instrumental variables (IV) estimates reported below. All regressions in these tables and throughout the paper include a full set of year dummies and country fixed effects, so all estimates exploit only the within-country variation. Moreover, throughout, all standard errors are robust and allow for arbitrary serial correlation of the residual at the country level (i.e., they correspond to the fully robust variance-covariance matrix, see Wooldridge, 2002, p. 275).

Table 2 focuses on log population (Panels A and B) and on log number of births (Panels C and D). We report results in pairs; first, we estimate versions of equation (7) using our baseline panel, which consists of observations at 10 year intervals between the indicated dates (1940-1980, 1930-1980, etc.). Second, we estimate "long-difference" models, essentially the same equation using only two data points—at the beginning and the end of the sample period. The first approach uses all the available data, while the second approach exploits only the longer-run changes. The latter may be useful both because it may be less vulnerable to problems caused by serial correlation in the error term and also because it enables us to be agnostic on how quickly life expectancy should affect the outcome variables. Also for comparison with previous work, we report results for the period 1960 to 2000.

A number of features are notable in Table 2. First, the 1960-2000 sample gives very similar results to our baseline sample of 1940-1980. For example, for the panel between 1960 and 2000, the estimate of the effect of log life expectancy on log population is between 1.46 and 1.69 (standard errors of, respectively, 0.29 and 0.43), whereas the estimate for our base sample of 1940-1980 is 1.21 (standard error = 0.20). Second, excluding the (initially) richest countries from the sample (column 4) makes little difference; now the estimate is 1.24 (standard error = 0.28). Third, in columns 5-10, we look at the effect of life expectancy on future levels

of population. In terms of equation (7), this corresponds to the case where $k > 0$. These results are broadly similar to the contemporaneous results. In all cases, a 1 percent increase in life expectancy is associated with approximately a 1-1.7 percent increase in population. The estimates using the long-differences in Panel B are slightly larger (and slightly less precise), but broadly similar.

To interpret the effect of (log) life expectancy on (log) population, it is useful to consider a simple continuous-time statistical model. Suppose each individual faces a Poisson death rate of $1/a$. This implies that life expectancy is a. Denote the flow of total births as a function of life expectancy by $B(a)$—a constant birth rate would correspond to $B(a)$ being proportional to a. Equating the flow of deaths, N/a, with the flow of total births, $B(a)$, gives the steady-state population level as:

$$\ln N = \ln a + \ln B(a). \tag{11}$$

This implies that in a regression of log population on log life expectancy, when the total number of births remains constant, we should expect an elasticity of 1. Naturally if there were no change in fertility, there would be an increase in the total number of births because of the increase in population. The elasticity we estimate here suggests that the birth rate did not decline enough to reduce or keep constant the number of births. This is confirmed in Panels C and D of Table 2, which show an overall increase in the total number of births in response to the change in life expectancy.

Table 3 presents results that are parallel to those in Table 2, but now the dependent variables are log GDP (Panels A and B) and log GDP per capita (Panels C and D). Again, all regressions have a full set of country and time fixed effects, and we show both panel and long-difference estimates.

Panels A and B in Table 3 indicate a positive relationship between log life expectancy and log GDP. For example, the results in columns 1-4 indicate an effect of life expectancy on GDP with an elasticity of approximately 0.7-1.7.[32]

Columns 5-10 again look at leads. With the exception of column 6, which corresponds to a 20-year lead, the estimates are similar to those in columns 1-4. Overall, the results in Table 3 suggest the presence of a positive and typically significant effect of life expectancy on total GDP. Nevertheless, as pointed out above, these results do not correspond to the causal effect of life expectancy on total output, and might reflect the fact that life expectancy increases precisely when countries are adopting other measures that increase income, or alternatively,

[32]Interestingly, the (conditional) correlation between life expectancy and income per capita in the period 1960-2000 appears to be twice as large as that during our base sample period (1.70 versus 0.73). This is consistent with the fact that a large part of the variation in life expectancy during our base sample period is exogenous, driven by the international epidemiological transition, so the upward bias in the OLS estimate resulting from reverse causality and common shocks to income per capita and health should have less effect during the 1940-80 period than during 1960-2000.

as emphasized by demographers, it may be that the increase in income raises life expectancy.

While Panels A and B show a positive relationship between life expectancy and total income, the rest of Table 3 suggests that the positive effect on population size outweighs the increase in GDP; the net effect on GDP per capita, though typically not significant, is generally negative. There is no evidence of a positive effect of life expectancy on GDP per capita in Table 3. Nevertheless, since these estimates are not necessarily causal, the true effect of life expectancy on income per capita might be larger or smaller than those shown in Table 3.[33] The rest of the paper investigates this question.

5 Predicted Mortality and First Stages

5.1 The Predicted Mortality Instrument

Prior to the international epidemiological transition, there was considerable variation in the prevalence of diseases across the world. For example, during the 1940s, while malaria was endemic in parts of South Asia and Central America, it was relatively rare in much of Western Europe and in the Southern Cone of Latin America. We therefore expect variation in the effects of global interventions on life expectancy in different countries depending on the baseline distribution of diseases. For example, DDT should reduce malarial infections and mortality, and increase life expectancy, in Central America and South Asia relative to Western Europe or the Southern Cone of Latin America.

Motivated by this reasoning, our instrument, *predicted mortality,* is constructed as

$$M_{it}^{I} = \sum_{d \in \mathcal{D}} \left((1 - \Delta_{dt}) M_{di40} + \Delta_{dt} M_{dFt} \right), \tag{12}$$

where M_{dit} denotes mortality in country i from disease d at time t, Δ_{dt} is a dummy for intervention for disease d at time t (it is equal to 1 for all dates after the intervention), and $\mathcal{D}$ includes the 15 diseases listed above. It is measured as the number of deaths per 100 individuals per annum. M_{di40} refers to the *pre-intervention* mortality from this disease in the same units, while M_{dFt} is the mortality rate from disease d at the *health frontier* of the world at time t. In our baseline instrument, we take M_{dFt} to be equal to zero.[34] Predicted mortality, M_{it}^{I}, thus uses a country's pre-intervention (1940) mortality rate from the 15 diseases until there is a

[33] If, instead, we estimate a version of equation (7) or the growth regression in footnote 31 *without* country dummies, we obtain a strong positive association between life expectancy and income per capita or growth as in many previous studies (e.g., Bloom and Sachs, 1998, Gallup and Sachs, 2001), though as noted above this association is not informative about the causal relationship between life expectancy and income per capita or economic growth.

[34] We also calculated an alternative measure of predicted mortality using the average mortality rate from disease d at time t among the richest countries, but since these rates are close to zero, this alternative measure is very similar to our baseline predicted mortality series, and gives identical results.

global intervention, and after the global intervention, the mortality rate from the disease in question declines to the frontier mortality rate.

Equation (12) makes it clear that the only source of variation in predicted mortality comes from the interaction of the baseline distribution of diseases with global interventions (in particular, note that M_{di40} applies until the time of global intervention). Whether a country has successfully eradicated a disease or has been quick at adopting international technologies will have no effect on M_{it}^I; the dummy Δ_{dt} turns on for all countries at the same time. This makes our exclusion restriction, that $\text{Cov}(M_{it}^I, \varepsilon_{it+k}) = 0$, plausible (where recall that ε_{it+k} is the error term in the second stage equation, (7)). Since variations in M_{it}^I are unrelated to any actions or economic events in the country, there is no obvious reason for it to be correlated with economic or population shocks in the country in question. The only potential threat to the exclusion restriction would be that the baseline mortality rates, the M_{di40}'s, are correlated with future changes in population or income. To show that this is unlikely to be the case, we allow for differential trends by a range of baseline characteristics and also report results from a number of different falsification exercises.

5.2 Alternative Instruments

We construct a number of alternative instruments to investigate the robustness of our results. The first alternative is the global mortality instrument,

$$M_{it}^I = \sum_{d \in \mathcal{D}} \frac{M_{dt}}{M_{d40}} M_{di40}, \tag{13}$$

where M_{di40} denotes mortality in country i from disease d in 1940, M_{dt} (M_{d40}) is global mortality from disease d in year t (1940), calculated as the unweighted average across countries in our sample. The advantage of the global mortality instrument is that it does not use any information on global intervention dates, instead relying on aggregate changes in world-wide disease-specific mortality rates. It is therefore useful in showing that none of our results depend on the coding of intervention dates.

Second, to further investigate the importance of intervention dates, we construct an alternative instrument, which uses different timings of interventions whenever there is any potential doubt about the exact dates. The details of this instrument are discussed in Appendix B.

Finally, we create yet an alternative predicted mortality series using only the three big killers, malaria, tuberculosis and pneumonia (influenza is left out of this list, because our sources do not separate deaths from viral influenza and the timing of the key intervention for influenza is less clear-cut than the other three cases).

We check the robustness of our results using these alternative instruments and in all cases, the results are very close to those with the baseline instrument.

5.3 Zeroth-Stage Estimates

Our approach is predicated on the notion that global interventions reduce mortality from various diseases. Therefore, before documenting the first-stage relationship between our predicted mortality measure and log life expectancy, we show the effect of various global interventions on mortality from specific diseases. In this exercise, in addition to the 15 diseases above, we also use deaths from cancers and malignant tumors as control diseases, since these were not affected by the global interventions.

Panel A of Table 4 estimates the following "zeroth-stage regression":

$$M_{idt} = \theta \Delta_{dt} + \mu_t + \pi_d + \delta_i + v_{it}. \tag{14}$$

The dependent variable is mortality in country i from disease d at time t, and the regression includes a full set of time, disease, and country dummies. The coefficient of interest, θ, measures whether there is a decline in mortality from a specific disease associated with an intervention.

Table 4 reports estimates of equation (14). In all cases, as expected, the estimate of θ is negative and significant. For example, in column 1, θ is estimated to be -46.04 (standard error = 9.40), which indicates an average reduction of 46 deaths per 100,000 population per intervention. In column 2, when we add lagged intervention, the coefficient on the intervention dummy is largely unchanged (-43.33), while the lagged intervention itself is insignificant.

More challenging is the specification in column 3, which includes contemporaneous and lead interventions. This specification is useful both as a check for pre-existing trends and for whether the dates of the interventions are coded correctly. Reassuringly, the estimate of the negative coefficient on contemporaneous intervention, θ, is unaffected, while lead intervention has the opposite (positive) sign (perhaps reflecting the lower quality of the pre-1940 data on individual disease mortality). These results show that mortality from specific diseases around the world fell sharply following the global health interventions.

Columns 4-7 investigate whether one of the main diseases is responsible for the results in columns 1-3, by excluding tuberculosis, pneumonia, malaria, and influenza one at a time. Without tuberculosis or pneumonia, the coefficient estimates are somewhat smaller, but still highly significant (-33.93 and -36.31, with standard errors of 8.66 and 8.99, respectively). Without malaria or influenza, the coefficient estimates are very similar to the baseline.

In Panel B, we look at each disease separately. The estimates in this case show how effective interventions have been in reducing mortality from each specific disease and also give an indication of how important mortality rates from different diseases were. For example, the coefficient of -108.51 for tuberculosis in column 4 and -137.92 for pneumonia in column 5 show the large declines in tuberculosis and pneumonia mortality resulting from the introduction of antibiotics. The estimate of -19.97 in column 6 shows a significant decline in malaria

mortality, but the lower magnitude of this number indicates that mortality from malaria was less important for our entire sample than mortality from tuberculosis or pneumonia (partly because large areas of the world were not affected by malaria). The declines in mortality from the other diseases are even smaller, but with the exception of influenza and measles (not shown), they are always statistically significant.

5.4 First-Stage Estimates

We next turn to the first-stage relationship between life expectancy and predicted mortality. While the zeroth-stage regression in equation (14) is at the disease-country-time level, our first-stage relationship is at the country-time level, since the left-hand side variable is life expectancy (at birth).

Figure 3 shows the first-stage relationship visually. The horizontal axis is the change in predicted mortality between 1940 and 1980, while the vertical axis is the change in log life expectancy during the same time period. We focus on the 1940-1980 period, since 1940 represents a pre-intervention year and 1980 is the end of the sample for most of our specifications. A strong negative relationship is clearly visible in Figure 3. Predicted mortality declined by a large amount in India, the Philippines, Indonesia, and parts of Central America, while remaining largely unchanged in parts of Western Europe, Uruguay, Argentina, Korea, Australia, and New Zealand. Life expectancy, in turn, increases by a large amount in the first group of countries, and much less in the second group.

Figure 4 depicts that the same relationship without the richest countries. It shows that the first-stage relationship is not driven by the comparison of rich countries to middle and low-income countries.

Table 5 shows the first-stage relationship in regression form by estimating equation (8). Country and year dummies are again included, and this set of specifications does not include any covariates. The top panel uses our entire data starting from either 1940 or 1930, while the bottom panel reports the long-difference specifications.

The first column is our baseline specification. It shows an estimate of ψ equal to -0.33 with a standard error of 0.06, which is significant at less than 1%.[35] This estimate implies that an improvement in predicted mortality of 0.43 (per 100 or 430 per 100,000 p.a., which is the mean improvement between 1940 and 1950 in our base sample) leads approximately to a 13 percent increase in life expectancy (mean life expectancy in our sample in 1940 was 49.30, so this is an increase of about 6.5 years, while the actual mean improvement in life expectancy between 1940 and 1950 was 5.3 years). With long differences, the coefficient estimate is -0.44, which is

[35]Note that the t-statistics in the basic first-stage relationships are above 5, so there is no issue of weak instruments (see, for example, Stock, Wright, and Yogo, 2002). Hence, in the 2SLS regressions below we use the standard Wald confidence intervals.

somewhat larger, but also slightly less precisely estimated (standard error = 0.09).

Results are similar for 1930-1980 in column 2 (and also for 1940-1970 or 1930-1970—not reported in the table). Column 3 shows analogous results when we include Eastern Europe. Column 4 excludes the initially rich countries and shows a statistically significant (though smaller) estimate of ψ (e.g., -0.23 with a standard error of 0.08 in Panel A).

Our baseline sample consists of an unbalanced panel. Column 5 shows that limiting the sample to a balanced panel makes little difference. The estimate of ψ is now -0.32 (standard error = 0.06).

Columns 6-8 investigate the robustness of the first stage to the inclusion of a range of interactions between country-specific variables and time dummies; these specifications are therefore similar to equation (10) above, except that they include interactions with initial values of institutions, log GDP per capita and continent dummies. For example, column 6 allows countries with different institutions (as measured by average constraint on the executive, from the Polity IV dataset, in 1950, 1960, and 1970) to have different changes in life expectancy in every year. This has little effect on the baseline estimates, which are now -0.27 (standard error = 0.07) in Panel A and -0.35 (standard error = 0.09) in Panel B. Column 7 includes interactions with initial (1930) log GDP per capita, flexibly allowing for differential trends in life expectancy for countries starting with different levels of prosperity. This also has very little effect on the estimates. Column 8 includes a full set of interactions between continent dummies and life expectancy, to control for the potential differential impact of distinct disease environments on the evolution of life expectancy. Once again, this has very little effect on the estimates, which remain highly significant and very close to the baseline.

Columns 9–12 investigate robustness to alternative instruments. Columns 9 and 10 use the global mortality instrument for the base sample and for the sample including only initially low and middle-income countries. The estimates are slightly larger and more significant.[36] For example, in Panel A the estimate of ψ is -0.41 (standard error = 0.08). Column 11 uses the alternative timing of global interventions as described in Appendix B, again with very similar estimates. These results show that the exact coding of global interventions and whether we use aggregate trends in disease-specific mortality or information on global interventions have little effect on the first-stage relationship. Finally, column 12 shows very similar results when the instrument uses information from only tuberculosis, malaria and pneumonia.

Overall, the results in Table 5 show a large and robust effect of the predicted mortality instrument on life expectancy. We next investigate the robustness of these results further.

[36]The exception is column 10 in Panel B, where the estimate is significant only at 10%.

5.5 Further Robustness Checks

Appendix Table C1 investigates the importance of disease composition to see whether a specific disease is responsible for the first-stage relationships shown in Figures 4 and 5 and in Table 5.[37] Columns 2, 3 and 4 of this table present results dropping data on the three main killers from our predicted mortality measure: tuberculosis, malaria and pneumonia respectively. Dropping tuberculosis or pneumonia strengthens the first stage estimates slightly, while none of the other diseases has a significant impact on the first stage coefficient. We conclude from these results that the first-stage relationship does not reflect the impact of any single disease.

The specifications in Table 5 do not allow for mean reversion in life expectancy, and also assume that it is contemporaneous predicted mortality that affects life expectancy. Failure to correctly specify the mean-reverting dynamics in life expectancy may bias our results. Moreover, in more general specifications we may find that it is lags or leads of predicted mortality that affect life expectancy. In particular, if it is the leads of (future changes in) predicted mortality that affect life expectancy, this would shed doubt on our interpretation of the first-stage relationship. Table 6 investigates these issues. Column 1 repeats our baseline specification (from column 1 of Table 5). Column 2 reports OLS estimates from the following model:

$$x_{it} = \nu x_{it-1} + \psi M_{it}^{I} + \delta_i' + \mu_t' + u_{it}, \tag{15}$$

which allows lagged log life expectancy to affect current log life expectancy. There is indeed evidence for mean reversion; the coefficient ν in the top panel is estimated to be 0.44 (standard error = 0.09). Nevertheless, the negative relationship between predicted mortality and life expectancy remains. The parameter of interest, ψ, is now estimated at -0.18 (standard error = 0.08), and implies a long-run impact similar to that in our baseline specification (the long-run impact in this case is $0.18/\left(1-0.44\right) \approx 0.32$).

Because we have a relatively short panel, OLS estimation of (15) will lead to inconsistent estimates. To deal with this problem, we follow the method of Anderson and Hsiao (1992) in column 3. This involves first-differencing (15), to obtain:

$$\Delta x_{it} = \nu \Delta x_{it-1} + \psi \Delta M_{it}^{I} + \Delta \mu_t' + \Delta u_{it},$$

where the fixed country effects are removed by differencing. Although this equation cannot be estimated consistently by OLS either, in the absence of serial correlation in the original residual, u_{it}, there will be no second order serial correlation in Δu_{it}, so x_{it-2} will be uncorrelated with Δu_{it} and can be used as instrument for Δx_{it-1} to obtain consistent estimates. Similarly M_{it-1}^{I} is used as an instrument for ΔM_{it}^{I}. This procedure leads to very similar results to the OLS estimates. The estimate of ψ is -0.27 (standard error = 0.14).

[37] Appendix Tables C1-C4 are included in Appendix C and are not for publication.

Although the instrumental variable estimator of Anderson and Hsiao (1982) leads to consistent estimates, it is not efficient, since, under the assumption of no serial correlation in u_{it}, not only x_{it-2}, but all earlier lags of x_{it} in the sample are also uncorrelated with Δu_{it}, and can also be used as additional instruments. Arellano and Bond (1991) develop a Generalized Method-of-Moments (GMM) estimator using all of these moment conditions. When all these moment conditions are valid, this GMM estimator is more efficient than Anderson and Hsiao's (1982) estimator. GMM estimation, which we use in column 4, leads to similar but more precisely estimated coefficients. The estimate of ψ in the full sample is now -0.19 (standard error = 0.06). Tests for second-order autocorrelation in the residuals, reported at the bottom of the column, show that there is no evidence of additional serial correlation. However, the Hansen J-test shows that the overidentification restrictions are rejected, presumably because different lags of life expectancy lead to different estimates of the mean reversion coefficient. This rejection is not a major concern for our empirical strategy since the exact magnitude of the mean reversion coefficient, ν, is not of direct interest to us. Essentially because the models in (8) and (15) are the first stage in our 2SLS procedure, all we need is for M^I_{it-1} not to have a direct effect on the second-stage outcomes.

Columns 5-7 investigate the effect of lagged and lead mortality. In column 5, contemporaneous and lagged mortality are included together. Not surprisingly, both of these are significant, since, in many countries, global health interventions were implemented gradually over time (recall that an intervention is coded at the time of the major global breakthrough).

The more important challenge for our approach is the inclusion of lead predicted mortality. Since global interventions did not start before 1940, lead mortality should have no effect on life expectancy. Column 6 investigates this by including contemporaneous and lead mortality together. In this case, the estimate of the effect of contemporaneous predicted mortality is -0.33 (standard error = 0.06), while lead mortality is not significant and has the wrong sign. Column 7 includes contemporaneous, lag, and lead predicted mortality together, and in this case both contemporaneous and lag mortality are statistically significant, while lead mortality remains highly insignificant. These results suggest that, consistent with our hypothesis, it was indeed the global interventions of the 1940s onwards that led to the increase in life expectancy in countries previously affected by these diseases.

Finally, columns 8 and 9 shows that controlling for the effect of income per capita has little impact on the relationship between predicted mortality and life expectancy, and column 10 shows very similar to our baseline estimates from the balanced panel of countries.

5.6 Pre-Existing Trends and Falsification

Table 6 already showed that life expectancy responds to contemporaneous changes in predicted mortality and does not respond to future changes. This suggests that our first stage is unlikely to be driven by pre-existing trends. Nevertheless, the exercise in Table 6 uses only data from 1940 onwards. An alternative falsification exercise on pre-existing trends is to look at changes in life expectancy during the pre-period, 1900-1940, and see whether they correlate with future (post-1940) changes in predicted mortality. This is done in Figures 5 through 8 and in Table 7.

Figure 5 shows the change in log life expectancy 1900-1940 against the change in predicted mortality 1940-1980. There is no evidence of a negative relationship similar to those in Figures 3 and 4. In fact, there is a slight positive slope (which is statistically insignificant—see Table 7). Figure 6 shows the same relationship without the richest countries, and there is now a somewhat stronger positive relationship (again insignificant—see Table 7). There is thus no evidence of pre-existing trends that could explain our first-stage results.

Figures 7 and 8 substantiate the patterns in Figures 5 and 6 further by showing changes in log life expectancy just before the international epidemiological transition, between 1930 and 1940 against the predicted mortality instrument. These figures also show no evidence of a significant negative relationship either for the whole sample or for the subsample excluding the initially richest countries. Our measure of predicted mortality explains changes in life expectancy *after* 1940 but *not before* 1940.

Table 7 also extends our examination of potential pre-existing trends to the outcome measures, by looking for a potential relationship between our measure of post-1940 predicted mortality and changes in log population, log GDP, and log GDP per capita between 1900 and 1940.[38] Columns 1 and 2 confirm the positive and insignificant relationship between change in predicted mortality between 1940 and 1980 and change in life expectancy between 1900 and 1940 shown in Figures 5 and 6. Columns 3 and 4 show that there are no differential pre-existing trends in log population between 1900 and 1940 either for the entire sample or for the sample excluding the richest countries. Columns 5-8 show similar results for log GDP and log GDP per capita.

These results therefore indicate that there were no pre-existing trends in life expectancy or in our key outcome variables prior to the international epidemiological transition.[39] This gives us greater confidence in using predicted mortality as an instrument to investigate the effect of

[38] We do not have enough data to do this for total births. Data limitations also make our sample sizes for the other variables smaller for this exercise than for our main regressions.

[39] For a more qualitative confirmation that there was no pre-existing trend, see Carr-Saunders (1936). In this comprehensive review of population trends, there is no hint of the increase in life expectancy and population that was to occur shortly.

life expectancy on a range of economic outcomes.

Finally, we further use Table 7 to show the reduced-form relationships between predicted mortality and some of our outcome variables. Recall that life expectancy is a proxy for overall health of the population, so the reduced-form relationships between predicted mortality and the outcome variables are as informative as the 2SLS estimates reported below. Panel B of Table 7 shows these reduced-form relationships. As already shown, there is a significant negative relationship between life expectancy and predicted mortality in the period 1940-80. In addition, there is a significant negative relationship between predicted mortality and population during the same period, which indicates an increase in population in previously high-mortality areas resulting from the international epidemiological transition. The other columns show a negative but insignificant relationship between predicted mortality and total GDP, and a positive relationship between predicted mortality and GDP per capita. These results imply that declines in mortality were associated with lower GDP per capita (since total GDP did not increase much and population grew substantially). The 2SLS estimates presented in the next section confirm these reduced-form relationships.

6 Main Results

We now present our main results, which are the 2SLS (two-stage least square) estimates of the effect of log life expectancy on six outcome variables: log population, log total births, log GDP, log GDP per capita, log GDP per working age population, and years of schooling.

For each outcome we use two estimation strategies. The first is a full panel with decadal observations between 1940 and 1980, while the second looks only at the long difference using data from 1940 and 1980. The tables have a parallel structure (except for schooling, where data availability makes this impossible). In addition, in each case, we look both for contemporaneous effects and for "longer-run" effects after 10, 20, 30, and 40 years.

6.1 Population

Figure 9 shows a strong negative reduced-form relationship between change in log population 1940-80 and the change in predicted mortality over the same period. This pattern, already seen in Panel B of Table 7, implies that countries with a larger decline in predicted mortality experienced a larger increase in log population, i.e., more population growth. Given the negative relationship between predicted mortality and life expectancy in Figure 4, this translates into a positive effect of life expectancy on population. This is confirmed in Table 8, which reports 2SLS results from regressing log population on log life expectancy in either a panel specification (Panel A) or in long differences (Panel B). The first stages for these regressions are reported in Table 5 and are not repeated here to save space.

In column 1 we look at contemporaneous effects during 1940-80 and find a coefficient on log life expectancy of 1.31, with a standard error of 0.37 (statistically significant at 1%). This estimate is comparable to the OLS estimates in Table 2.

The coefficient increases to 1.35 when we look at 1930-80 (column 2) and is even larger when we include Eastern Europe (column 3). When we exclude the initially richest countries in column 4, the coefficient estimate is again similar, 1.58 (standard error = 0.76).

Column 5 shows that the results are generally robust (though slightly smaller) when we include the full set of interactions between year dummies and institutions (both in the first and second stages).[40] These interactions are jointly significant, suggesting that initial institutional differences have some predictive power for subsequent population growth. Column 6 estimates equation (10), allowing for a full set of interactions between year dummies and initial (1930) log population. As noted above, this specification flexibly controls for both mean reversion and potential differential trends. Remarkably, the estimate of the effect of log life expectancy on log population is essentially unaffected, 1.33 (standard error = 0.35), though interactions between year dummies and initial population are jointly statistically significant. The corresponding estimate in Panel B is also very similar to the baseline, 1.68 (standard error = 0.44).

Column 7 repeats the baseline regression using the global mortality instrument. In Panel A, the estimate of the effect of log life expectancy on log population is 1.65 (standard error = 0.40), while in Panel B, it is 1.70 (standard error = 0.48).

Columns 8-11 investigate the longer-term effects of life expectancy on population growth by looking at the specifications where the dependent variable is various leads of log population (i.e., $k > 0$ in terms of equation (7)). The coefficients are on the whole very similar to the baseline estimate (slightly higher for 10 and 20 year leads and slightly smaller for the 40 year lead). This suggests that changes in life expectancy led to relatively enduring increases in population. Panel B shows the same results with the long difference specifications.

Overall, we find a large, relatively precise, and robust effect of life expectancy on population. The elasticity is estimated consistently to lie between 1 and 2, which is similar to the OLS estimates.

6.2 Births

Table 9 presents 2SLS estimates of log life expectancy on log total births. Consistent with the magnitude of the response of population to life expectancy, Table 9 indicates that the increase in life expectancy was associated with an increase in the total number of births. In column 1, Panel A, the estimate is 2.39 (standard error = 0.69). The estimates are similar in the long-difference specifications, when we include Eastern Europe, when we exclude the initially richest

[40]The results including the interactions between year dummies and initial log GDP per capita or continent dummies are also very similar and are not reported to save space.

countries, when we include interactions between year dummies and institutions, or initial log GDP per capita, continent dummies, and initial log total births, and when we use the global mortality instrument.

Looking at the leads shows an interesting pattern whereby the effects become smaller at future dates. This suggests that there was a delayed decline in fertility in response to the increase in life expectancy (which is consistent with the evidence reviewed in Kelley, 1988).

6.3 GDP

Figure 10 shows the reduced-form relationship between change in log (total) GDP and change in predicted mortality during 1940-1980. Consistent with the pattern in Panel B of Table 7, there is a slight (but not statistically significant) downward slope, which indicates that countries with larger declines in predicted mortality experienced somewhat higher GDP growth between 1940 and 1980, though this effect is not very large.

Table 10 presents the related 2SLS regression evidence. In column 1, the estimate of the key parameter is -0.03 (standard error = 0.67). The estimate using long differences in Panel B (corresponding to Figure 10) is positive, 0.32, but also statistically insignificant (standard error = 0.84). In both cases, the standard errors are large enough that economically significant positive effects cannot be ruled out. For example, the two standard error (95% confidence) intervals always include a response of GDP to life expectancy with an elasticity that could be as high as 1.3. Nevertheless, the standard errors will be somewhat smaller when we look at GDP per capita below, enabling us to exclude any positive effects on per capita growth.

The pattern of response of GDP to life expectancy is broadly similar when we look at different sample periods, when we include Eastern Europe, exclude the initially richest countries, when we include interactions between year dummies and institutions or initial GDP per capita, and when we use the global mortality instrument.

The estimates in columns 8-11 show that at longer horizons there is a more positive effect of life expectancy on GDP (though still not significant). For example, with the 10-year lead the coefficient is now 0.52 (standard error = 0.48) and with the 20-year lead it is 0.53 (standard error = 0.44). The effect starts declining after the 30-year lead. Estimates using the long differences are close to and somewhat larger (though considerably less precise) than the panel estimates in Panel A. The over-time increase in the impact of life expectancy on GDP could be a result of a combination of the larger population reaching working age, and consistent with the neoclassical growth model, capital inputs and other factors of production adjusting to the increase in population.

We interpret these estimates as suggesting that the increase in life expectancy and the associated increase in population had a relatively small effect on total GDP at first, with a

somewhat larger effect over time. Nevertheless, the relatively large standard errors make it impossible for us to pin down the exact magnitude or timing of the impact of life expectancy on total GDP.

6.4 GDP Per Capita and Per Working Age Population

The response of total GDP already reveals that the effect of the increase in life expectancy on GDP per capita (or GDP per working age population) was negative. This is shown in Figure 11, which depicts a strong positive reduced-form relationship between the change in log GDP per capita and the change in predicted mortality during 1940-1980. Evidently, countries with larger declines in predicted mortality also experienced lower growth in GDP per capita. Clearly, this is the result of the larger increase in population than in GDP in these countries, which was already shown in Figures 11 and 12 and in Panel B of Table 7.

The 2SLS estimates of the effect of log life expectancy on GDP per capita in Table 11 confirm this pattern. There is a significant negative effect of life expectancy on GDP per capita in columns 1 and 2 of Panels A and B. In either case, the coefficient estimate for π in equation (7) is around -1.30 (with standard errors ranging between 0.46 and 0.61).

The results in columns 3-6, which look at alternative samples and include interactions with initial institutions and initial log GDP per capita, are similarly negative and hover around statistical significance. Estimates from equation (10) in column 7, on the other hand, lead to still negative but smaller effects of log life expectancy on GDP per capita. In all cases, the two standard error bands always exclude positive effects of life expectancy on GDP per capita.

As with the results for total GDP in Table 10, the lead results indicate a more positive (less negative) impact of life expectancy on GDP per capita over the following 40 years than initially. Nevertheless, even after 40 years, there is no evidence of a positive effect of life expectancy on GDP per capita.

One concern with these results is that the increase in population is largely at young ages, so GDP per capita may be low precisely because the denominator has increased, while the working age population has not. To investigate the importance of this issue, Appendix Table C2 looks at GDP per working age population,[41] and shows that the impact of life expectancy on GDP per working age population is very similar to its impact on GDP per capita.

Overall, our 2SLS estimates show no evidence that the large increase in life expectancy in many parts of the world starting in the 1940s led to a significant increase in GDP per capita.[42] Instead, the increase in life expectancy was associated with a significant increase in population

[41] We define working age population as population between the ages of 15 and 60. Estimates of the age distribution of the population and hence of the working age population for this time period are often rough.

[42] As noted in footnote 40, the results are similar when we control for a full set of continent dummies interacted with time. For example, in the specification of Table 11, the coefficient on log life expectancy is -0.27 (standard error = 0.45).

and a somewhat smaller increase in total GDP.

These results are broadly consistent with the neoclassical growth model. In terms of the model in Section 2, suppose that the contemporaneous effects correspond to the "medium run" impact with the capital stock held constant. The coefficient of interest, in this case, is $\pi = (\alpha(\gamma+\eta) - (1-\alpha)\lambda)$ in terms of equation (6). Recall that λ here is the response of population to changes in life expectancy, so according to the estimates in Table 8, we can think of $\lambda \approx 1.5$. The coefficient α corresponds to the share of labor. Since the countries in question here include many low-income countries where land is an important factor of production, we take the share of land as 1/3, i.e., $1-\alpha-\beta \approx 1/3$ (see footnote 13), and thus set $\alpha \approx 1/3$ and $\beta \approx 1/3$. This would imply that our estimate of $\pi = (\alpha(\gamma+\eta) - (1-\alpha)\lambda) \approx -1.3$ is consistent with $\gamma+\eta$ close to zero or even slightly negative. If, on the other hand, we were to take λ to be around 1.7 as suggested by the high-end estimates in Table 8, $\gamma+\eta$ would be small but positive.[43] Therefore, these results suggest that the benefits of higher life expectancy in terms of direct productivity gains and human capital gains are relatively small. This is also confirmed when we look at the longer-run effects. For example, if we take the long-run effect to be approximately -0.75 and $\beta \approx 1/3$, then the long-run relationship of $\pi = (\alpha(\gamma+\eta) - (1-\alpha-\beta)\lambda)/(1-\beta)$ implies a value of $\gamma+\eta$ equal to zero. Smaller negative effects, which are within the two standard error bands of the estimates in Table 11, would be consistent with positive values of $\gamma+\eta$.[44]

6.5 Years of Schooling

The results so far do not show any evidence of large gains from increases in life expectancy in terms of economic growth per capita. Instead, the greater population associated with the increase in life expectancy appears to have somewhat reduced income per capita. This suggests that the indirect benefits of improved health in terms of greater education and greater (total factor) productivity may be limited (see the calculations in the last paragraph of the previous subsection). As a further check on this conclusion and as a way of investigating whether there are any substantial effects of life expectancy working through human capital (as posited by equation (4)), we can also directly look at whether increasing life expectancy raised human capital during and in the aftermath of the international epidemiological transition.

Table 12 estimates the corresponding 2SLS regressions using the available data on schooling starting in 1960. Data availability implies that we can only look at the effect of life expectancy

[43] But in turn, if α were higher, the implied values of $\gamma+\eta$ would be correspondingly lower. For example, Hansen and Prescott (2002) suggest a value of 0.3 for $1-\alpha-\beta$, 0.1 for β and 0.6 for α in pre-industrial societies.

[44] The comparison of these results to the OLS estimates in Table 3 (together with the pattern discussed in footnote 32) suggests that the lack of a significant OLS relationship between life expectancy and GDP per capita is likely to be due to a combination of a short-run negative effect of life expectancy on GDP per capita and a positive effect of income on life expectancy. See also Pritchett and Summers (1998) for estimates of income per capita on life expectancy.

on 10-year or 20-year leads of schooling (which is not a severe limitation since there are likely to be important lags in the effect of life expectancy on schooling). The results in Table 12 show that there is no effect of life expectancy on schooling in the OLS and in the IV either in the base sample or for only low and middle-income countries (columns 1-6). With 30-year leads, there is a positive and significant OLS estimate, but the IV estimates are again insignificant (either positive or negative depending on the sample, as shown in columns 8 and 9).

Overall, there seems to be no evidence that the increase in life expectancy has been associated with substantially greater investment in human capital, which is consistent with the finding in the previous subsection. The most likely reason why the increase in life expectancy did not translate into greater education during this episode is that the affected countries faced bottlenecks in their education systems, making it impossible for them to increase the education of the much larger cohorts of children that survived and were born as a result of the international epidemiological transition.

7 Further Results

The results in the previous section suggest that the increase in life expectancy led to a substantial increase in population, but not to more rapid economic growth. In this section, we investigate the robustness of these results further.

7.1 Alternative Samples

An important question is whether including sub-Saharan Africa in the analysis changes any of the main results documented above. This is hard to answer with great certainty as the detailed data for Africa before at least 1950 are either not available or not reliable. Although there is a sizable historical literature on medical conditions in Africa, much of this is not accompanied by statistics that are comparable with our base sample data.[45] Nevertheless, it is possible to include sub-Saharan Africa after 1950 in our regressions using UN data (which are nonetheless less reliable than the non-African data, see Appendix C for details). This is done in columns 1-4 and 7-10 of Table 13. The results for the first and the second stages are similar to our previous results both using the baseline and the global mortality instruments.[46] In this case,

[45] In general terms, we know that health in Africa improved, at least for a while after World War II. For example, Cutler et al (2006, p. 17) write: "life expectancy [in Africa] rose by more than 13 years from the early 1950s to the late 1980s, before declining in the face of HIV/AIDS." Estimates in Gwatkin (1980, e.g., Figure 2) also suggest that increases in life expectancy were at least as dramatic in Africa as in other developing countries, but only until average life expectancy for these societies reached 40; at that point the rate of increase slowed sharply. This could point to a failure to sustain health improvements or some other factor, and needs further investigation.

[46] The sample used here is limited both by lack of life expectancy data in 1940 and by the fact that Maddison does not have population or GDP data for Africa before 1950. Consequently, even though Table 13 uses information on 43 more countries than the previous tables, the additional observations are all post-1950.

estimates using the global mortality instrument are more reliable since they do not use the baseline disease distributions in Africa.

A second alternative sample drops countries that were demographically most affected by World War II. Urlanis (2003) documents demographic effects that were both direct, through loss of population, and indirect, through reducing birth rates and increasing non-casualty death rates in a number of countries. Interestingly, however, in relatively few cases was there a first-order effect on population. Based on Urlanis (2003), columns 5-6 and 11-12 of Table 13 report results dropping Germany, Italy, Finland, Austria, and China (Japan is not in our sample due to data issues; Eastern Europe is not in the baseline sample). The first-stage relationship between log life expectancy and predicted mortality remains strong and highly significant, and there is again a large effect on population and a smaller, insignificant effect on total GDP.

We also estimated regressions dropping countries that were involved in developing the new "miracle" drugs and chemicals of the 1940s and 1950s: the UK, the US, Germany and Switzerland. For these countries one might be concerned that the medical innovations were partly endogoneous to their disease conditions. In any case, this has hardly any effect on the estimates (not reported).

7.2 Mean Reversion in the Second Stage

In Appendix Table C3, for our main variable of interest, income per capita, we estimate a version of equation (9), which explicitly allows for mean reversion in the dependent variable. Recall that the presence of such mean reversion does not affect the consistency of the estimates presented so far as long as our instrument for life expectancy is valid (i.e., as long as $\text{Cov}(M_{it}^I, \varepsilon_{it+k}) = 0$), so we report these estimates mostly for completeness.

Our strategy is to estimate a transformed model that removes the effect of mean reversion in income per capita. Suppose we know the mean-reversion parameter ρ in equation (9). Then, subtract ρy_{it-1} from y_{it}, which, using (9) without covariates, gives

$$\tilde{y}_{it}^{\rho} = \pi \tilde{x}_{it}^{\rho} + \zeta_i^{\rho} + \mu_t^{\rho} + \tilde{\varepsilon}_{it}^{\rho},$$

where the transformed dependent variable is $\tilde{y}_{it}^{\rho} \equiv y_{it} - \rho y_{it-1}$, and on the right hand side we have $\tilde{x}_{it}^{\rho} \equiv x_{it} - \rho x_{it-1}$ (and $\tilde{\varepsilon}_{it}^{\rho} \equiv \varepsilon_{it} - \rho \varepsilon_{it-1}$). M_{it}^I can be used as an instrument for $\tilde{x}_{it}^{\rho}$ in this equation (since $\text{Cov}(M_{it}^I, \varepsilon_{it+k}) = 0$ for all k, we also have $\text{Cov}(M_{it}^I, \varepsilon_{it}^{\rho}) = 0$). Therefore, a 2SLS regression of $\tilde{y}_{it}^{\rho}$ on $\tilde{x}_{it}^{\rho}$ will identify the coefficient of interest, π. Although we do not know ρ, we can implement a two-stage version of this procedure by first estimating ρ.[47] Appendix Table C3 reports results from applying this procedure using a range of values for ρ that encompasses (and exceeds) the range of estimates of ρ. There is a robust first stage between transformed

[47] In regressions of log income per capita on its lag and country and time fixed effects, the estimates of ρ vary between 0.4 and 0.75 depending on estimation strategy and on whether or not log life expectancy is included.

log life expectancy and predicted mortality, and the second-stage estimates are similar to (but somewhat more negative than) those in Table 11. These estimates show that irrespective of the value of ρ, the relationship between life expectancy and GDP per capita is never positive (the point estimate is always negative).

7.3 Interaction Results

As discussed in Section 2, we may expect the impact of log life expectancy on GDP per capita to differ depending on the investment rate. We investigate this issue in Appendix Table C4 using two variables to measure investment rates: (1) initial (1930) log GDP per capita and (2) investment rates from the 1940s (or immediately after). Although income differences in 1930 likely had various causes, we expect them to be correlated with savings and investment rates, and these data are likely to be more reliable than estimates of investment rates around the same time.

Our empirical strategy is to include an interaction between log life expectancy and initial log GDP per capita or investment as a percent of GDP. This interaction term is instrumented by the interaction between predicted mortality and initial log GDP per capita (or investment). In all regressions, the main effects are evaluated at the sample mean. Panel A of Appendix Table C4 shows that the effect of log life expectancy on population is the same irrespective of initial log GDP p.c. or the investment rate; the interactions between log life expectancy and these baseline characteristics are insignificant both in contemporaneous and lead specifications.

The picture is different in Panels B and C, where we look at log GDP and log GDP per capita. In the regressions with contemporaneous effects, the interaction terms both with GDP per capita in 1930 and investment share of GDP in 1940s are positive, and except for the effect of the interaction with GDP per capita in 1930 on log total GDP (in Panel B), they are statistically significant. For example, the coefficient on the interaction between GDP per capita in 1930 and log life expectancy in the log GDP per capita regression (Panel C, column 1) is 0.79 (standard error = 0.37), while the interaction with investment share of GDP for the same variable (Panel C, column 5) is 0.12 (standard error = 0.04). These estimates imply that, consistent with our theoretical expectations, there is some evidence that countries with high investment rates (measured directly or proxied by high initial income per capita) suffered less adverse income effects from the increase in population. Moreover, consistent with equation (5) in Section 2, these investment rate and life expectancy interactions appear not to have had a positive impact on log GDP or log GDP per capita in the long run. Nevertheless, the results of this exercise have to be interpreted with caution, since data quality and relatively large standard errors limit the extent to which we can pin down the exact timing of changes in GDP.

8 Conclusion

A newly-emerging consensus in academic and policy circles holds that disease environment and health conditions lie at the root of large income differences across countries today, and argues that improving health will not only improve lives but will by itself spur rapid economic growth.

This paper investigated these claims by estimating the effect of life expectancy at birth on economic growth. The innovation in our approach is to exploit the international epidemiological transition, which led to potentially-exogenous differential changes in mortality from a number of major diseases across the world. As a result of new chemicals, drugs, and other international interventions, mortality from tuberculosis, pneumonia, malaria, and various other diseases declined sharply in many parts of the world, while other countries that were largely unaffected by these diseases did not experience similar improvements in health and life expectancy. Exploiting these differential changes in predicted mortality as an instrument for life expectancy, we estimate the effect of life expectancy on a range of economic variables, most importantly population and GDP.

Our results indicate that the increase in life expectancy led to a significant increase in population; birth rates did not decline sufficiently to compensate for the increase in life expectancy. We find a small initial positive effect of life expectancy on total GDP, and this effect grows somewhat over the next 40 years, but not enough to compensate for the increase in population. Overall, the increases in life expectancy (and the associated increases in population) appear to have reduced income per capita at first, with this negative effect slowly wearing off over the next 40 years. There is no evidence that the increase in life expectancy led to faster growth of income per capita. This evidence sheds considerable doubt on the view that health has a first-order impact on economic growth.

It is also important to emphasize the limitations of our results. The most important limitation is that since our approach exploits the international epidemiological transition around the 1940s, the results may not be directly applicable to today's world. This is for at least two reasons. First, the international epidemiological transition was a unique event and perhaps similar changes in life expectancy today will not lead to an increase in population and the impact on GDP per capita may be more positive. Second, the diseases that take many lives in the poorer parts of the world today are not the same as those 60 years ago; most notably HIV/AIDS is a major killer today but was not so in 1940. Most of the diseases we focus on had the greatest impact on children (with the notable exception of tuberculosis), while HIV/AIDS affects individuals at the peak of their labor productivity and could have a larger negative impact on growth. Further study of the effects of the HIV/AIDS epidemic on economic outcomes is an important area for future research.

9 Appendix A: Data Sources and Construction

Population, GDP, and GDP per capita data are from Maddison (2003), specifically the downloadable data available to purchasers of his 2003 book. Working age population is defined as population between the ages of 15 and 60 and is obtained from the on-line UN demographic database from 1950 (http://esa.un.org/unpp). Population structure for 1940 is from the UN Demographic Yearbook 1948 (United Nations 1949, Table 4, pp. 108-158). We use data for 1940 or the closest available year or range of years. For 1930 we assume the same age structure as 1940 (this is relevant only for column 2 of Appendix Table C2).

Life expectancy in 1940 and earlier are from various UN Demographic Yearbooks. Key Yearbooks are the original 1948 edition (United Nations 1949) and subsequent issues for 1949-50 (United Nations 1950), for 1951 (United Nations 1951), and particularly the retrospective section of the Demographic Yearbook 1967 (United Nations, 1967). We use the most recently revised UN data available to calculate the unweighted averages of male and female life expectancy for 1940 (we also check these data against United Nations, 2000, but the coverage of this generally begins no earlier than 1948). When there is no data for 1940, but such data exist for neighboring years, e.g., 1938 and 1942, we use linear interpolation to obtain an estimate for 1940. In a few cases, we use information from neighboring countries when they have similar crude death rates (from the UN Demographic Yearbooks). Appendix C provides further details and gives the specifics for each country.

Life expectancy from 1950 onwards was downloaded from the on-line UN demographic database; these data are in five year intervals, so we use 1950-55 for 1950 and 1960-65 for 1960, etc. Life expectancy in 1900, used in the falsification tests, is from Maddison (2001, Table 1-5a, p. 30). These estimates for life expectancy in 1900 for Europe, Latin America, and Asia are consistent with the numbers in Arriaga and Davis (1969), Riley (2001), and Bengtsson et al (2004).

To classify the cause of death, we use the Abridged List of the 1938 revision of the International Classification of Disease. This list is comprehensive and has 44 categories. We omit any diseases that are not infectious or could be degenerative, e.g., "diseases of the heart" (Abridged List No. 24) and residual categories, such as "other infectious or parasitic diseases" (Abridged List No. 14). Syphilis (Abridged List No. 9) and puerperal fever/infection (Abridged List No. 35), which results from an infection after childbirth, are omitted because their prevalence depends on sexual and fertility behavior, which fall outside our focus here. Finally, we further omit diseases that were never major causes of death, even though they may have had serious effects on health (e.g., acute poliomyelitis). In all, there are 15 infectious diseases for which we can obtain comparable cross-country data on deaths per 100,000 in 1940 (or 1939 or a close year). Of these 15, 3 are reviewed in more detail in the main text and 12 are covered in Appendix B. We have checked that the data we use in or around 1940 are not significantly affected by the impact of World War II; this is generally possible as in most cases some combination of United Nations sources yields numbers for at least two early years. For European countries affected by the war, we prefer data from 1937 or 1938, where available. Also, in our robustness checks, we drop all data from countries where Urlanis (2003) deemed that war had a major demographic impact.

The classification of death rates by cause changed in 1948, and some of our data for 1950 and after are available only according to the Abbreviated List, 1948 Revision of the International Classification of Disease. For example, the UN Demographic Yearbook (1954) reports cause of death in and around 1950 for some countries using the 1938 classification and for others using the 1948 classification. The terminology of the Abridged List for the 1938 classification and the Abbreviated List for the 1948 classification is as used in the Demographic Yearbook. Most of our 15 diseases can be tracked through this reclassification, but dysentery/diarrhea-related diseases cannot—we have information on these diseases only for 1940 (which is what we need to construct the predicted mortality instrument), but they are not included in our zeroth-stage regressions in Table 4 or in our calculation of the global mortality instrument.

For our data on cause of death in 1940, we start with the Summary of International Vital Statistics, 1937-1944, published by the Federal Security Agency (1947) of the US government immediately after World War II. This source provides comparable comprehensive data on cause of death around 1940, as well as longer time series on the more important diseases (i.e., death rates by country), primarily from

League of Nations sources; however, it did not use all the available data (Federal Security Agency, 1947, p. 2). For this reason, we fill gaps for 1940 using the original sources, which are national health statistics collected, cleaned and republished between the wars by the League of Nations Health Organization (see Federal Security Agency, 1947, pp. 1-3); we also use information from the League and its direct postwar successors for earlier and later data as discussed in Appendix C. A key issue is the area covered by the registration of deaths in various countries. Apart from the very richest countries in 1940, there was seldom universal registration of death, with a death certificate signed by a doctor. Consequently, some of the data are for major cities, while others are for all towns or for the entire population. Unfortunately, our sources do not always document clearly the precise coverage of the underlying data (for lower income countries, the data almost certainly overweigh towns relative to rural areas and diseases related to urban overcrowding are likely to be overrepresented). Nevertheless, our results are robust to using only the more reliable data.

The League of Nations Health Organization established comparable international health statistics for a large number of countries, but never to our knowledge published a comprehensive retrospective of the data. Their first relevant publication was Issue No. 7 of the Annual Epidemiological Report, which appeared in October 1923. But only from 1929 (covering the year 1927) did this publication include death rates from specific causes (League of Nations Health Organization, 1929). Early issues of this publication are also refered to as Statistics of Notifiable Diseases. The first six issues focused on Eastern Europe, particularly typhus and malaria epidemics in Russia. For a comprehensive list of publications by the League of Nations on health, see Aufricht (1951), particularly pp. 176-177. For an explanation of the structure and purpose of the League of Nations Health Organization, see League of Nations (1931). For more on the early development of internationally comparable health statistics, see Stocks (1950).

We use the death rates by disease for 1930 from League of Nations Health Organization (1933). For 1940 we use World Health Organization (1951), which provided data for 1939-46, based on the League of Nations' work. In addition, for malaria in 1930, we use data from the Leauge of Nations' Malaria Commission (League of Nations Health Organization, 1932). We also check our data against information on location of malaria in the 1940s from American Geographical Society (1951a). Data on deaths by disease for 1950 and 1960 are from the UN Demographic Yearbooks for 1954, 1962 and 1966. Data for 1970 are from the UN Demographic Yearbook for 1974 and data for 1980 are from the UN Demographic Yearbook for 1985.

We further confirmed that our data do not miss major epidemics by reviewing every available inter-war issue of the League of Nations' Weekly Epidemiological Record. For example, for the distribution of cholera in 1938, see Weekly Epidemiological Record, March 3rd, 1938. For the distribution of small pox in 1930, see Weekly Epidemiological Record, August 21st, 1930; for 1938, see Weekly Epidemiological Record, March 3rd, 1938; for the early 1940s see Weekly Epidemiological Record, January 3rd, 1946. For the pre-war distribution of diphtheria, with a focus on Europe, see Weekly Epidemiological Record, December 21st, 1939. For the distribution of plague in 1938, see Weekly Epidemiological Record, March 3rd, 1938. For more detail on the pre-1940 distribution of typhus, see Weekly Epidemiological Record, September 14th, 1939. For the endemic yellow fever zone in 1951, see the Supplement to the Weekly Epidemiological Record, 25 September 1952. We also confirm that our numbers are consistent with contemporary qualitative assessments, in particular in the League of Nations and WHO's annual reports. Further details on these checks and data sources are provided in Appendix C.

Predicted mortality in 1940 is calculated by adding deaths per 100,000 from the 15 component diseases (for ease of exposition, we then convert to per 100 of population). Preston (1980) points out that data on precise cause of death should be handled with care; for example, it is notoriously difficult to determine how many deaths are due directly and indirectly to malaria. While this is an important warning in general, our analysis is about changes in total predicted mortality from infectious disease and because most of the global interventions were clustered in the late 1940s and early 1950s, this issue is less of a concern here.

Years of schooling are from the Barro-Lee dataset, downloadable from the NBER website. Our investment data are based on Maddison (1992), but we fill gaps with data for the early 1950s from Kuznets (1960). More details are provided in Appendix C.

10 Appendix B: List and Details On Diseases

The main text reviewed the etiology of and global "interventions" against the three diseases in our data responsible for the most deaths: malaria, pneumonia, and tuberculosis. Here we provide details on the remaining 12 infectious diseases, in rough descending order of their contribution to global deaths around 1940 (see Kiple, 1993, Hoff and Smith, 2000, Heymann 2004, and the Centers for Disease Control and Prevention website). The relevant global interventions are (a) new drugs for treatment that became available globally (particularly antibiotics where relevant), (b) new preventive measures that became available globally (particularly vaccines and chemicals that were effective against insects) and, (c) specific WHO campaigns against diseases. It is useful to note that the timing of interventions would not be changed if we word to put greater emphasis on sulphur drugs. Sulfonamide drugs were invented in the 1930s, but were often toxic and not available in the most effective doses (see Conybeare, 1948, pp. 65-66). This changed only from 1939, when the drugs became more effective (though Loudon, 2002, puts the useful breakthrough a little earlier).

Influenza is caused by various strains of the influenza virus, including type A (the most dangerous), type B, and type C. Transmission is through coughing, sneezing, or directly through mucous membranes. Associated deaths are often due to various secondary bacterial infections. The primary control mechanism is vaccination, but the introduction of antibiotics from the 1940s reduced deaths from secondary bacterial infections. There has been no global campaign to eradicate influenza, but WHO efforts to control and track the disease started in the 1950s. For an assessment of measures taken against influenza during 1921-50, see Deutschman (1953). In our baseline instrument we take the intervention date as the 1940s (antibiotics) and in our alternative instrument we take the 1950s (WHO action).

Cholera is caused by the bacterium Vibrio cholerae, and is transmitted by drinking contaminated water or eating contaminated food. Public works to properly treat or dispose of sewage have been effective against the disease since the mid-nineteenth century. Some antibiotics reduce the symptoms, but oral rehydration or intraveneous fluids are needed to replace minerals and fluids lost due to diarrhoea. Major steps to improve the effectiveness of oral rehydration were taken during the 1950s; in part these innovations were supported by the US military. For our baseline instrument we take the intervention date as the 1950s (rehydration therapy) and in our alternative instrument we take the 1940s (antibiotics).

Typhoid is caused by the bacterium Salmonella typhi and is transmitted through feces, either directly or by flies. It can be treated effectively with antibiotics (available since the 1940s). We take the introduction of antibiotics in the 1940s as the intervention date for both our baseline and alternative instruments.

Smallpox was caused by the viruses Variola major (the more deadly) and Variola minor. The disease was highly contagious, with the virus spreading through contact or through the air. Since 1798 the primary treatment has been vaccination. The WHO passed a resolution declaring the need to eradicate the disease in 1958 and the invention of the jet injector with foot pedal in 1962 made it possible to easily vaccinate people in places without electricity. In 1979, smallpox was declared entirely eradicated. In our baseline instrument we take the 1950s as our intervention date and in our alternative instrument we take the 1960s.

Shigella dysentery is caused by the bacterium Shigella dysenteriae type 1 or by the protozoan Endamoeba histolytica and is transmitted in the same fashion as typhoid. While we do not have fully comparable international data on dysentery, there are data on deaths from diarrhea among infants under the age of 2; we convert these into per 100 population equivalent and add to our predicted mortality estimates. The disease is controlled with public health measures, antibiotics, and rehydration therapy. We take the 1940s as our intervention date for our baseline instrument (based on antibiotics) and the 1950s for our alternative instrument (based on rehydration therapy).

Whooping cough is caused by the bacteria Bordetella pertussis. It can be treated with antibiotics and prevented by vaccination (which is one component of the DTP vaccine). The vaccine became available in the 1920s. We take the 1940s as our intervention date both for our baseline and alternative instruments (based on the effectiveness of antibiotics).

Measles (rubeola) is caused by a virus of the Rubivirus genus; it spreads through airborne droplets

from an infected person.[48] Prevention is through vaccination, which became available in 1963; this is also effective if administered within three days of exposure to the disease. Currently the largest vaccine-preventable killer of children, it may be targeted for global eradication. We take the 1960s as our intervention date for both our baseline and alternative instruments.

Diphtheria is caused by the bacterium Corynebacterium diphtheriae when it has been infected by certain bacteriophages (parasites that only infect bacteria). Transmission is through the air or by touch. It can be treated with antitoxins and antibiotics. An antitoxin has been available since the 1890s and immunization spread after its introduction in the early 1920s (usually provided today in the DTP, diphtheria-tetanus-pertussis, vaccine for infants). Treatment became more effective with the introduction of antibiotics in the 1940s. We take the 1940s as our intervention date for our baseline and alternative instruments (based on antibiotics).

Scarlet fever is caused by the Streptococcus bacteria; it often develops in strep throat patients and is similarly spread by droplets from an infected person (e.g., coughing or sneezing). It generally can be treated with antibiotics, including penicillin. We take the 1940s as our intervention date for our baseline and alternative instruments (based on antibiotics).

Yellow fever is caused by the yellow fever virus, and transmitted by the bite of an infected Aedes aegepti mosquito. It is controlled by vaccination and public health measures against the mosquito vector. The vector was definitively identified by Walter Reed, head of the U.S. Army Yellow Fever Commission, in 1900-1901. The first vaccine was developed by Max Theiler in the 1937 and was widely used in the 1940s. We take the 1940s as the intervention date for our baseline instrument and the 1930s for our alternative instrument.

Plague is caused by the bacterium Yersinia pestis and is transmitted from infected animals to humans through the bite of an infected flea. The disease is controlled through antibiotics, especially streptomycin, and the elimination of rodent population near human habitations. Some protection from vaccination has been available since the end of the nineteenth century. The WHO attempts to help deal with outbreaks. We take the introduction of the antibiotics in the 1940s as the intervention date for both our baseline and alternative instruments.

Typhus is caused by any microbe of the genus Rickettsia, and is transmitted by insects (lice, fleas, mites, and ticks). Antibiotics are usually an effective treatment. Public health measures include good hygiene and sanitation. Once again, based on antibiotics, the 1940s are the intervention date for both our baseline and alternative instruments.

[48] This is a different disease, caused by a different virus, than German measles (rubella). Vaccines for both are included in the MMR vaccine (measles-mumps-rubella).

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Table 1
Descriptive Statistics

	Whole World	Base Sample	Initially Rich Countries	Initially Middle Income Countries	Initially Poor Countries
Life expectancy in 1900	30.90	37.04	49.36	36.92	28.77
	(8.83)	(10.45)	(3.67)	(8.13)	(5.42)
Life expectancy in 1940	47.77	49.30	65.14	50.94	40.63
	(11.53)	(12.68)	(1.86)	(9.38)	(8.40)
Life expectancy in 1980	61.14	66.19	74.31	69.66	61.93
	(11.02)	(7.49)	(1.13)	(4.58)	(7.19)
Predicted mortality in 1940	n.a.	0.48	0.17	0.48	0.53
		(0.28)	(0.05)	(0.22)	(0.32)
Log population in 1940	8.94	9.07	9.35	8.82	9.15
	(1.55)	(1.55)	(1.34)	(1.41)	(1.79)
Log population in 1980	8.89	9.71	9.76	9.44	10.00
	(1.62)	(1.31)	(1.29)	(1.26)	(1.75)
Log GDP in 1940	9.78	9.89	11.08	9.75	9.19
	(1.68)	(1.61)	(1.40)	(1.49)	(1.71)
Log GDP in 1980	10.00	11.34	12.47	11.42	10.89
	(1.98)	(1.40)	(1.33)	(1.36)	(1.52)
Log GDP per capita in 1940	7.65	7.73	8.64	7.84	6.95
	(0.69)	(0.71)	(0.15)	(0.34)	(0.33)
Log GDP per capita in 1980	7.99	8.54	9.62	8.89	7.79
	(1.08)	(0.90)	(0.13)	(0.45)	(0.74)

Mean values of variables; standard deviation in parentheses. Base sample is 59 countries. Initially rich countries had log GDP per capita over 8.4 in 1940; middle income had log GDP per capita between 7.37 and 8.4 in 1940; and low income countries had log GDP per capita below 7.37 in 1940. Predicted mortality is per 100 per annum. "n.a." denotes not available. See text and Appendix A for details and definitions.

Table 2
Life Expectancy, Population, and Births: OLS Estimates

Dependent variable indicated for each panel separately

	All Countries	*Base Sample*		*Low & Middle Income Countries Only*	*All Countries*		*Base Sample*			
	No leads	No leads	No leads	No leads	10 year lead	20 year lead	10 year lead	20 year lead	10 year lead	20 year lead
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
				Panel A: Dependent variable is log population						
	Panel, 1960-2000	Panel, 1960-2000	Panel, 1940-1980	Panel, 1940-1980	Panel, 1960-1990	Panel, 1960-1980	Panel, 1960-1990	Panel, 1960-1980	Panel, 1940-1980	Panel, 1940-1980
Log Life Expectancy	1.46	1.69	1.21	1.24	1.72	1.61	1.34	0.97	1.33	1.26
	(0.29)	(0.43)	(0.20)	(0.28)	(0.26)	(0.34)	(0.46)	(0.46)	(0.22)	(0.21)
Number of observations	600	294	282	249	480	360	235	176	282	282
Number of countries	120	59	59	48	120	120	59	59	59	59
				Panel B: Dependent variable is log population						
	Just 1960 and 2000	Just 1960 and 2000	Just 1940 and 1980	Just 1940 and 1980	Just 1960 and 1990	Just 1960 and 1980	Just 1960 and 1990	Just 1960 and 1980	Just 1940 and 1980	Just 1940 and 1980
Log Life Expectancy	1.60	1.74	1.62	1.86	1.92	1.70	1.42	0.98	1.71	1.62
	(0.42)	(0.57)	(0.22)	(0.36)	(0.35)	(0.41)	(0.57)	(0.58)	(0.24)	(0.21)
Number of observations	240	118	94	72	240	240	118	118	94	94
Number of countries	120	59	47	36	120	120	59	59	47	47
				Panel C: Dependent variable is log number of births						
	Panel, 1960-1990	Panel, 1960-1990	Panel, 1940-1980	Panel, 1940-1980	Panel, 1960-1990	Panel, 1960-1980	Panel, 1960-1990	Panel, 1960-1980	Panel, 1930-1970	Panel, 1930-1970
Log Life Expectancy	1.90	2.02	1.87	1.85	1.65	0.75	1.39	0.30	1.46	1.14
	(0.40)	(0.46)	(0.28)	(0.36)	(0.42)	(0.47)	(0.49)	(0.57)	(0.20)	(0.23)
Number of observations	460	188	233	198	345	230	141	94	234	187
Number of countries	115	47	47	36	115	115	47	47	47	47
				Panel D: Dependent variable is log number of births						
	Just 1960 and 1990	Just 1960 and 1990	Just 1940 and 1980	Just 1940 and 1980	Just 1960 and 1980	Just 1960 and 1970	Just 1960 and 1980	Just 1960 and 1970	Just 1940 and 1980	Just 1940 and 1970
Life Expectancy	2.09	2.00	1.88	1.97	1.72	0.75	1.37	0.30	1.55	1.30
	(0.53)	(0.42)	(0.41)	(0.47)	(0.50)	(0.47)	(0.59)	(0.57)	(0.25)	(0.31)
Number of observations	230	94	92	70	230	230	94	94	92	92
Number of countries	115	47	46	35	115	115	47	47	46	46

OLS regressions with a full set of year and country fixed effects. Robust standard errors, adjusted for clustering by country, in parentheses. Panels A and C are unbalanced panels with one observation per decade. Panels B and D are long-difference specifications with observations for only the beginning and end dates. Dependent variable is log population in Panels A and B and log total births in Panels C and D. Independent variable in all regressions is log life expectancy at birth. In columns 1-4, the dependent variable and independent variable are for the same time period; in columns 5-10, the dependent variable is for t+10 or t+20 as indicated, while the independent variable is for time t. "All countries" are those for which we have data on the dependent and independent variables. Base sample is countries for which we have disease data. Assignment of countries to low and middle income categories is based on 1940 income per capita; see text and Appendix A for details and definitions.

Table 3
Life Expectancy, GDP and GDP per capita: OLS Estimates

Dependent variable indicated for each panel separately

	All Countries	*Base Sample*		*Low & Middle Income Countries Only*	*All Countries*		*Base Sample*			
	No leads	No leads	No leads	No leads	10 year lead	20 year lead	10 year lead	20 year lead	10 year lead	20 year lead
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
				Panel A: Dependent variable is log GDP						
	Panel, 1960-2000	Panel, 1960-2000	Panel, 1940-1980	Panel, 1940-1980	Panel, 1960-1990	Panel, 1960-1980	Panel, 1960-1990	Panel, 1960-1980	Panel, 1940-1980	Panel, 1940-1980
Log Life Expectancy	1.35	1.70	0.73	0.65	1.09	0.29	1.37	0.97	0.73	0.90
	(0.49)	(0.45)	(0.35)	(0.42)	(0.44)	(0.62)	(0.37)	(0.52)	(0.24)	(0.30)
Number of observations	600	294	283	228	480	360	235	176	283	283
Number of countries	120	59	59	48	120	120	59	59	59	59
				Panel B: Dependent variable is log GDP						
	Just 1960 and 2000	Just 1960 and 2000	Just 1940 and 1980	Just 1940 and 1980	Just 1960 and 1990	Just 1960 and 1980	Just 1960 and 1990	Just 1960 and 1980	Just 1940 and 1980	Just 1940 and 1980
Log Life Expectancy	1.17	1.55	0.78	0.65	1.07	0.39	1.61	1.11	0.75	0.92
	(0.80)	(0.49)	(0.58)	(0.73)	(0.59)	(0.76)	(0.48)	(1.02)	(0.39)	(0.47)
Number of observations	240	118	94	72	240	240	118	116	94	94
Number of countries	120	59	47	36	120	120	59	58	47	47
				Panel C: Dependent variable is log GDP per capita						
	Panel, 1960-1990	Panel, 1960-1990	Panel, 1940-1980	Panel, 1940-1980	Panel, 1960-1990	Panel, 1960-1980	Panel, 1960-1990	Panel, 1960-1980	Panel, 1940-1980	Panel, 1940-1980
Log Life Expectancy	-0.10	0.003	-0.44	-0.44	-0.63	-1.31	0.03	-0.001	-0.57	-0.33
	(0.48)	(0.46)	(0.30)	(0.23)	(0.51)	(0.69)	(0.50)	(0.75)	(0.28)	(0.39)
Number of observations	600	294	283	228	480	360	235	176	283	283
Number of countries	120	59	59	48	120	120	59	59	59	59
				Panel D: Dependent variable is log GDP per capita						
	Just 1960 and 2000	Just 1960 and 2000	Just 1940 and 1980	Just 1940 and 1980	Just 1960 and 1990	Just 1960 and 1980	Just 1960 and 1990	Just 1960 and 1980	Just 1940 and 1980	Just 1940 and 1980
Log Life Expectancy	-0.42	-0.19	-0.81	-0.13	-0.84	-1.31	0.18	-0.48	-0.96	-0.70
	(0.82)	(0.76)	(0.42)	(0.69)	(0.70)	(0.85)	(0.82)	(1.18)	(0.43)	(0.50)
Number of observations	240	118	94	54	240	240	118	116	94	94
Number of countries	120	59	47	27	120	120	59	58	47	47

OLS regressions with a full set of year and country fixed effects. Robust standard errors, adjusted for clustering by country, in parentheses. Panels A and C are unbalanced panels with one observation per decade. Panels B and D are long-difference specifications with observations for only the beginning and end dates. Dependent variable is log total GDP in Panels A and B and log GDP per capita in Panels C and D. Independent variable in all regressions is log life expectancy at birth. In columns 1-4, the dependent variable and independent variable are for the same time period; in columns 5-10, the dependent variable is for t+10 or t+20 as indicated, while the independent variable is for time t. "All countries" are those for which we have data on the dependent and independent variables. Base sample is countries for which we have disease data. Assignment of countries to low and middle income categories is based on 1940 income per capita; see text and Appendix A for details and definitions.

Table 4

The Effect of Interventions on Disease Mortality (zeroth stage)

	Dependent Variable is mortality per 100,000 from disease i in country j at period t						
Panel A: diseases are --	*Base Sample*	*Base Sample*	*Base Sample*	*Without TB*	*Without pneumonia*	*Without malaria*	*Without influenza*
	Panel, 1930-1960						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Intervention	-46.04	-43.33	-46.04	-33.93	-36.31	-48.57	-48.62
	(9.40)	(10.36)	(9.40)	(8.66)	(8.99)	(9.23)	(9.69)
Lagged Intervention		-4.59					
		(8.05)					
Lead Intervention			20.57				
			(9.47)				
R-squared	0.52	0.47	0.47	0.49	0.48	0.48	0.48
Number of observations	1479	1479	1479	1327	1364	1361	1328
Panel B: diseases are --	*Just scarlet fever*	*Just typhoid*	*Just diphtheria*	*Just TB*	*Just pneumonia*	*Just malaria*	*Just influenza*
Intervention	-0.25	-8.84	-2.47	-108.51	-137.92	-19.97	-14.95
	(0.10)	(3.01)	(0.92)	(22.91)	(26.96)	(9.67)	(11.37)
R-squared	0.56	0.71	0.63	0.72	0.82	0.58	0.61
Number of observations	140	148	147	152	115	118	151
Number of countries	49	49	49	49	49	49	49

OLS regressions with a full set of disease, year, and country fixed effects. Robust standard errors, adjusted for clustering by country-disease pair, in parentheses. Unbalanced panels with data for 1930, 1940, 1950 and 1960. Data are stacked; dependent variable is deaths per 100,000 from disease i in country j at year t. Base sample is 15 infectious diseases plus cancer and malignant tumors. Independent variables: dummy for intervention (e.g., for malaria equals 1 for 1950 and 1960, zero otherwise), dummy for lead intervention (e.g., for malaria equals 1 for 1940, 1950 and 1960), dummy for lagged intervention (e.g., for malaria equals 1 for 1960).

Table 5

First Stage Estimates: Predicted Mortality and Life Expectancy

Dependent Variable is log life expectancy

	Baseline predicted mortality								Using global mortality rate		Alternative timing	TB, malaria, and pneumonia mortality only
	Base Sample		*Including Eastern Europe*	*Low and Middle Income Countries Only*	*Balanced Panel Sample*	*Base Sample, Interaction with Institutions*	*Base Sample, Interaction with Initial (1930) log GDP p.c.*	*Base Sample, Interaction with Continent Dummies*	*Base Sample*	*Low and Middle Income Countries Only*	*Base Sample*	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Panel A	Panel, 1940-1980	Panel, 1930-1980	Panel, 1940-1980	Panel, 1940-1980	Balanced Panel, 1940-1980	Panel, 1940-1980	Panel, 1940-1980	Panel, 1940-1980	Panel, 1940-1980	Panel, 1940-1960	Panel, 1940-1980	Panel, 1940-1980
Predicted Mortality	-0.33	-0.36	-0.34	-0.23	-0.32	-0.27	-0.24	-0.25	-0.41	-0.26	-0.33	-0.35
	(0.06)	(0.06)	(0.06)	(0.08)	(0.06)	(0.07)	(0.10)	(0.07)	(0.08)	(0.10)	(0.06)	(0.08)
R-squared	0.93	0.93	0.92	0.93	0.94	0.94	0.95	0.95	0.93	0.93	0.93	0.93
Number of observations	283	316	312	228	230	271	243	283	263	208	283	283
Number of countries	59	59	65	48	46	56	49	59	59	48	59	59
Panel B	Just 1940 and 1980	Just 1930 and 1980	Just 1940 and 1980	Just 1940 and 1980	Just 1940 and 1980	Just 1940 and 1980	Just 1940 and 1980	Just 1940 and 1980	Just 1940 and 1960	Just 1940 and 1960	Just 1940 and 1980	Just 1940 and 1980
Predicted Mortality	-0.44	-0.53	-0.46	-0.31	-0.45	-0.35	-0.25	-0.30	-0.40	-0.29	-0.45	-0.49
	(0.09)	(0.11)	(0.06)	(0.12)	(0.09)	(0.10)	(0.13)	(0.11)	(0.12)	(0.17)	(0.09)	(0.11)
R-squared	0.95	0.95	0.95	0.95	0.95	0.95	0.96	0.96	0.95	0.94	0.95	0.95
Number of observations	94	66	106	72	92	94	94	94	94	72	94	94
Number of countries	47	33	53	36	46	47	47	47	47	36	47	47

OLS regressions with a full set of year and country fixed effects. Robust standard errors, adjusted for clustering by country, in parentheses. Panel A is unbalanced panel with one observation per decade. Panel B is long-difference specifications with observations for only the beginning and end dates. Dependent variable in both panels is log life expectancy at birth. Independent variable in columns 1-8 is baseline predicted mortality; in columns 9-10, global mortality; in column 11, predicted mortality has alternative timing, and in column 12 predicted mortality is constructed from tuberculosis, pneumonia, and malaria deaths only. See text and Appendix A for the construction of the predicted mortality instrument, definitions and data sources. Eastern Europe is countries that became part of the Soviet bloc after 1945. Assignment of countries to low and middle income categories is based on 1940 income per capita.

Balanced panel is countries with no missing data between 1940 and 1980. In columns 6-8 we include time dummies interacted with: in column 6, institutions, measured as constraint on the executive in 1950, 1960, and 1970, from Polity IV; in column 7, log GDP per capita in 1930; and in column 8, a full set of continent dummies (Africa, Asia, Americas, Europe; Oceania is the omitted category).

Table 6

First Stage Estimates: Mean Reversion and Robustness

	Dependent Variable is log life expectancy									
	Base Sample									
	Panel, 1940-1980									Balanced Panel, 1940-1980
	OLS		Instrument lagged LE w/ second lag of LE	GMM (Arellano Bond)	OLS		OLS			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Predicted Mortality	-0.33	-0.18	-0.27	-0.19	-0.20	-0.33	-0.20	-0.31	-0.14	-0.15
	(0.06)	(0.08)	(0.14)	(0.06)	(0.06)	(0.08)	(0.07)	(0.06)	(0.08)	(0.07)
Lagged Log Life Expectancy		0.44	0.32	0.71					0.45	0.53
		(0.09)	(0.39)	(0.06)					(0.09)	(0.07)
Lagged Predicted Mortality					-0.17		-0.17			
					(0.03)		(0.03)			
Lead Predicted Mortality						0.19	0.14			
						(1.04)	(1.04)			
Lagged Log GDP per capita								-0.06	-0.07	
								(0.04)	(0.02)	
p-value of test for 2nd order autocorrelation				0.83						
Hansen J Test (p-value)				0.014						
R-squared	0.93	0.95	0.95		0.94	0.93	0.95	0.93	0.95	0.96
Number of observations	283	267	231	248	283	283	283	273	257	266
Number of countries	59	59	57	59	59	59	59	59	59	56

OLS (columns 1-2 and 5-10) and 2SLS (columns 3-4) regressions with a full set of year and country fixed effects. Robust standard errors, adjusted for clustering by country, in parentheses. All columns are unbalanced panels with one observation per decade, using base sample countries. Dependent variable in is log life expectancy at birth. Independent variables vary by column; lagged values are 10 years earlier and lead predicted mortality is 10 years ahead. Assignment of countries to low and middle income categories is based on 1940 income per capita. In column 3, the second lag of log life expectancy is used as an instrument for lagged log life expectancy. In column 4, GMM of Arellano-Bond uses all available lags of log life expectancy as instruments. Balanced panel is countries with no missing data between 1940 and 1980.

Table 7

Falsification Exercise and Reduced Forms

	Base Sample	*Low & Mid. Income Countries Only*	*Base Sample*	*Low & Mid. Income Countries Only*	*Base Sample*	*Low & Mid. Income Countries Only*	*Base Sample*	*Low & Mid. Income Countries Only*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: falsification exercise								
Dependent variable is: --	*change in life expectancy from 1900 to 1940*		*change in log population from 1900 to 1940*		*change in log GDP from 1900 to 1940*		*change in log GDP per capita from 1900 to 1940*	
Change in Predicted Mortality from 1940 to 1980	0.14	0.21	-0.06	-0.08	-0.18	-0.27	-0.12	-0.18
	(0.11)	(0.16)	(0.14)	(0.29)	(0.22)	(0.36)	(0.17)	(0.22)
R-squared	0.04	0.06	0.003	0.005	0.01	0.02	0.0095	0.01
Number of countries	47	36	29	19	29	19	29	19
Panel B: reduced forms								
Dependent variable is: --	*change in life expectancy from 1940 to 1980*		*change in log population from 1940 to 1980*		*change in log GDP from 1940 to 1980*		*change in log GDP per capita from 1940 to 1980*	
Change in Predicted Mortality from 1940 to 1980	-0.43	-0.30	-0.76	-0.65	-0.27	-0.03	0.48	0.59
	(0.07)	(0.08)	(0.15)	(0.21)	(0.25)	(0.32)	(0.17)	(0.23)
R-squared	0.46	0.26	0.31	0.19	0.003	0.0003	0.12	0.12
Number of countries	57	46	49	38	49	38	49	38

OLS regressions. Robust standard errors in parentheses. Both panels regress change in variable indicated from start to end date on change in predicted mortality from 1940 to 1980. Predicted mortality is deaths per 100 population. Panel A uses subset of base sample for which data on all outcome variables are available and for which there is no discontinuity in boundaries of country during the relevant period.

Table 8

The Effect of Life Expectancy on Log Population: 2SLS Estimates

	Dependent variable is log population										
	Baseline instrument						Global mortality instrument	Baseline instrument			
	Base Sample		*Including Eastern Europe*	*Low and Middle Income Countries Only*	*Base Sample, Interaction with Institutions*	*Base Sample, Interaction with Initial (1930) Log Population*	*Base Sample*				
	No leads Panel, 1940-1980	No leads Panel, 1930-1980	No leads Panel, 1940-1980	No leads Panel, 1940-1980	No leads Panel, 1940-1980	No leads Panel, 1940-1980	No leads Panel, 1940-1980	10 year lead Panel, 1940-1980	20 year lead Panel, 1940-1980	30 year lead Panel, 1940-1970	40 year lead Panel, 1940-1960
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Panel A											
Log Life Expectancy	1.31	1.35	1.48	1.58	1.22	1.33	1.65	1.50	1.58	1.49	1.17
	(0.37)	(0.36)	(0.39)	(0.76)	(0.50)	(0.35)	(0.40)	(0.37)	(0.35)	(0.37)	(0.39)
p-value for Year Dummies x Institutions or initial log population					[0.02]	[0.003]					
Number of observations	283	316	312	228	272	244	263	284	284	226	167
Number of countries	59	59	63	46	56	49	59	59	59	59	59
	No leads Just 1940 and 1980	No leads Just 1930 and 1980	No leads Just 1940 and 1980	No leads Just 1940 and 1980	No leads Just 1940 and 1980	No leads Just 1940 and 1980	No leads Just 1940 and 1980	10 year lead Just 1940 and 1980	20 year lead Just 1940 and 1980	30 year lead Just 1940 and 1980	40 year lead Just 1940 and 1980
Panel B											
Log Life Expectancy	1.67	1.62	1.79	2.40	1.63	1.68	1.70	1.79	1.75	1.63	1.48
	(0.50)	(0.56)	(0.50)	(1.01)	(0.73)	(0.44)	(0.48)	(0.47)	(0.42)	(0.47)	(0.45)
Post year dummy x Institutions or initial log population					-0.01	-0.06					
					(0.05)	(0.03)					
Number of observations	94	66	106	72	94	94	94	94	94	80	80
Number of countries	47	33	53	36	47	47	47	47	47	40	40

2SLS regressions with a full set of year and country fixed effects. Robust standard errors, adjusted for clustering by country, in parentheses. Panel A is unbalanced panel with one observation per decade. Panel B is long-difference specification with observations for only the beginning and end dates. Dependent variable in both panels is log total population. Independent variable in both panels is log life expectancy at birth. In columns 1-6 and 8-11, log life expectancy is instrumented by predicted mortality (baseline instrument), and in column 7 it is instrumented by global mortality. First stages are in Table 5. In columns 1-7, the dependent and independent variables are for the same time period; in columns 8-11, the dependent variable is t+10, t+20 etc., as indicated, while the independent variable is at time t. Columns 5 and 6 include year dummies interacted with: institutions, in column 5, as average of constraint on executive in 1950, 1960, and 1970 from Polity IV, where scores range from 1 to 7 and non-independent countries are assigned score of 1; and initial log population, in column 6, is for 1930. See text and Appendix A for construction of the mortality instruments, definitions, and data sources.

Table 9
The Effect of Life Expectancy on Log Births: 2SLS Estimates

	Dependent variable is log total births										
	Baseline instrument						Global mortality instrument	Baseline instrument			
	Base Sample		*Including Eastern Europe*	*Low and Middle Income Countries Only*	*Base Sample, Interaction with Institutions*	*Base Sample, Interaction with Initial (1930) Log Births*	*Base Sample*				
	No leads Panel, 1940-1980	No leads Panel, 1930-1980	No leads Panel, 1940-1980	No leads Panel, 1940-1980	No leads Panel, 1940-1980	No leads Panel, 1940-1980	No leads Panel, 1940-1980	10 year lead Panel, 1940-1980	20 year lead Panel, 1940-1980	30 year lead Panel, 1940-1980	40 year lead Panel, 1940-1980
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Panel A											
Log Life Expectancy	2.39	2.16	2.59	3.10	2.32	2.27	2.46	1.66	1.81	1.03	0.04
	(0.69)	(0.60)	(0.72)	(1.49)	(1.01)	(0.60)	(0.60)	(0.38)	(0.50)	(0.52)	(0.53)
p-value for Year Dummies x Institutions or initial log births					[0.33]	[0.03]					
Number of observations	233	264	261	178	233	221	231	234	187	140	93
Number of countries	47	47	53	36	47	45	47	47	47	47	47
	No leads Just 1940 and 1980	No leads Just 1930 and 1980	No leads Just 1940 and 1980	No leads Just 1940 and 1980	No leads Just 1940 and 1980	No leads Just 1940 and 1980	No leads Just 1940 and 1980	10 year lead Just 1940 and 1980	20 year lead Just 1940 and 1970	30 year lead Just 1940 and 1960	40 year lead Just 1940 and 1950
Panel B											
Log Life Expectancy	2.53	2.03	2.66	2.92	2.40	2.53	2.50	1.62	1.52	0.87	0.05
	(0.73)	(0.87)	(0.73)	(1.40)	(1.12)	(0.70)	(0.73)	(0.46)	(0.54)	(0.58)	(0.53)
Post year dummy x Institutions or initial log births					-0.02	-0.06					
					(0.09)	(0.05)					
Number of observations	90	88	98	68	90	88	90	90	90	90	90
Number of countries	45	44	49	34	45	44	45	45	45	45	45

2SLS regressions with a full set of year and country fixed effects. Robust standard errors, adjusted for clustering by country, in parentheses. Panel A is unbalanced panel with one observation per decade. Panel B is long-difference specification with observations for only the beginning and end dates. Dependent variable in both panels is log total births. Independent variable in both panels is log life expectancy at birth. In columns 1-6 and 8-11, log life expectancy is instrumented by predicted mortality (baseline instrument), and in column 7 it is instrumented by global mortality. First stages are in Table 5. In columns 1-7, the dependent and independent variables are for the same time period; in columns 8-11, the dependent variable is t+10, t+20 etc., as indicated, while the independent variable is at time t. Columns 5 and 6 include year dummies interacted with: institutions, in column 5, as average of constraint on executive in 1950, 1960, and 1970 from Polity IV, where scores range from 1 to 7 and non-independent countries are assigned score of 1; and initial log births, in column 6, is for 1930. See text and Appendix A for construction of the mortality instruments, definitions, and data sources.

Table 10
The Effect of Life Expectancy on Log GDP: 2SLS Estimates

	Dependent variable is log GDP										
	Baseline instrument						Global mortality instrument	Baseline instrument			
	Base Sample		*Including Eastern Europe*	*Low and Middle Income Countries Only*	*Base Sample, Interaction with Institutions*	*Base Sample, Interaction with Initial (1930) log GDP*	*Base Sample*				
	No leads Panel, 1940-1980	No leads Panel, 1930-1980	No leads Panel, 1940-1980	No leads Panel, 1940-1980	No leads Panel, 1940-1980	No leads Panel, 1940-1980	No leads Panel, 1940-1980	10 year lead Panel, 1940-1980	20 year lead Panel, 1940-1980	30 year lead Panel, 1940-1980	40 year lead Panel, 1940-1980
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Panel A											
Log Life Expectancy	-0.03	-0.13	0.11	-0.28	-0.35	-0.49	0.45	0.52	0.53	0.61	0.14
	(0.67)	(0.62)	(0.66)	(1.19)	(0.82)	(0.58)	(0.59)	(0.48)	(0.44)	(0.60)	(0.85)
p-value for Year Dummies x Institutions or initial GDP					[0.005]	[0.01]					
Number of observations	283	316	312	228	271	243	263	283	283	224	165
Number of countries	59	59	65	48	56	49	59	59	59	59	59
	No leads Just 1940 and 1980	No leads Just 1930 and 1980	No leads Just 1940 and 1980	No leads Just 1940 and 1980	No leads Just 1940 and 1980	No leads Just 1940 and 1980	No leads Just 1940 and 1980	10 year lead Just 1940 and 1980	20 year lead Just 1940 and 1980	30 year lead Just 1940 and 1970	40 year lead Just 1940 and 1960
Panel B											
Log Life Expectancy	0.32	0.06	0.43	-0.39	-0.11	-0.07	0.51	0.55	0.64	0.64	0.33
	(0.84)	(0.95)	(0.82)	(1.44)	(0.98)	(0.73)	(0.71)	(0.63)	(0.66)	(0.76)	(0.94)
Post year dummy x Institutions or initial GDP					-0.06	-0.11					
					(0.06)	(0.06)					
Number of observations	94	94	106	72	94	94	94	94	94	94	94
Number of countries	47	47	53	36	47	47	47	47	47	47	47

2SLS regressions with a full set of year and country fixed effects. Robust standard errors, adjusted for clustering by country, in parentheses. Panel A is unbalanced panel with one observation per decade. Panel B is long-difference specification with observations for only the beginning and end dates. Dependent variable in both panels is log GDP. Independent variable in both panels is log life expectancy at birth. In columns 1-6 and 8-11, log life expectancy is instrumented by predicted mortality (baseline instrument), and in column 7 it is instrumented by global mortality. First stages are in Table 5. In columns 1-7, the dependent and independent variables are for the same time period; in columns 8-11, the dependent variable is t+10, t+20 etc., as indicated, while the independent variable is at time t. Columns 5 and 6 include year dummies interacted with: institutions, in column 5, as average of constraint on executive in 1950, 1960, and 1970 from Polity IV, where scores range from 1 to 7 and non-independent countries are assigned score of 1; and initial GDP, in column 6, is for 1930. See text and Appendix A for construction of the mortality instruments, definitions, and data sources.

Table 11

The Effect of Life Expectancy on Log GDP per capita: 2SLS Estimates

	Dependent variable is log GDP per capita										
	Baseline instrument						Global mortality instrument	Baseline instrument			
	Base Sample		*Including Eastern Europe*	*Low and Middle Income Countries Only*	*Base Sample, Interaction with Institutions*	*Base Sample, Interaction with Initial (1930) log GDP p.c.*	*Base Sample*				
	No leads Panel, 1940-1980	No leads Panel, 1930-1980	No leads Panel, 1940-1980	No leads Panel, 1940-1980	No leads Panel, 1940-1980	No leads Panel, 1940-1980	No leads Panel, 1940-1980	10 year lead Panel, 1940-1980	20 year lead Panel, 1940-1980	30 year lead Panel, 1940-1980	40 year lead Panel, 1940-1980
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Panel A											
Log Life Expectancy	-1.30	-1.39	-1.32	-1.76	-1.45	-0.46	-1.17	-0.98	-1.04	-0.87	-1.04
	(0.53)	(0.46)	(0.53)	(1.13)	(0.74)	(0.85)	(0.45)	(0.39)	(0.45)	(0.55)	(0.90)
p-value for Year Dummies x Institutions or initial GDP pc					[0.02]	[0.03]					
Number of observations	283	316	312	228	271	243	263	283	283	224	165
Number of countries	59	59	65	48	56	49	59	59	59	59	59
	No leads Just 1940 and 1980	No leads Just 1930 and 1980	No leads Just 1940 and 1980	No leads Just 1940 and 1980	No leads Just 1940 and 1980	No leads Just 1940 and 1980	No leads Just 1940 and 1980	10 year lead Just 1940 and 1980	20 year lead Just 1940 and 1980	30 year lead Just 1940 and 1970	40 year lead Just 1940 and 1960
Panel B											
Log Life Expectancy	-1.32	-1.44	-1.33	-2.35	-1.64	-1.59	-1.17	-1.24	-1.12	-0.92	-0.89
	(0.56)	(0.61)	(0.54)	(1.13)	(0.77)	(1.22)	(0.51)	(0.66)	(0.78)	(0.81)	(1.01)
Post year dummy x Institutions or initial GDP pc					-0.05	0.07					
					(0.06)	(0.28)					
Number of observations	94	94	106	72	94	94	94	94	94	94	94
Number of countries	47	47	53	36	47	47	47	47	47	47	47

2SLS regressions with a full set of year and country fixed effects. Robust standard errors, adjusted for clustering by country, in parentheses. Panel A is unbalanced panel with one observation per decade. Panel B is long-difference specification with observations for only the beginning and end dates. Dependent variable in both panels is log GDP per capita. Independent variable in both panels is log life expectancy at birth. In columns 1-6 and 8-11, log life expectancy is instrumented by predicted mortality (baseline instrument), and in column 7 it is instrumented global mortality. First stages are in Table 5. In columns 1-7, the dependent and independent variables are for the same time period; in columns 8-11, the dependent variable is t+10, t+20 etc., as indicated, while the independent variable is at time t. Columns 5 and 6 include year dummies interacted with: institutions, in column 5, as average of constraint on executive in 1950, 1960, and 1970 from Polity IV, where scores range from 1 to 7 and non-independent countries are assigned score of 1; and initial GDP per capita, in column 6, is for 1930. See text and Appendix A for construction of the mortality instruments, definitions, and data sources.

Table 12

The Effect of Life Expectancy on Years of Schooling: 2SLS Estimates

Dependent variable is years of schooling

	OLS	Baseline instrument	Baseline instrument	OLS	Baseline instrument	Baseline instrument	OLS	Baseline instrument	Baseline instrument
	Base Sample		*Low and Middle Income Countries Only*	*Base Sample*		*Low and Middle Income Countries Only*	*Base Sample*		*Low and Middle Income Countries Only*
	10 year lead	10 year lead	10 year lead	20 year lead	20 year lead	20 year lead	30 year lead	30 year lead	30 year lead
	Panel, 1950-1980	Panel, 1950-1980	Panel, 1950-1980	Panel, 1950-1970	Panel, 1950-1970	Panel, 1950-1970	Panel, 1950-1960	Panel, 1950-1960	Panel, 1950-1960
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log Life Expectancy	-0.50	-0.42	-0.73	-0.14	0.07	1.10	5.01	1.40	-1.40
	(1.45)	(4.15)	(5.92)	(1.63)	(4.51)	(6.52)	(1.65)	(3.67)	(5.17)
Number of observations	212	212	168	159	159	126	106	106	84
Number of countries	53	53	40	53	53	42	53	53	42

OLS and 2SLS regressions with a full set of year and country fixed effects. Robust standard errors, adjusted for clustering by country, in parentheses.Unbalanced panel with one observation per decade. Dependent variable is years of schooling. Independent variable is log life expectancy at birth. In columns 2, 3, 5, 6, 8 and 9, log life expectancy is instrumented by predicted mortality (baseline instrument). First stages are in Table 5. In columns 1-3, the dependent and independent variables are for the same time period; in columns 4-9, the dependent variable is t+10, t+20, and t+30 as indicated, while the independent variable is at time t. See text and Appendix A for construction of the predicted mortality instrument, definitions and data sources.

Table 13
The Effect of Life Expectancy on Population and Log GDP, Alternative Samples: 2SLS Estimates, with First Stages

Instrument:	*Baseline*	*Global Mortality*	*Baseline*	*Global Mortality*	*Baseline*	*Global Mortality*	*Baseline*	*Global Mortality*	*Baseline*	*Global Mortality*	*Baseline*	*Global Mortality*
	Base Sample plus Africa		*Base Sample plus Africa*		*Base Sample without countries most affected by WWII*		*Base Sample plus Africa*		*Base Sample plus Africa*		*Base Sample without countries most affected by WWII*	
	No leads Panel, 1940-1980	*No leads* Panel, 1940-1980	*30 year lead* Panel, 1940-1980	*30 year lead* Panel, 1940-1980	*No leads* Panel, 1940-1980	*No leads* Panel, 1940-1980	*No leads* Panel, 1940-1980	*No leads* Panel, 1940-1980	*30 year lead* Panel, 1940-1980	*30 year lead* Panel, 1940-1980	*No leads* Panel, 1940-1980	*No leads* Panel, 1940-1980
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Panel A: Dependent variable -	*Log population*						*Log GDP*					
Log Life Expectancy	1.35	1.77	3.87	2.63	1.26	1.55	-0.12	0.03	-0.80	-0.09	-0.22	0.33
	(0.37)	(0.35)	(2.42)	(0.93)	(0.39)	(0.38)	(0.63)	(0.49)	(2.11)	(1.09)	(0.70)	(0.59)
Panel B: Dependent variable is log life expectancy (first stage regression)												
Predicted Mortality	-0.34	-0.39	-0.29	-0.34	-0.33	-0.44	-0.34	-0.39	-0.29	-0.34	-0.33	-0.44
	(0.06)	(0.06)	(0.06)	(0.07)	(0.07)	(0.08)	(0.06)	(0.06)	(0.06)	(0.07)	(0.07)	(0.08)
R-squared	0.96	0.97	0.97	0.97	0.94	0.95	0.96	0.97	0.97	0.97	0.94	0.95
Number of observations	445	445	343	343	238	238	445	445	343	343	238	238
Number of countries	102	102	102	102	54	54	102	102	102	102	54	54

All regressions have full set of year and country fixed effects. Robust standard errors, adjusted for clustering by country, in parentheses. Unbalanced panel with one observation per decade. Panel A is 2SLS results; dependent variable in columns 1-6 is log population and in columns 7-12 is log GDP; independent variable is log life expectancy at birth. Panel B is corresponding first stage, with predicted mortality as the instrument. In odd columns, log life expectancy is instrumented by predicted mortality (baseline instrument), and in even columns it is instrumented by global mortality. For the second stage, columns 1-2, 5-6, 7-8, and 11-12, the dependent and independent variables are for the same time period; in columns 3-4 and 9-10, the dependent variable is t+30, while the independent variable is at time t. For columns 1-4 and 7-10, data on post-1950 Africa are added to our base sample. For columns 5-6 and 11-12, data on countries most affected demographically by World War II are excluded (Austria, China, Finland, Germany, and Italy). See text and Appendix A for construction of the mortality instruments, definitions, and data sources.

Appendix Table A1

Key Data used in Base Sample

Country	Initial Income	Year	Predicted Mortality	Life Expectancy	Population	Total GDP	GDP per capita
Argentina	Middle	1940	0.205	56.5	14,169	58,963	4,161
Argentina		1980	0.000	69.6	28,370	232,802	8,206
Australia	Rich	1940	0.232	66.8	7,042	43,422	6,166
Australia		1980	0.000	74.4	14,616	210,642	14,412
Austria	Middle	1940	0.299	60.2	6,705	26,547	3,959
Austria		1980	0.000	72.7	7,549	103,874	13,759
Bangladesh	Poor	1940	0.668	29.9	41,966	25,044	597
Bangladesh		1980	0.000	48.5	88,077	48,239	548
Belgium	Rich	1940	0.156	61.8	8,346	38,072	4,562
Belgium		1980	0.000	73.2	9,847	142,458	14,467
Brazil	Poor	1940	0.525	36.7	41,114	51,381	1,250
Brazil		1980	0.000	62.7	122,958	639,093	5,198
Canada	Rich	1940	0.121	64.2	11,688	62,744	5,368
Canada		1980	0.000	74.7	24,593	397,814	16,176
Chile	Middle	1940	0.803	42.0	5,093	16,596	3,259
Chile		1980	0.000	69.3	11,094	63,654	5,738
China	Poor	1940	0.291	43.9	518,770	291,603	562
China		1980	0.000	65.3	981,235	1,046,781	1,067
Colombia	Middle	1940	0.535	37.9	9,174	17,386	1,895
Colombia		1980	0.000	65.9	26,583	113,375	4,265
Costa Rica	Middle	1940	0.667	49.3	620	1,093	1,763
Costa Rica		1980	0.000	72.7	2,299	11,290	4,911
Denmark	Rich	1940	0.121	65.5	3,832	19,606	5,116
Denmark		1980	0.000	74.3	5,123	78,010	15,227
Ecuador	Poor	1940	0.930	39.3	2,466	3,344	1,546
Ecuador		1980	0.000	63.3	7,920	32,706	4,129
El Salvador	Poor	1940	0.970	34.5	1,630	1,811	1,111
El Salvador		1980	0.000	57.1	4,566	10,748	2,354
Finland	Middle	1940	0.223	57.3	3,698	11,909	3,220
Finland		1980	0.000	73.2	4,780	61,890	12,949
France	Middle	1940	0.279	60.0	41,000	165,729	4,042
France		1980	0.000	74.3	53,870	813,763	15,106
Germany	Rich	1940	0.183	63.5	69,835	377,284	5,403
Germany		1980	0.000	72.6	78,298	1,105,099	14,114
Greece	Middle	1940	0.409	54.4	7,280	16,183	2,223
Greece		1980	0.000	74.4	9,643	86,505	8,971
Guatemala	Middle	1940	0.806	30.4	2,200	6,033	2,742
Guatemala		1980	0.000	57.4	7,235	26,632	3,681
Honduras	Poor	1940	0.609	32.5	1,150	1,334	1,160
Honduras		1980	0.000	60.0	3,635	7,014	1,930
India	Poor	1940	1.126	30.0	321,565	265,455	686
India		1980	0.000	54.4	679,000	637,202	938
Indonesia	Poor	1940	0.877	34.3	70,175	86,682	1,235
Indonesia		1980	0.000	54.8	147,490	275,805	1,870
Ireland	Middle	1940	0.306	59.8	2,958	9,028	3,052
Ireland		1980	0.000	72.7	3,401	29,047	8,541
Italy	Middle	1940	0.816	58.7	44,341	155,424	3,505

Country	Initial Income	Year	Predicted Mortality	Life Expectancy	Population	Total GDP	GDP per capita
Italy		1980	0.000	73.9	56,451	742,299	13,149
Korea, Rep.	Poor	1940	0.185	48.7	15,627	22,536	1,442
Korea, Rep.		1980	0.000	66.8	38,124	156,846	4,114
Malaysia	Poor	1940	0.317	42.6	5,434	6,945	1,278
Malaysia		1980	0.000	66.9	13,764	50,333	3,657
Mexico	Middle	1940	0.621	43.6	20,393	37,767	1,852
Mexico		1980	0.000	66.8	68,686	431,983	6,289
Myanmar	Poor	1940	0.621	36.6	16,594	12,274	740
Myanmar		1980	0.000	52.1	33,283	27,381	823
Netherlands	Rich	1940	0.180	67.4	8,879	42,898	4,831
Netherlands		1980	0.000	75.7	14,144	207,979	14,705
New Zealand	Rich	1940	0.214	67.7	1,636	10,308	6,300
New Zealand		1980	0.000	73.2	3,170	39,141	12,347
Nicaragua	Poor	1940	0.476	34.5	830	1,139	1,372
Nicaragua		1980	0.000	58.7	2,804	6,043	2,155
Norway	Middle	1940	0.214	67.3	2,973	12,152	4,088
Norway		1980	0.000	75.7	4,086	61,811	15,129
Pakistan	Poor	1940	0.813	30.0	28,169	20,137	715
Pakistan		1980	0.000	55.1	85,219	98,907	1,161
Panama	Middle	1940	0.595	42.4	697	1,199	1,721
Panama		1980	0.000	70.1	1,956	9,961	5,091
Paraguay	Middle	1940	0.364	46.6	1,111	1,947	1,752
Paraguay		1980	0.000	66.8	3,193	10,549	3,304
Peru	Middle	1940	0.832	40.6	6,298	11,483	1,823
Peru		1980	0.000	60.4	17,295	72,723	4,205
Philippines	Poor	1940	0.976	47.3	16,585	26,326	1,587
Philippines		1980	0.000	61.1	50,940	121,012	2,376
Portugal	Middle	1940	0.623	50.3	7,675	12,396	1,615
Portugal		1980	0.000	71.4	9,778	78,655	8,044
Spain	Middle	1940	0.387	50.2	25,757	53,585	2,080
Spain		1980	0.000	75.5	37,488	344,987	9,203
Sri Lanka	Poor	1940	0.617	42.3	6,134	7,673	1,251
Sri Lanka		1980	0.000	68.2	14,900	27,550	1,849
Sweden	Rich	1940	0.125	66.7	6,356	30,873	4,857
Sweden		1980	0.000	75.9	8,310	124,130	14,937
Switzerland	Rich	1940	0.144	64.1	4,226	27,032	6,397
Switzerland		1980	0.000	75.8	6,385	119,909	18,779
Thailand	Poor	1940	0.506	42.6	15,513	12,820	826
Thailand		1980	0.000	63.6	47,026	120,116	2,554
United Kingdom	Rich	1940	0.270	65.0	48,226	330,638	6,856
United Kingdom		1980	0.000	73.8	56,314	728,224	12,931
United States	Rich	1940	0.132	63.8	132,637	929,737	7,010
United States		1980	0.000	73.7	227,726	4,230,558	18,577
Uruguay	Middle	1940	0.344	56.5	1,965	7,193	3,661
Uruguay		1980	0.000	70.4	2,920	19,205	6,577
Venezuela, RB	Middle	1940	0.496	33.9	3,784	15,307	4,045
Venezuela, RB		1980	0.000	68.3	14,768	149,735	10,139

This list contains data only on the countries in our base sample for which we have pre-1950 data.

Figure 1: Log life expectancy at birth for initially rich, middle-income and poor countries

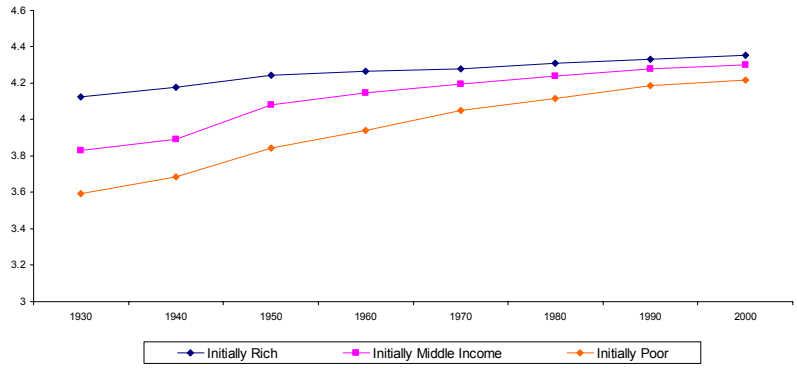


Figure 2: Log GDP per capita for initially rich, middle-income and poor countries

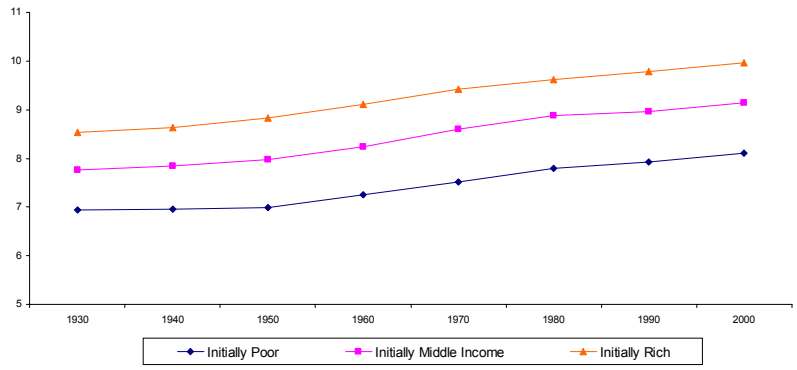


Figure 3: Change in log life expectancy and change in predicted mortality, 1940-80, base sample

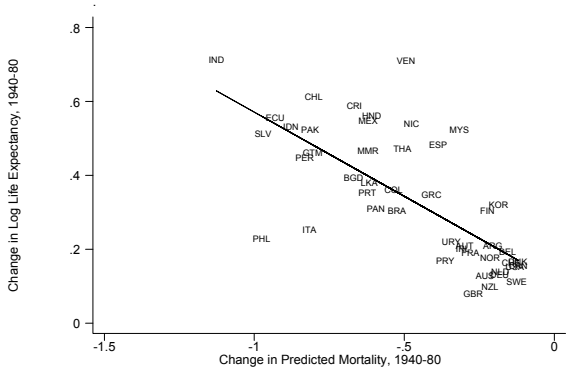


Figure 4: Change in log life expectancy and change in predicted mortality, 1940-80, low and middle-income countries

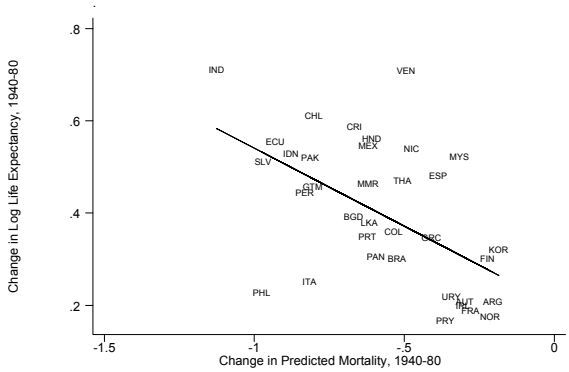


Figure 5: Change in log life expectancy, 1900-40, and change in predicted mortality, 1940-80, base sample

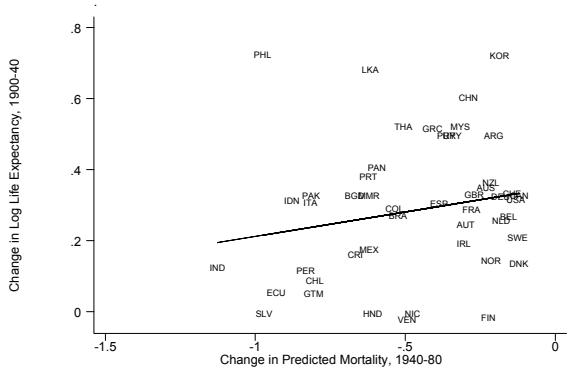


Figure 6: Change in log life expectancy, 1900-40, against change in predicted mortality, 1940-80, low and middle-income countries

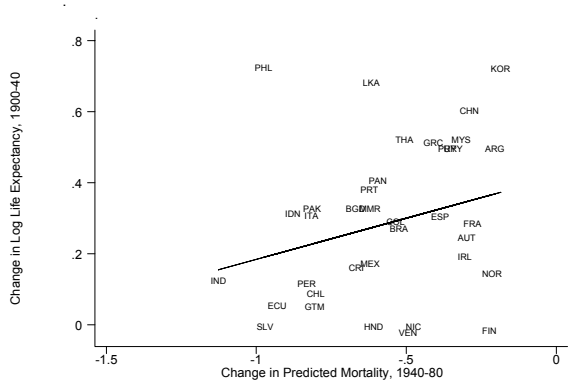


Figure 7: Change in log life expectancy, 1930-40, and change in predicted mortality, 1940-80, base sample

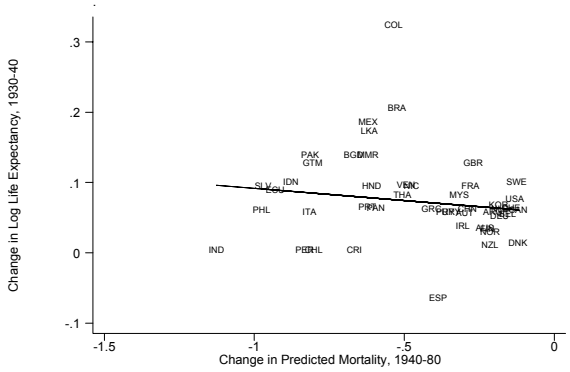


Figure 8**:** Change in log life expectancy, 1930-40, and change in predicted mortality, 1940-80, low and middle-income countries

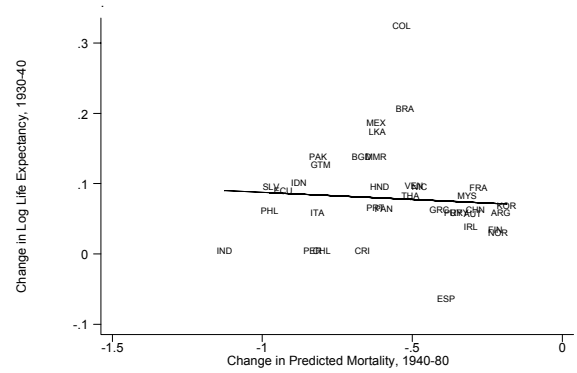


Figure 9: Change in log population and change in predicted mortality, 1940-80, base sample

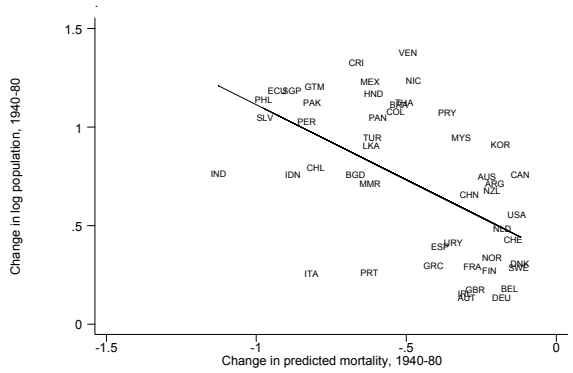


Figure 10: Change in log total GDP and change in predicted mortality, 1940-80, base sample

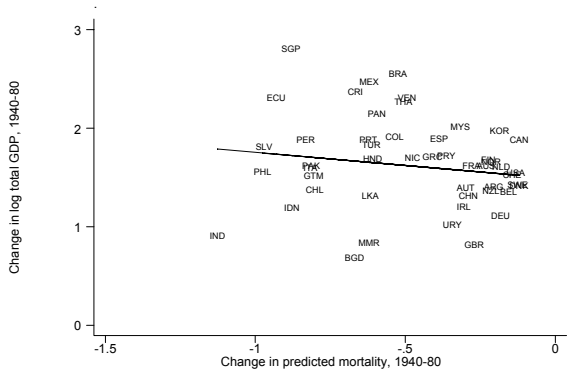


Figure 11: Change in log GDP per capita and change in predicted mortality, 1940-80, base sample

