On the Determinants of Mortality Reductions in the Developing World

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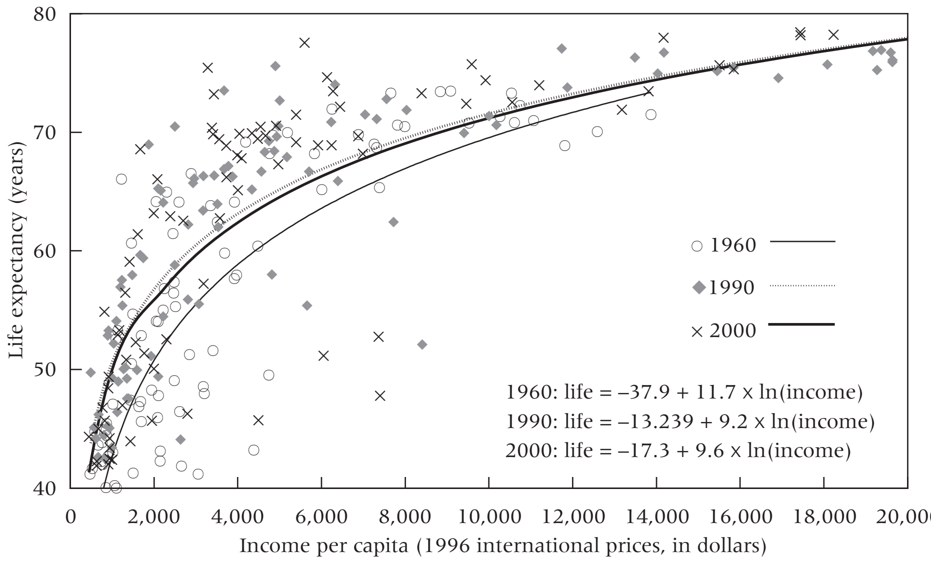
THE LAST CENTURY witnessed profound transformations in the living conditions faced by the vast majority of humans. Income per capita worldwide is estimated to have risen fivefold between 1900 and 2000. Life expectancy at birth in developed countries rose from around 45 years at the end of the nineteenth century to above 75 in 2000. For many developing countries, gains in life expectancy in the 40-year interval between 1960 and 2000 exceeded 20 years (see Maddison 2004; Keyfitz and Flieger 1968; and World Bank 2005).

A closer look at life expectancy changes

Traditionally, changes in health have been treated as intrinsically linked to income. Therefore, income growth has been seen as the cause of improved health, through better education, nutrition, housing, sanitation, and higher demand for health services. Although this relationship is clearly present, social scientists have become increasingly aware that this view gives an incomplete picture of reality. Several dimensions of human welfare, including life expectancy, have become gradually dissociated from income. Figure 1 portrays the cross-country relationship between income per capita and life expectancy at birth in 1960, 1990, and 2000. At any point in time, there is a clear positive correlation between the two variables (expressed by the logarithmic curves fitted to the data). Nevertheless, the figure shows a positive shift in this relationship throughout the period. This positive shift, first documented by Preston (1975), seems to have been occurring at least since 1930. For constant levels of income, life expectancy has been rising, particularly for poorer countries. After 1990, the devastating effect of AIDS in Africa changed this trend for countries at very low income levels, and halted the shift that had been observed in the previous 50 years.

Figure 1 also illustrates the fact that a significant portion of the recent changes in life expectancy was unrelated to changes in income. The relation-

FIGURE 1 The changing relationship between income and life expectancy: 1960, 1990, and 2000



ship between the two variables is also associated with the distinct patterns of cross-country inequality in income and life expectancy observed in the period after World War II. Table 1 presents inequality measures for income per capita and life expectancy at birth for 1960, 1990, and 2000. These data show no evidence of reduction in income inequality across countries up to the 1990s. During the 1990s, mainly because of the experiences of China and India, the cross-country disparity in income per capita was reduced significantly (without these two countries, income inequality was stable between 1990 and 2000). In the case of life expectancy, the evidence is diametrically opposite. By any measure, inequality in life expectancy declines substantially over the whole period, but the decline in inequality with respect to life expectancy was concentrated entirely between 1960 and 1990. After that, the effects of AIDS in Africa are felt, and inequality increases slightly between 1990 and 2000. Vallin and Meslé (2004) and Ram (2006) show that, excluding sub-Saharan countries from the sample, there are significant reductions in life expectancy inequality also between 1990 and 2000.[1]

Figure 2 plots the regression to the mean in life expectancy between 1960 and 2000 (change in life expectancy between 1960 and 2000 plotted against life expectancy in 1960). During this 40-year period, countries starting with high life expectancy levels tended to experience smaller gains than countries starting with low life expectancy. According to the unweighted regression line in Figure 2 (as opposed to the weighted results presented in

TABLE 1 Evolution of cross-country inequality in income and life expectancy, 1960–2000

	Income per capita			Life expectancy		
	1960	1990	2000	1960	1990	2000
Relative mean dev	0.4751	0.4733	0.4215	0.1179	0.0507	0.0509
Coeff of variation	1.2344	1.2529	1.1662	0.2629	0.1245	0.1361
Std dev of logs	1.0178	1.0300	0.9620	0.2552	0.1326	0.1513
Gini coeff	0.5104	0.5187	0.4873	0.1293	0.0690	0.0730
Regression to the mean over previous date		–0.0069 (p=0.86)	–0.0741 (p=0.00)		–0.6133 (p=0.00)	0.0364 (p=0.31)

NOTE: Income per capita is GDP per capita in 1996 international prices in dollars, adjusted for terms of trade (Penn World Tables 6.1). Life expectancy is life expectancy at birth (*World Development Indicators*, World Bank). Inequality measures are weighted by country population (abstracting from within-country inequality). Sample includes 96 countries, comprising more than 82 percent of the world population. Regression to the mean is the coefficient of a regression of the change in the variable over the period on its initial level (natural logs used in the income regressions; weighted regressions).
SOURCE: Becker, Philipson, and Soares (2005).

Table 1), life expectancies ten years higher in 1960 were associated, on average, with gains in life expectancy 1.5 years lower in the following 40 years. But the average relationship over the entire period hides radical changes taking place within specific intervals. Figure 3 breaks down the regression to the mean observed in Figure 2 into two periods, between 1960 and 1990 and between 1990 and 2000. In the first period, regression to the mean was stronger and more homogeneously distributed than in Figure 2, while in the second period the trend was reversed.

FIGURE 2 Cross-country regression to the mean in life expectancy 1960–2000

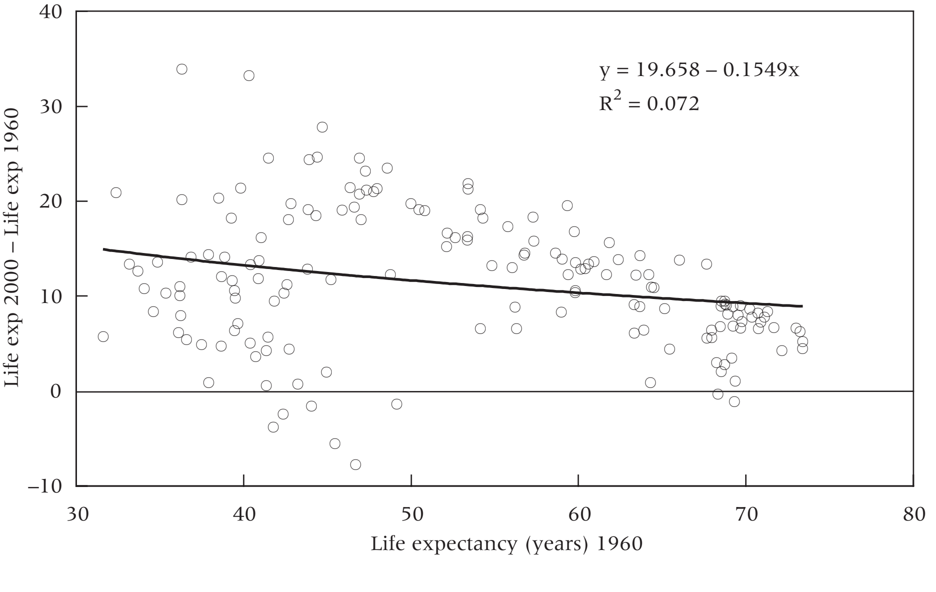
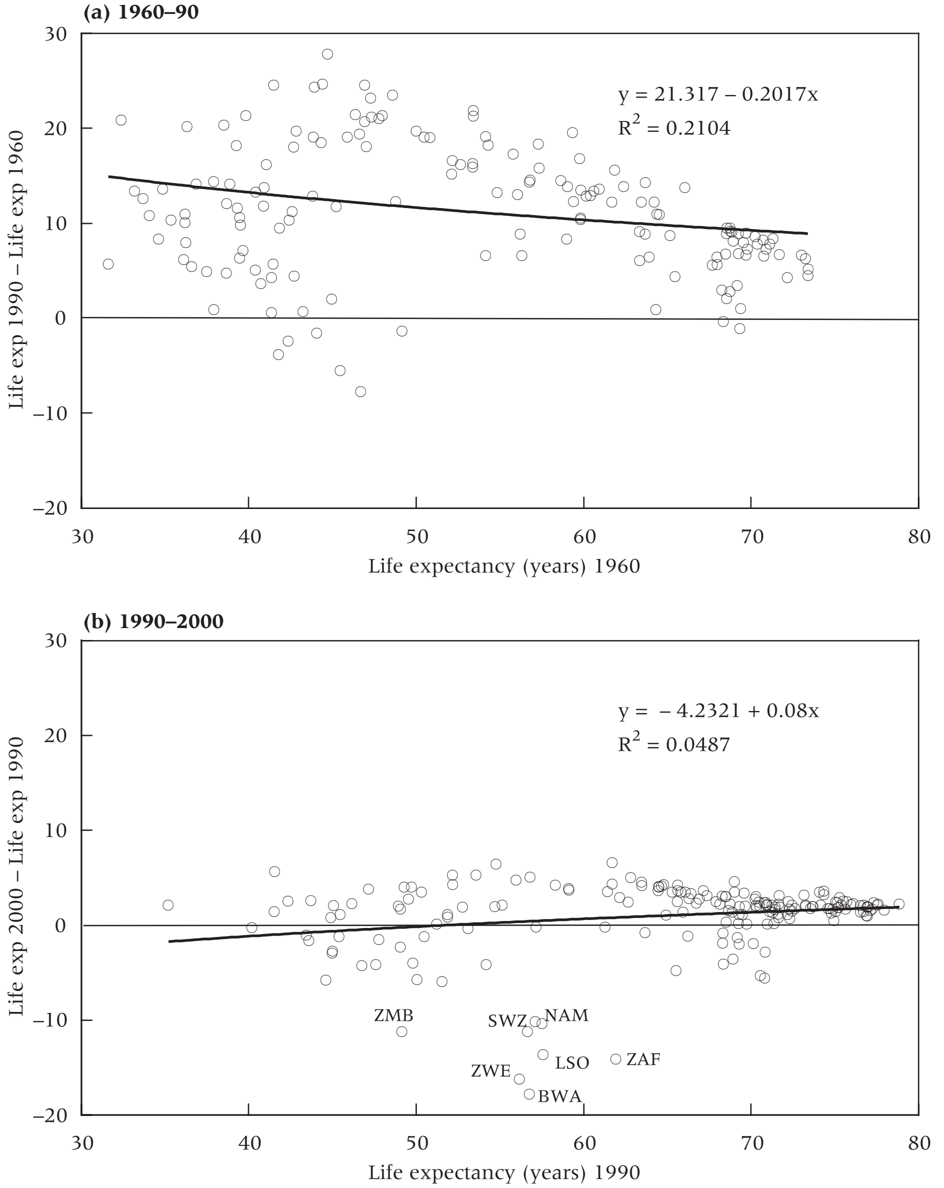
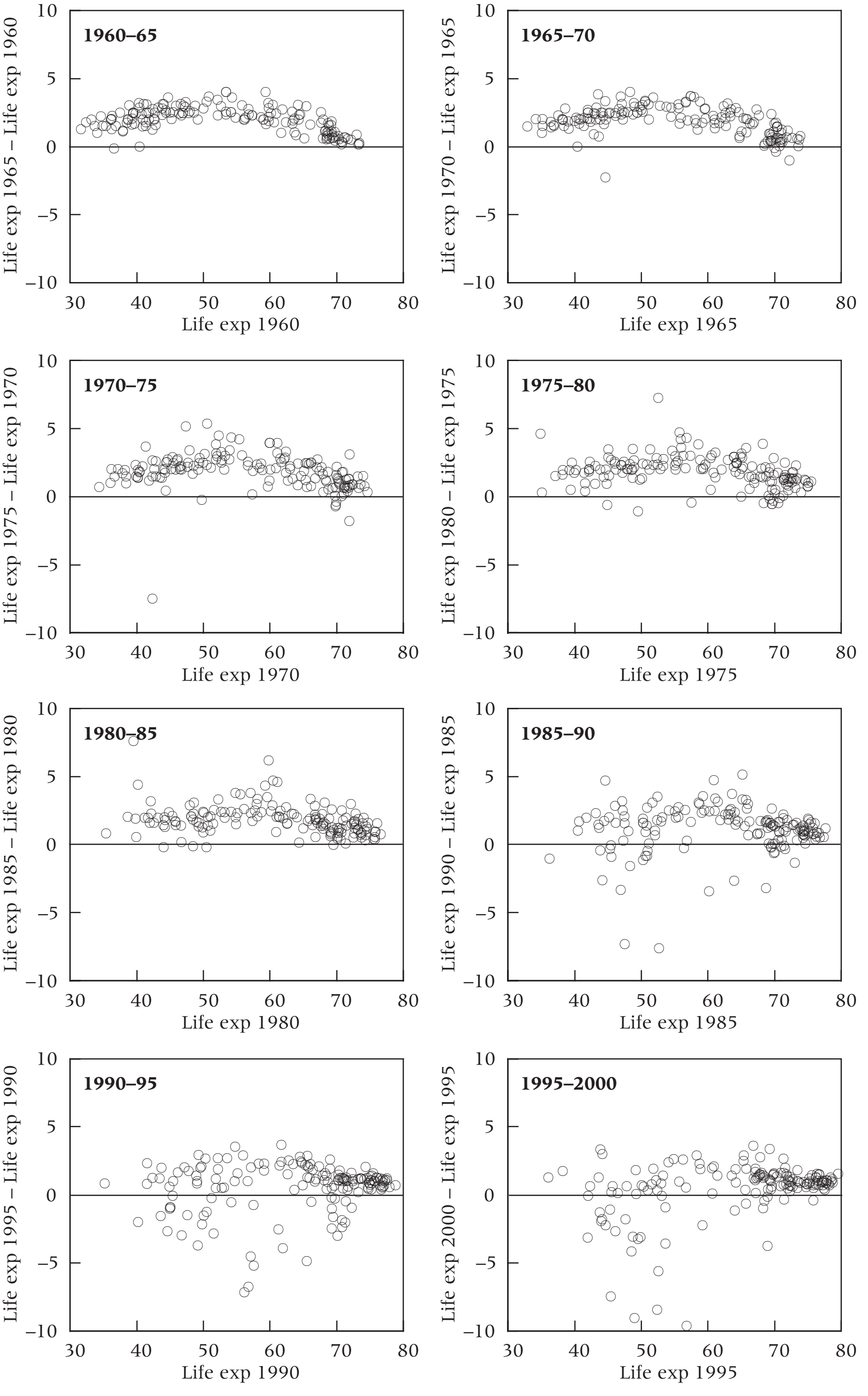


FIGURE 3 Cross-country regression to the mean in life expectancy, 1960–90 and 1990–2000



The destabilizing nature of the changes observed at the beginning of the 1990s becomes more obvious when I perform this same type of decomposition for consecutive five-year intervals (see Figure 4). From 1960 to the 1990s, the relationship between initial life expectancy and the change in life expectancy observed in the following five years is stable. This relationship is characterized by a positive slope for very low levels of initial life expectancy

FIGURE 4 Cross-country regression to the mean in changes in life expectancy (years) in five-year intervals, 1960–2000



(below 50 years), with higher initial life expectancy associated with higher gains in life expectancy. For initial life expectancy above intermediate levels, this relationship becomes negative, and higher initial life expectancy is associated with lower life expectancy gains. The relationship between initial life expectancy and gains in life expectancy in the following five years remains virtually identical in the 30-year interval between 1960 and 1990. Such a stable relationship necessarily implies regression to the mean in life expectancy over the long run. Together with the evidence from Table 1, we also know that as countries starting with low life expectancy moved from left to right over the horizontal axis, they eventually reached a period of very large gains that led to convergence toward higher levels of life expectancy and reduced inequality in life expectancy.

The stability of this relationship over the 30-year period in question suggests that a continuous and natural process of change was underway. Riley (2005a) highlights the puzzling stability and homogeneity of mortality reductions in the period after World War II, despite different patterns of access to water, sanitation, education, income, and housing across countries. Although by the mid-1980s researchers expressed concerns about the possible halt to mortality declines in developing countries, most countries sustained substantial gains in life expectancy up to 1990 (Hill and Pebley 1989; Riley 2005a). Apart from eastern Europe and sub-Saharan Africa, most countries have continued to experience substantial gains in life expectancy up to the present (Riley 2005a). Nevertheless, around 1990, and before all countries could fully benefit from the improvements, the emergence of AIDS and—to a much lesser extent—the institutional turmoil in former Communist countries led to the collapse of the characteristic regression to the mean that had remained unchanged at least since 1960 (this point is explored by Ram 2005, 2006). The overwhelming effect of AIDS on the cross-country trend in life expectancy after 1990 can be seen from the fact that all countries experiencing declines in life expectancy exceeding five years in Figure 3(b) are affected by the epidemic (Botswana, Lesotho, Namibia, Swaziland, South Africa, Zambia, and Zimbabwe; see Philipson and Soares 2005). The effect of AIDS at the end of the twentieth century dwarfs any other change observed in the period. Although the importance of AIDS in this context is self-evident, the specific determinants of the previous improvements in life expectancy in the developing world remain inadequately known.

The goal of this article is to examine the determinants of the improvements in life expectancy in the developing world during the period after World War II. Recent estimates suggest that longevity has been a quantitatively vital component of the overall gains in welfare during the twentieth century, both within and across countries (see Cutler and Richardson 1997; Nordhaus 2003; Murphy and Topel 2003; Burström, Johannesson, and Diderichsen 2003; Becker, Philipson, and Soares 2005). From a research perspective, pinning down the factors determining the observed reductions in mortality may shed light on the interactions between health, human capital, and income, and on their relative importance for economic development and social change. From a policy perspective, it may help maximize the impact of future health interventions in countries that still lag behind in health improvements. In particular, this knowledge may be fundamental in designing policies to enable sub-Saharan Africa to recover from its present circumstances.[2]

The next section summarizes a large body of evidence to draw a broad picture of the nature, age, and cause-of-death profile of recent reductions in mortality in the developing world. The following section raises theoretical considerations on the determinants of mortality that are suggested by this general picture. Two subsequent sections present the available empirical evidence on the specific determinants of reductions in mortality. The aggregate evidence is described with particular attention to the determinants of the diffusion of health technologies and to cross-country correlates of mortality, and the micro-evidence from regional and country-specific studies is analyzed. The final section, drawing on the evidence available, gives a wide-ranging interpretation of the process of mortality reductions across the world.

The pattern of mortality reductions in developing countries

As noted in the introduction, a large part of the life expectancy gains in developing countries in the postwar period seems to be unrelated to improvements in income or, more generally, material living conditions. In Bolivia, Honduras, and Nicaragua, for example, modest—or even negative—economic growth was accompanied by gains in life expectancy at birth on the order of 20 years. This phenomenon is not restricted to Latin America. Figure 1 shows that, in a broad cross-section of countries, life expectancy has been increasing for constant levels of income. In this section, I discuss the nature of recent changes in mortality and analyze their profile in terms of age and cause of death.

Nature of mortality changes

The shift in the income–life expectancy profile observed at least since 1930 does not imply the absence of a relationship between income and mortality. Figure 1 shows that at any point in time there is a close positive association between income per capita and life expectancy at birth. This relationship to a great extent reflects differential nutrition and use of health services across different income levels. The role of income in determining mortality, mainly through nutrition, was extensively discussed by Fogel (e.g., Fogel 1994, 2004). His controversial analysis attributes a dominantly large fraction of the reductions in mortality to improved nutrition. But even so, he claims that nutrition explains almost all the mortality reductions in some European countries up to the end of the nineteenth century, but only 50 percent after that. Starting in the beginning of the twentieth century, even according to Fogel's calculations, roughly half of the changes in mortality seem to come from sources unrelated to improved material conditions. This is also what Figure 1 reveals. Although nutrition and use of health services imply a positive relationship between income and life expectancy, some type of technological change has taken place such that, for constant income, life expectancy has been rising.

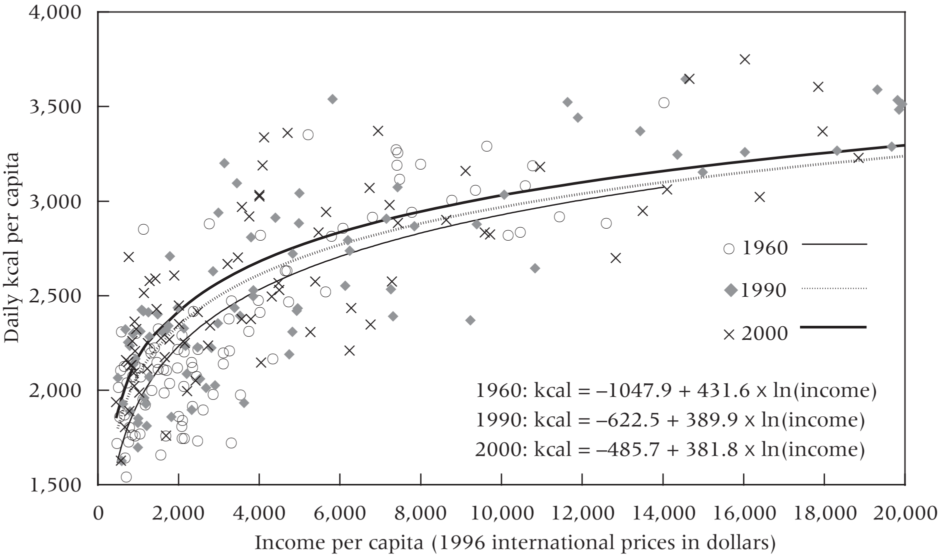
Evidence from developing countries also supports the idea that the shift in the income–life expectancy profile is not an artifact of improved nutrition for constant levels of income. Table 2 presents information on life expectancy at birth in 1940 and 1970 for countries at different income and nutrition levels. Life expectancy gains took place in every nutrition bracket shown in the table. For the lowest nutrition group (less than 2,100 calories daily), life expectancy at birth increased by 10 years. Recent data confirm this same pattern for the period between 1960 and 2000. Figure 5 first shows that, for constant levels of income, nutrition seems to have improved slightly in the last 40 years, as measured by daily calorie consumption. This may be the result of rising agricultural production and declining relative prices of food. But the shift in the cross-sectional relationship is modest: typically, for constant income, calorie consumption increased by little more than 200 kcal a day. This is far from enough to explain the shift in the income–life expectancy profile, as becomes clear in Figure 6. The figure shows that, between 1960 and 2000,

TABLE 2 Mean life expectancy (years) of countries in various ranges of national income and calorie consumption, 1940 and 1970

Daily kilocalories per capita	Year	National income per capita in 1970 US dollars				
		<150	150–299	300–699	>700	All income levels
<2,100	1970	42.7	51.5	53.3	69.5	47.5
	1940	38.3	36.0			37.9
2,100–2,399	1970	42.6	49.9	56.2	71.4	49.1
	1940	40.0	43.9	46.1		43.4
2,400–2,899	1970	45.4	57.9	61.3	68.0	61.4
	1940		44.1	50.4	59.6	51.1
>2,900	1970				71.6	71.6
	1940			58.7	65.2	64.0
All calorie levels	1970	42.7	52.4	57.8	70.8	55.9
	1940	38.6	42.4	52.2	64.1	52.2

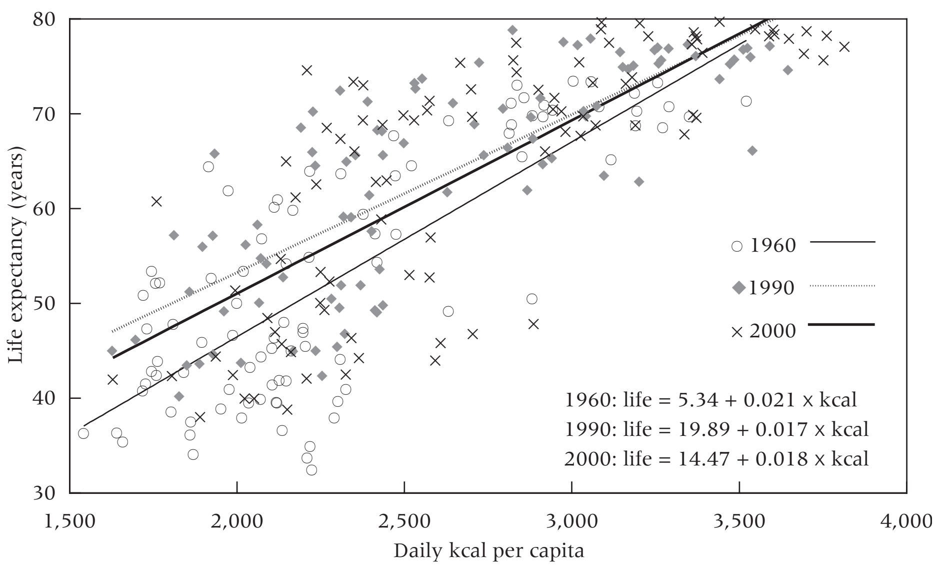
SOURCE: Preston (1980, Table 5.4, p. 305).

FIGURE 5 The relationship between income and nutrition: 1960, 1990, and 2000



the cross-sectional relationship between nutrition and life expectancy at birth shifted in much the same way as the cross-sectional relationship between income and life expectancy. Between 1960 and 1990, for constant nutritional levels, life expectancy at birth increased by as much as 8 years for countries in

FIGURE 6 The relationship between nutrition and life expectancy: 1960, 1990, and 2000



the lowest calorie consumption range. After 1990, with the arrival of AIDS, the outward shift observed since 1960 was partially reversed, but still the relationship remained considerably above its initial profile.[3]

With a cross-country econometric analysis relating life expectancy improvements to income and calorie consumption, Preston (1980) concludes that approximately 50 percent of the changes in life expectancy between 1940 and 1970 were due to "structural factors" unrelated to economic development or nutrition. Although this proportion is similar to the one obtained by Fogel, Preston hypothesizes that income per capita also captures dimensions related to the provision of public health infrastructure, which are not present in Fogel's framework. Heuveline (2001) extends Preston's analysis and finds similar results for the period 1960–2000.[4]

Other evidence also supports the idea that improvements in nutrition and income are insufficient to explain the gains in mortality observed in recent decades. Palloni and Hill (1997), for example, analyze the pattern and extent of mortality changes in Latin America between 1950 and 1990. Although concluding that mortality responds to short-term economic crisis (they looked mainly at child mortality), they show that these responses are quantitatively unimportant when compared to the historical trend (though morbidity changes may be substantial). Caldwell (1986) describes historical experiences of "mortality breakthroughs" that were not accompanied by similar economic growth, while Hill and Pebley (1989), Easterlin (1996), Deaton (2004), and Cutler et al. (2006) all conclude that the relationship between economic growth, nutrition, and mortality is far from sufficient to explain the improvements in life expectancy observed during the twentieth century.

To better understand this pattern of gains in life expectancy, I first explore the profile of changes in age and cause of death and how it relates to reductions in mortality.

Age and cause of death

Changes in the distribution of mortality by age and cause characterize the progression of the demographic and epidemiological transitions. The term epidemiological transition was first coined by Omran (1971) to describe the process of change in leading causes of death, from infectious diseases to chronic non-transmissible diseases, that takes place as mortality reduction progresses (see discussion in Riley 2001). Associated with this change in leading causes of death is a shift in the age distribution of deaths, from mostly concentrated at younger ages to a concentration at older ages, and eventually to a distribution where child and infant mortality become relatively unimportant.[5]

This transformation process has been widely documented in the now-developed world, for cases where long-term mortality data are available. Preston and Haines (1991) analyze changes in child mortality in the United

States around the end of the nineteenth century. They show that, between ages 0 and 4 years, infectious diseases of the gastrointestinal and respiratory tracts combined were responsible for 45 percent of all deaths, with premature birth, malformation, and childhood diseases accounting for an additional 30 percent. Improvements in the period were driven mainly by practices introduced with the acceptance of the germ theory of disease, including boiling milk and sterilizing bottles, washing hands before handling food, and isolating sick family members. Thus began the evolution toward systematic improvements in life expectancy observed during the twentieth century.

Cutler and Meara (2001) complement this analysis by discussing changes in the cause and age distribution of mortality in the United States throughout the twentieth century. They show that during the first half of the century infectious diseases were the leading cause of death. During this period, nutrition and public health interventions were the most important factors in reducing mortality, and these reductions were mostly concentrated on mortality from infectious diseases at younger ages (80 percent of the life expectancy gains were concentrated before age 45, and roughly 65 percent before age 14; reduced deaths from infectious diseases were responsible for 75 percent of the gains in life expectancy in the period).

Between 1940 and 1960, infectious diseases continued to play a key role, but specific medical innovations (mainly antibiotics) became critical factors in mortality reduction. In this period, mortality change was more evenly distributed across age groups and was strongly concentrated in diseases for which new drugs became available.

Finally, between 1960 and 1990, mortality reduction increasingly reflected sophisticated and technologically intensive medical advances. These were concentrated on reducing mortality from heart and circulatory diseases at older ages and on mortality due to low birth weight at earlier ages. In this last period, changes in mortality above age 45 accounted for 66 percent of the overall gain in life expectancy.[6]

These authors show that mortality from infectious diseases declined significantly well before specific medical treatments became available. This is in line with the evidence presented by Cutler and Miller (2005), who estimate that the introduction of clean water technologies was responsible for 43 percent of the reductions in mortality observed in major American cities between 1900 and 1936. Clean water is estimated to have accounted for 74 percent of the reduction in infant mortality, and the nearly complete eradication of typhoid fever. In addition, Cutler and Miller present evidence that poor populations benefited more from clean water systems than rich populations, even though the poor were not the first group with access to these systems—evidence of the public good dimension of public health technologies.

Historical evidence from England tells a similar story. McKeown and Record (1962) discuss the causes of death behind the improvements in life expectancy observed in England and Wales between 1837 and 1900. They conclude that a decline in mortality attributable to tuberculosis was responsible for 45 percent of the overall mortality reduction, while declines in mortality attributable to typhus and typhoid fever (22 percent), scarlet fever (19 percent), cholera, dysentery, and diarrhea (8 percent), and smallpox (6 percent) were also important sources of life expectancy improvements. Overall, they argue that living conditions probably contributed roughly 50 percent of the total reduction in mortality in the period (mostly through tuberculosis, with some effect on typhus and typhoid fever), while sanitary reforms were responsible for another 25 percent (most of the reduction through typhus, typhoid fever, and cholera). Although McKeown (1976) eventually defended the idea that nutrition was the main determinant of susceptibility to diseases and, therefore, that improvement in living conditions was the key determinant of mortality reductions, his first interpretation gave more credit to public policy.

Following chronologically, Livi-Bacci (2001) discusses the determinants of mortality in England from the end of the nineteenth century until 1951. Over this period, England gained more than 26 years in life expectancy at birth. Roughly 55 percent of this gain can be attributed to reduction in mortality due to infectious diseases, bronchitis, pneumonia, and influenza, with diseases of infancy, diarrhea, and enteritis being responsible for another 13 percent.

In Italy, gains of 30 years in life expectancy at birth were registered between the end of the nineteenth century and the middle of the twentieth. As in England, roughly 55 percent of the gain can be attributed to reductions in mortality from infectious diseases, bronchitis, pneumonia, and influenza, with diseases of infancy, diarrhea, and enteritis being responsible for another 18 percent. By 1981, Italy had shown substantial reductions in mortality throughout the entire age distribution, with the probability of survival from birth to age 15 increasing from 58 percent in 1881 to 98 percent in 1981, survival to age 50 increasing from 41 percent to 94 percent, and survival to age 80 increasing from 6 percent to 42 percent (ibid.).

The well-documented historical experience of developed countries sheds light on the potentially important forces behind the changes registered in developing countries, even when these forces cannot be directly observed. In addition, it hints at the path ahead. As long as we can characterize reduction in mortality in terms of underlying causes of death or by age groups, and by the technologies available at a given point in time, the evidence discussed above suggests candidates for the main determinants of mortality reduction.

The first significant effort to identify the diseases responsible for mortality reductions in the developing world was undertaken by Preston (1980). Table 3 indicates the approximate percentage of mortality decline in developing countries between 1900 and 1970 accounted for by different diseases. Preston argues that, apart from influenza/pneumonia/bronchitis, preventive

TABLE 3 Mortality decline in developing countries attributable to prevention and treatment of particular diseases and principal methods of prevention and treatment, 1900–70

Dominant mode of transmission/ Diseases	Approximate % of mortality decline due to prevention/ treatment	Principal methods of prevention	Principal methods of treatment
Airborne			
Influenza/ pneumonia/ bronchitis	30		Antibiotics
Respiratory tuberculosis	10	Immunization; identification and isolation	Chemotherapy
Smallpox	2	Immunization	Chemotherapy
Measles	1	Immunization	Antibiotics
Diphtheria/ whooping cough	2	Immunization	Antibiotics
Subtotal	45		
Water-, food-, and feces-borne			
Diarrhea, enteritis, gastroenteritis	7	Purification and increased supply of water; sewage disposal; personal sanitation	Rehydration
Typhoid	1	Purification and increased supply of water; sewage disposal; personal sanitation; partially effective vaccine	Rehydration, antibiotics
Cholera	1	Purification and increased supply of water; sewage disposal; personal sanitation; partially effective vaccine; quarantine	Rehydration
Subtotal	9		
Insect-borne			
Malaria	13–33	Insecticides, drainage, larvicides	Quinine drugs
Typhus	1	Insecticides, partially effective vaccines	Antibiotics
Plague	1	Insecticides, rat control, quarantine	
Subtotal	15–33		

SOURCE: Preston (1980, Table 5.3, p. 300).

measures were probably the most effective factors in determining mortality reductions. Large-scale immunization of populations and improvements in water supply and sewage disposal took place in several developing countries throughout the second half of the twentieth century. Preston contends that the direct impact of economic development in reducing mortality probably operated mostly through influenza/pneumonia/bronchitis, for which there was no effective deployment of preventive measures and treatment only became widely available later in the period. For infectious and diarrheal diseases, improvements came through development of water supply, sewerage, and immunization. Preston's interpretation considers public health infrastructure (water and sanitation) as part of economic development and, therefore, does not include it in what he calls "structural factors." This view generates numbers similar to the income-nutrition-mortality analysis, with roughly 50 percent of the life expectancy gains being unrelated to simple improvements in material conditions.

Palloni and Wyrick (1981) find similar evidence for Latin America between 1955 and 1973. They show that reductions in mortality due to infectious diseases, influenza/pneumonia/bronchitis, and diarrhea were the main factors contributing to the gains in life expectancy observed in the period. Factors unrelated to living standards seem to have been particularly significant in regions where malaria was endemic, and where other infectious diseases were more prevalent. In line with the results mentioned above, they find that 55 percent of the reductions in mortality were attributable to exogenous factors, while only 45 percent came from improvements in living standards.

The relationship between changes in mortality by cause of death and methods of prevention and treatment portrayed in Table 3 and discussed above is similar to that suggested by Cutler and Meara (2001). In general, changes in mortality by cause of death are also closely linked to changes in mortality by age of death, reflecting the epidemiological stage of development of a specific society (see Palloni 1981). At a point in time, both age and cause of death will be related to the type of health technology available and employed in each setting. In this sense, the historical pattern observed in developed countries foretells the cross-country differences in mortality changes observed in the period after World War II. Mortality reductions experienced by developing regions in the last 40 years mirror those experienced by the United States in the beginning of the twentieth century.

Table 4 illustrates this point for the period between 1965 and 1995. These results are based on a relatively small sample (49 countries), so that they are representative only of middle-range developing and developed countries. The table shows how the pattern of cause- and age-specific life expectancy gains changes across different development levels (sub-Saharan Africa and South Asia are absent from the sample). In the poorest region (Middle East and North Africa), life expectancy gains are almost entirely concentrated on infectious diseases of the respiratory and digestive tract, and on congenital anomalies and on conditions of the perinatal period. As a result, 90 percent of the mortality reductions are concentrated before age 19. As the develop-

TABLE 4 Decomposition of life expectancy gains by cause of death and age group, world regions, 1965–95

Change in life expectancy	Europe and Central Asia	East Asia and Pacific	Latin America and Caribbean	Middle East and North Africa	North America
Total change (years)	**8.6**	**5.4**	**10.2**	**18.0**	**5.8**
By cause of death (percent)					
Infectious diseases	9.8	6.5	10.6	–0.3	0.8
Nervous system and sense organs	27.2	26.2	9.3	0.7	20.0
Heart and circulatory	–2.1	0.5	–3.9	–8.9	38.9
Respiratory and digestive	14.5	19.4	34.4	67.0	7.8
Congenital anomalies and perinatal conditions	8.6	19.3	11.3	14.4	16.6
By age group (percent)					
0–19	28	41	58	90	26
20–49	14	7	14	5	10
50+	53	49	23	3	61

NOTE: Calculated from Table 4 in Becker, Philipson, and Soares (2005). Decomposition of life expectancy calculated by the authors based on age- and cause-specific mortality data from the World Health Organization. Regional averages weighted by country population. Sample includes 49 countries. The decomposition of life expectancy changes by age groups does not add to 100 percent because of the interaction between reductions in mortality across different age groups (second-order effects of reductions in mortality, resulting from the competing risks nature of mortality changes).

ment level increases, mortality shifts monotonically from early toward older ages (following, in order, Latin America and the Caribbean, East Asia and the Pacific, Europe and Central Asia, and North America). In the case of North America, 60 percent of the life expectancy gain between 1965 and 1995 is attributed to reductions in mortality from heart and circulatory diseases and conditions of the nervous system and sense organs, all concentrated above age 50.

Both the within-country historical trends in mortality and the cross-country variation in life expectancy gains suggest a process of mortality reductions that describes the progression of a country through the different stages of the epidemiological transition. Nevertheless, there is no agreement as to the specific factors that determined these reductions. In the next sections I raise some theoretical considerations suggested by the stylized facts discussed above and confront the theoretical considerations with the available evidence on the specific determinants of mortality reductions in developing countries.

Theoretical considerations

The evidence discussed above suggests that "structural factors" not directly related to economic development were responsible for a substantial fraction of the postwar reductions in mortality in developing countries. The question remains what these "structural factors" were. Because significant reductions in mortality took place at very low income levels and with minimal expenditures on health, diffusion of new technologies (incorporated in ideas, personal health practices, and public goods) must have played an important role.

It is therefore tempting to draw on the well-established literature on international diffusion of productive technologies to guide the discussion on the determinants of mortality reduction (for an extensive review of this literature, see Keller 2004). A central idea in the trade literature is that technology is embodied in goods. When a country imports a capital good from a technology-generating center, the country immediately becomes more productive, since the new capital good incorporates a more efficient technology. In this case, improved productivity is simply a result of the use of a better intermediate good, not necessarily implying the understanding of this new technology or the capacity of the user to reproduce it. In addition, this literature stresses the possibility that researchers in a given country may benefit from the R&D generated elsewhere, through increases in the stock of knowledge available in society. Of course, the possibility of this second mechanism rests on the nature of the R&D in foreign countries (it should be nonexcludable) and on the capacity of the home country to access and "absorb" this new knowledge.

Although the diffusion of productive technologies offers some insight into the diffusion of health technologies, key aspects of the latter are sui generis. First, to a great extent, health is the outcome of a household production process. This is true in terms of household behaviors related to personal hygiene, handling and preparation of food, treatment of water, and child care. From this perspective, absorption of technology demands absorption of knowledge by the consumers/producers themselves. This aspect is probably more critical at low levels of income (or high levels of mortality), so that the idea of embodiment of new technologies in goods purchased on the market is likely to be relatively unimportant in these cases. As health improvements become more dependent on specific medical interventions, as in the examples cited by Deaton (2004), the relative importance of the "embodied technology" idea is likely to increase. This would probably take place mainly through the imports of medicines and medical equipment, both of which may incorporate new technologies leading to higher productivity in terms of health outcomes.

A distinguishing characteristic of health technologies is their large public good dimension. Basic ideas and knowledge embody this notion. For example, as soon as the germ theory of disease became widely accepted, its main implications became publicly available to agents who had the capacity to absorb them. This is the most extreme version of a public good, where the idea itself is literally nonexcludable, nonrival, and not subject to any type of congestion.[7] In typical health technologies, however, this is not the case. But externalities and traditional public goods are still very important when considering, among other things, the development of new medicines and the implementation of public health programs. Several public health programs are implemented precisely because private provision is not viable or efficient. This is the case in the provision of clean water and sewerage systems, vaccination campaigns, and environmental regulations. In some of these examples, technologies are not particularly sophisticated and goods do not incorporate new knowledge, but implementation involves large fixed costs and low marginal costs of operation and is the outcome of an intricate political process that is affected by many other considerations. In other examples, goods incorporate new technologies, but their adoption still depends on the outcome of a centralized political process. In any case, changes depend on processes that are outside the control of any individual agent in society and that, given their political and technological nature, may be exogenous even to the economic conditions faced by the country.

Easterlin (1996, 1999) distinguishes between innovations in health technologies and in "productive" technologies. He suggests that the profit motive is not enough to lead to technological investments in health improvements, as opposed to technological investments in productive technologies. For that reason, mortality reductions in the past were not due exclusively to market forces. Externalities, public goods, and principal-agent and free-rider problems plague investments and interventions related to health, and therefore government action or centralized provision is required to achieve efficiency. In some cases, efficient government action requires overriding of property rights and personal freedoms, as in the cases of compulsory immunization, sanitary reforms in slums, or slaughter of animals due to risk of contamination (tuberculosis-infected cows in the historical example, or avian flu–infected birds in recent years). The necessity of political action, together with institutional ability and willingness to implement known technologies, is also highlighted by Mosley (1984) and Cutler et al. (2006).

For all these reasons, the diffusion of health technologies—in contrast to the diffusion of productive technologies—is likely to depend much more on the absorption of knowledge on the part of agents and on public provision, and less on the embodiment of new technologies. This is particularly important for changes in mortality observed at very low levels of development, when improvements can take place even with minimal expenditures on health. This logic opens space for reductions in mortality independent of improvements in income, as observed in the historical examples, but still leaves room for several alternative mechanisms through which this change could take place. Candidate mechanisms range from diffusion of pure nonrival and nonexcludable knowledge, to public or international interventions focused on particular diseases, and to family and community health programs targeted at health practices within the household.

One of the most remarkable examples of the diffusion of knowledge in the last century was the acceptance of the germ theory (developed at the close of the nineteenth century), which led to inexpensive gains in life expectancy via simple preventive measures (see Vacher 1979 [1886]; Ram and Schultz 1979; Preston 1980, 1996; Ruzicka and Hansluwka 1982; Easterlin 1999; Mokyr 2000). These new measures came in the form of both changes in personal practices and large-scale interventions. The role played by developed countries in information dissemination and program implementation is thought to have been particularly critical. Health programs became less tied to countries' economic conditions and more dependent on interventions by the developed world. Even though the monetary value of the assistance was typically small, the largest contribution came in the form of development of low-cost health measures, training of personnel, initiation of programs, and more effective and specific interventions (see Preston 1980; Ruzicka and Hansluwka 1982).

International mobilization was also key in determining the possibility and effectiveness of combating specific conditions and diseases. A celebrated example is the United Nations Expanded Program on Immunization (EPI). EPI was implemented in 1974 with the goal of bringing available vaccines against various diseases (including measles, diphtheria, pertussis, tetanus, tuberculosis, and polio) to the underserved populations of developing countries. In countries reached by the program, immunization rates skyrocketed in a few years, while infection rates dropped precipitously. EPI achieved virtual eradication of polio from the Americas in 1994 and raised immunization rates for the six target diseases mentioned above from 5 percent of the world's newborns in 1974 to more than 80 percent in 2000 (World Health Organization 2003; World Bank 2005). Country-specific interventions that focused on endemic conditions and on public health infrastructure were also successful, as exemplified by the case of malaria in Guyana, Guatemala, Mauritius, Mexico, Sri Lanka, and Venezuela (see Gray 1974).

Still, the potential value of community- and family-level interventions led some researchers to raise concerns about the effectiveness of narrow interventions focused on the delivery of specific technologies (see, for example, Mosley 1984, or discussion in Hill and Pebley 1989). Their objection was that, for example, vaccination for one disease might simply increase mortality resulting from competing causes of death for immediate later ages, having therefore a modest impact on overall life expectancy. According to this view, immunization or the use of "palliative measures" (such as rehydration therapy) would merely postpone the death of a child and would increase mortality by other causes. An adequate health intervention in this view would require a broader approach to the problem, taking into account the social factors determining mortality in different communities. This line of reasoning highlights the relevance of maternal education and household production as determinants of child mortality, and the importance of community-level interventions focused on the provision of comprehensive primary care. In addition, it stresses the cultural dimension as a key determinant of the success of any program (Mosley 1984).

Taking into account these different candidates for reductions in mortality, I examine the available evidence from cross-country and within-country perspectives.

Evidence on determinants of mortality reduction

Aggregate patterns

Table 5 presents mortality rates before ages 1 year and 5 years (per 1,000 live births) and between ages 15 and 60 (per 1,000 adults) for the years 1960 and 2000 by region.[8] The table shows that, in developing areas, reductions in mortality were significant in every age group, though they were largest for infant and child mortality. In Latin America, mortality before age 1 year was reduced by more than 70 percent between 1960 and 2000, while mortality before age 5 was reduced by almost 80 percent. At the same time, the death rate between ages 15 and 60 fell from 0.27 to 0.17, corresponding to a 35 percent reduction in adult mortality. In East Asia and the Pacific, infant and under-five mortality were reduced by 77 percent and 80 percent, while adult mortality declined by 73 percent. The Middle East and North Africa and South Asia experienced substantial mortality reductions in all age groups. The only exception to this pattern is sub-Saharan Africa, where reductions in infant and child mortality were more modest (both around 32 percent), and reductions in adult mortality nonexistent (mainly due to the effects of AIDS starting in the early 1990s).

Except in sub-Saharan Africa, developing countries are moving from the first stage of mortality reduction, when infant and child mortality are the most important factors, to the second stage, when adult mortality becomes

TABLE 5 Age-specific mortality rates, world regions, 1960 and 2000

	Infant (per 1,000 live births)		Under 5 yrs. (per 1,000 live births)		Adult (per 1,000 adults)	
Region	**1960**	**2000**	**1960**	**2000**	**1960**	**2000**
Europe and Central Asia	45	16	56	20	160	165
East Asia and Pacific	130	30	195	39	560	150
Latin America and Caribbean	97	27	149	33	269	173
Middle East and North Africa	157	41	252	50	299	165
North America	26	7	30	8	177	111
South Asia	145	70	243	96	425	228
Sub-Saharan Africa	149	102	247	165	498	492

NOTE: "Adult" is defined as aged 15–59.
SOURCE: World Bank (2005).

more important. This can be inferred from the regional differences seen in Table 5. While developed areas (North America and Europe) in 1960 already had low levels of child mortality, the poorest areas (sub-Saharan Africa) did not experience significant reductions in adult mortality up to the end of the period. In between are Latin America and the Caribbean, East Asia and the Pacific, and, lagging behind, South Asia, all of which experienced significant declines in both adult and child mortality.[9]

Within regions, differences in trends across countries can also be substantial. In Latin America, reductions in adult mortality in Guyana, Paraguay, and Uruguay have been minor when compared to changes in infant and child mortality. At the same time, in Chile, Costa Rica, Cuba, Guatemala, Mexico, Panama, and Peru, adult mortality was reduced by more than 50 percent over the interval 1960–2000. The only increase in mortality in Latin America during the period is registered for adult mortality in Haiti, which rose from 401 per 1,000 adults to 449.

Overall, the idea that reductions in infant and child mortality were virtually the only causes of life expectancy gains in developing countries is mistaken. Typically, mortality reductions took place across the entire age range, with significant improvements in the survival of both children and adults. Undoubtedly, the extent of reduction in early mortality was substantial, and its final effect on life expectancy was almost always higher than that of changes in mortality in any other age group (see Table 4, for example). But, at the same time, the probability of surviving from age 15 to age 60 increased between 10 and 45 percentage points across most of the developing world.

The analogy with the evidence from developed countries suggests that, in the period following World War II, the developing world was in transition between the first and second phases of the epidemiological transition. This corresponds to large reductions in mortality from infectious diseases at early ages, as well as significant gains in life expectancy from other causes of death at later ages. The source and extent of the reductions in infant and child mortality in this period are very similar to the changes observed in the United States during the first half of the twentieth century. In that case, reductions in mortality were driven mainly by preventive public health interventions related to the provision of clean water (Cutler and Meara 2001; Cutler and Miller 2005). But this was a consequence of the fact that, for most infectious diseases, alternative technologies—such as immunization and treatment (antibiotics)—were not yet widely available. In the case of developing countries in the postwar period, these technologies were already available and, in some cases, were actively subsidized or even directly implemented by international organizations (as in the example of the Expanded Program on Immunization discussed above). Some international programs also provided aid for implementation of clean water systems. It is likely that a mixture of prevention and treatment—identified as important in the first (1900–40) and second (1940–60) phases of the US health transition—played key roles in the changes observed in developing countries between 1960 and 2000.

Tables 6 and 7 present measures of health expenditures, infrastructure, and inputs by region.[10] Shortcomings related to data quality are potentially serious in the case of immunization coverage and hospital and physician availability. For number of physicians per capita and hospital beds, definitions may vary substantially across countries and sources. The effort to develop a comparable set of measures to evaluate the performance of health systems across countries and regions is relatively new, and this fact is reflected in the quality of the statistics currently available (Mathers et al. 2003a).[11]

Table 6 shows that private expenditures on health in developing regions have increased, on average, on par with income, so that the GDP percentage has remained roughly stable (except in East Asia and the Pacific and, to a lesser extent, in Europe). Public expenditures have shown a modest positive increase, leading to an increase in total expenditures on health between 0.5 percent and 1.3 percent of GDP between 1990 and 2000. As fractions of GDP, these levels are well below those observed in the developed world, and quantitatively correspond to very low values (below $300, as measured in 1996 international prices). Therefore, increases in expenditure do not seem to be the dominant mediating cause of the changes in mortality rates.

The number of hospital beds per head also does not seem to be an important factor. The table shows that, if anything, the number of hospital beds per inhabitant has been decreasing in most regions of the world. This reduction probably reflects the advent of new health technologies resulting in shorter hospital stays, rather than a deterioration in the provision of medical services. The physically limiting aspect of many chronic conditions and the recovery period after surgical intervention may have been significantly

TABLE 6 Health expenditures and infrastructure, world regions, 1990 and 2000

	Health expenditure (% of GDP)				Hospital beds (per 1,000 people)		Access to (% of population)			
	Private		Public				Improved sanitation		Treated water	
Region	1990	2000	1990	2000	1960	1995	1990	2000	1990	2000
Europe and Central Asia	1.3	1.9	4.7	4.8	8.4	8.4	96	93	93	93
East Asia and Pacific	1.5	2.8	2.0	2.0	3.9	3.3	36	47	72	77
Latin Am. and Carib.	3.5	3.5	2.4	3.4	3.4	2.4	72	77	82	86
Middle East and North Africa	2.3	2.3	1.9	2.5	1.9	1.9	74	85	86	88
North America	6.9	6.8	5.3	5.8	8.9	4.2	100	100	100	100
South Asia	3.3	3.7	0.9	1.0	0.5	0.5	22	34	72	84
Sub-Saharan Africa	2.1	2.4	1.5	1.8	1.4	0.7	54	53	53	58

SOURCE: World Bank (2005).

reduced by the availability of new drugs, and, in some cases, the prevalence of such conditions may have been reduced because of other technological innovations. In addition, the number of painful or fatal diseases for which no treatment was available and hospitalization was the only alternative may also have decreased. Therefore, technological innovation is likely to have shifted medical interventions away from continuous medical supervision in hospitals and toward more focused and technologically intensive care.

The factors in Table 6 that seem potentially critical in explaining the gains in health in developing countries are access to improved sanitation and to treated water. Access to both of these services has increased between 5 and 12 percentage points in East Asia and the Pacific, Middle East and North Africa, Latin America and the Caribbean, and South Asia, between 1990 and 2000. These changes encompass more than 5 percent of the population in the regions in a period of only ten years. Although data are not available, it is not difficult to imagine that gains along these dimensions of health inputs must have been significant between 1960 and 1990 and that they may have played an important role in the mortality reductions in the period. Casual observation supports this view. For example, the extreme outlier in terms of life expectancy in Latin America (Haiti) is also an extreme outlier in terms of access to improved sanitation and treated water. In addition, some of the countries in the same region that experienced very large life expectancy gains with very little economic growth—such as Bolivia, Honduras, and Nicaragua—also had significant improvements in the public provision of these services. This evidence suggests that factors playing a role in the first stages of mortality reductions in the United States were also important in the recent experience of developing countries.

Evidence suggests that other factors may also have been relevant. These are technologies related to widespread immunization, which were not available during the first half of the twentieth century and, therefore, could not have been responsible for the early mortality reductions in developed countries. The first set of columns in Table 7 presents data on immunization rates for DPT and measles between 1980 and 2000, measured as the percentage of children below one year of age receiving the vaccine. In this 20-year period, average immunization rates in East Asia and the Pacific, Middle East and North Africa, and Latin America and the Caribbean jumped from levels around 40 percent to close to 90 percent. South Asia and sub-Saharan Africa also realized significant improvements along these dimension, though at a much slower pace than other regions. Even accounting for the bias discussed by Murray et al. (2003), these numbers still imply an increase of near 100 percent in immunization rates. In several countries, at least one of the immunization rates increased by more than 50 percentage points in this 20-year interval. As of 2000, the averages observed in these developing regions were close to those observed in the developed world. Again, despite the unavail-

TABLE 7 Inputs and other indicators of child health, world regions, 1980 and 2000

	Immunization (% of children < 1 year)				Low-birth-weight babies (% of births)		Malnutrition prevalence (% children under 5 yrs.)	
	DPT		Measles					
Region	1980	2000	1980	2000	1980	1995	1985	1995
Europe and Central Asia	77	94	54	90	5.9	7.0	—	17.4
East Asia and Pacific	38	85	34	86	11.8	10.8	42.5	31.0
Latin Am. and Carib.	43	87	47	92	8.0	9.3	24.7	18.5
Middle East and North Africa	39	91	34	93	7.1	12.0	21.2	22.3
North America	96	95	93	92	6.6	7.2	—	2.0
South Asia	8	61	2	56	22.4	31.2	60.1	49.9
Sub-Saharan Africa	17	52	24	56	16.7	13.3	29.1	36.8

SOURCE: World Bank (2005).

ability of data, it is not difficult to imagine that similar improvements occurred between 1960 and 1980.

The fact that the United Nations Expanded Program on Immunization was established only in 1974 suggests that this view is probably accurate. This program subsidized large-scale immunization against several diseases and transferred immunization technologies to developing countries. The choice of target diseases itself had the explicit goal of maximizing impact, giving priority to diseases that had a high burden and for which well-tried vaccines were available at low cost (World Health Organization 2003; World Bank 2003). In the Americas, the Pan American Health Organization created the "Revolving Fund for Vaccine Procurement," which subsidized the purchase of vaccines by member countries, leading to savings that in some cases amounted to 80 percent of the price of vaccines (de Quadros et al. 1998).

Casual observation also suggests that immunization is a potentially important factor in explaining mortality reductions between 1960 and 2000. Again, the country with exceptionally poor performance in terms of life expectancy in Latin America and the Caribbean (Haiti) also lags far behind the rest of the region in immunization rates. And countries experiencing exceptional gains in life expectancy without significant improvements in income also experienced large increases in immunization rates (for Bolivia, Honduras, and Nicaragua immunization rates for both DPT and measles increased by at least 57 percentage points in only 20 years).

Widespread immunization is likely to play a particularly large role in the reduction of child mortality. But, in principle, reductions in child mortality may also have other determinants, such as improved nutrition of children and mothers. Table 7 shows that this is not likely to be the case. Although the prevalence of malnutrition for children under five years declined in East Asia and the Pacific, South Asia, and, more moderately, in Latin America and the Caribbean, it increased slightly in the Middle East and North Africa and in sub-Saharan Africa. During this period, the Middle East and North Africa experienced spectacular reductions in child mortality, with the mortality rate under age five dropping from 252 per 1,000 live births in 1960 to 50 in 2000. Countries in other regions had similar experiences. For example, in Nicaragua and Honduras, where under-five mortality was reduced from around 200 to 40 per 1,000 births, the prevalence of malnutrition actually increased. Other dimensions related to nutrition within the family also do not seem to be particularly relevant during this period. To the extent that these factors are reflected in a child's birth weight, the data show no consistent improvement. The percentage of low-birth-weight babies remained stable or increased slightly in most world regions between 1980 and 1995. This probably reflects improvements in medical sciences in dealing with problem pregnancies, and these improvements are reflected in a higher percentage of fragile babies surviving birth. This, however, implies a compositional change in the pool of children surviving birth that, if anything, would imply increased mortality in the first years of life.

The aggregate evidence suggests that, apart from income, two factors—large-scale immunizations and improved public health infrastructure—are strong candidates for being the determinants of the life expectancy gains observed in developing countries since World War II. I now consider the limited statistical evidence regarding the role of these factors, as well as the role of technological diffusion, in determining postwar reductions in mortality.

Cross-country correlates

Recent econometric attempts to identify the determinants of cross-country mortality changes draw heavily on the aforementioned literature on international diffusion of productive technologies. Maybe because of immediate data availability, the majority of econometric studies have focused on the transfer of technology through imports of goods. Jamison et al. (2001), Owen and Wu (forthcoming), and Papageorgiou et al. (forthcoming) find that imports and, more generally, openness to trade are associated with faster reductions in mortality. These authors develop arguments along the lines of the literature on diffusion of productive technologies, but they are not always able to deal convincingly with issues of endogeneity and identification, thus leaving open the possibility that trade variables are actually capturing the effects of other policies or unobservable variables.[12] Owen and Wu (forthcoming), in particular, find a strong positive correlation between trade and decreasing mortality for developing countries, while the correlation is virtually zero for rich countries. Given the arguments advanced above, it is not clear that this should be the case. Owen and Wu also present evidence on other critical factors: higher rates of immunization (DPT and measles), higher amounts of aid per capita targeted to water improvement, and higher female schooling are all systematically associated with lower mortality.

With respect to the effect of trade itself, Jamison et al. (2001) observe that, when the analysis does not control for openness to trade, countries with difficult access to the outside world (landlocked) and countries in tropical areas are found to experience smaller improvements in life expectancy. To the extent that these variables are related to access to trade and to the adaptability of imported technologies for local production of health, the results are more credible. If trade indeed captures the incorporation of technologies produced in developed areas, countries with difficult access to trade or with different environments should benefit less from new technologies.

Somewhat more convincing results related to trade are reached by Papageorgiou et al. (forthcoming), who measure the relevance of imports in a more sophisticated way. They focus on medical imports originating from the ten countries responsible for the bulk of medical research and development worldwide. In a series of specifications, they find these imports to be systematically related to lower mortality. They also find that female schooling, calorie intake, and physician availability are significantly correlated with the cross-country variation in mortality.

The relevance of medical technologies, specifically new drugs, is supported by Lichtenberg (2003). In a sample of 50 upper-middle-income developing and developed countries, he shows that the launch of new drugs between 1986 and 2000 had a strong positive impact on the probability of survival. He claims that these new drugs were responsible for 40 percent of the gains in life expectancy observed in the sample during the period.

Schultz (1993) analyzes the role of other determinants of mortality between 1972 and 1988 across countries. He finds that calorie consumption and maternal education were most closely related to mortality, with number of physicians, supply of water, and sanitation not statistically significant. His results related to female education are in line with those found by Owen and Wu (forthcoming), but other results related to public health infrastructure and access to health facilities are inconsistent with some of the later evidence. In any case, endogeneity and omitted variables remain open issues in most of the cross-country literature and no study has dealt convincingly with all of their implications.

The evidence discussed above indicates that new technologies incorporated in medical equipment and drugs are important determinants of gains in life expectancy. But these dimensions are likely to be relatively less critical for poor developing countries, where reductions in mortality have been observed even with very low expenditures directly targeted to health consumption. The cross-country evidence offers preliminary indications that other factors, such as schooling and provision of public health goods, may also be relevant. To shed further light on the role played by these factors, the next section discusses the micro-level evidence from developing countries. This evidence also allows us to uncover the role of country-specific interventions and community-level programs for which aggregate data are not available.

Micro-evidence from developing countries

Most of the demographic literature on within-country variations in mortality concentrates on the analysis of infant and child mortality, for which demographic techniques based on retrospective surveys on number of children ever born and number of children alive give fairly accurate estimates. Two major strands of research can be identified: the first one analyzes the impact of particular interventions, events, or health programs; the second looks at correlates of within-country variations in mortality. In this section, I selectively review some results from both strands of research.

On the evaluation of particular health interventions, Gray (1974) examines the contribution of malaria control to the postwar mortality decline observed in Ceylon (now Sri Lanka). Starting in 1945, commercial supplies of DDT became available and more effective control of malaria in Ceylon began. This led to elimination of the previous mortality differential between endemic and nonendemic areas, and to a rapid decline in national mortality rates. According to Gray's estimates, malaria control contributed 23 percent of the observed reduction in the crude death rate during the postwar period (up to 1960). In the initial control period (1946–50), malaria elimination contributed roughly 33 percent of the total mortality decline (particularly relevant for children below age 5 and adults above 45). Gray mentions similar results obtained in studies of malaria control in Guyana, Guatemala, Mexico, Venezuela, and Mauritius. Nevertheless, Langford (1996) argues that the numbers relating to Ceylon are likely to be overestimated, and suggests that DDT alone was probably responsible for no more than 16 percent of the reduction in mortality in the postwar period. He points to the fact that other anti-malaria measures and improvements in public health were both introduced before the 1940s and are likely to have played a role in the mortality reductions observed immediately after the war.

Chen et al. (1983) analyze the effect of family planning programs, tetanus vaccine, and oral rehydration therapy. They look at data from the International Centre for Diarrhoeal Disease Research (Matlab Thana, Bangladesh) collected between 1966 and 1981. During this period, several changes were introduced in the services provided to the target population. In some cases, randomized double-blind trials were implemented. The results indicate that tetanus vaccine given to pregnant women reduced newborn 4–14-day mortality by 68 percent. Other therapies also appeared to be important in reducing mortality, with a broad program of family planning being responsible for a 25 percent reduction in the crude death rate (half the decline in the period), and oral rehydration therapy for another 9 percent.

Macinko et al. (2006) use state-level panel data from Brazil (1990–2002) to evaluate the impact of a family health program on mortality. The program was largely based on preventive care, but evidence shows that inclusion of family health in the program also affected rates of breastfeeding and immunization, and improved maternal management of diarrhea and respiratory infections. The program was particularly effective in reducing deaths attributable to diarrhea.

Díaz-Briquets (1981) describes the evolution of mortality in Cuba (mainly Havana) between 1899 and 1953, when the country was subject to considerable American influence. Following the Spanish–American war, Cuba was occupied by the United States for four years (1898–1902). After emancipation, the Platt Amendment (1903) gave the US government authorization to intervene in Cuba's internal affairs if certain conditions—such as sanitary improvements—were not met. American occupation led to a series of sanitary reforms, bringing about the virtual elimination of yellow fever from the country (following the first verification of the mosquito theory of transmission) and reductions in mortality from tuberculosis and other infectious and parasitic diseases. Reduction in tuberculosis mortality seems to have been associated initially with improvements in economic conditions and nutrition and, after the 1940s, with the introduction of antibiotics. Other infectious and parasitic diseases were directly affected by sanitary and public health measures: diphtheria mortality was reduced by the use of antitoxin (freely distributed by national sanitation authorities); malaria by anti-mosquito campaigns; and diarrhea, gastritis, and enteritis by extensive sanitary reforms in Havana (improved and more abundant water supply and public health efforts to teach proper infant care, accompanied by increases in literacy rates). Mortality due to influenza, pneumonia, and bronchitis was reduced only after 1931, and mainly after 1943, at least partly owing to the use of modern drugs. McGuire and Frankel (2005), although recognizing the importance of education, urbanization, and targeted health programs, point out that improvements in these areas occurred well before 1945, whereas significant gains in life expectancy in Cuba were observed only thereafter. The authors argue therefore that the role of widespread access to health care (due to a large supply of doctors, the small size of the island, and access to services by the urban poor) should not be underestimated.

The roles of education, sanitation, and access to water and medical services are also stressed in several within-country studies on child mortality. Haines and Avery (1982) analyze the experience of Costa Rica between 1940 and 1970 to disentangle the effects of education, income, sanitation, housing, and medical services. They find that medical care (proportion of births having medical attention) had a substantial impact on child mortality independent of other variables. Mother's education, fertility, and sanitation appeared as important factors associated with mortality reductions over time. Overall, development (as related to income per capita, literacy, and calorie consumption) accounted for 50 percent of the mortality decline in Costa Rica between 1940 and 1970. McGuire (2001) shows that mortality decline continued in Costa Rica even after 1970 and argues that factors similar to those highlighted by Haines and Avery also played a critical role in this later experience. Similarly, Haines et al. (1983) use national samples of censuses from Guatemala (1959–73) to show that women's education and sanitation were the key factors determining child mortality differences. Alves and Belluzzo (2004) find that education and sanitation were the principal determinants of reductions in child mortality in Brazil between 1970 and 2000, a period during which substantial declines in child mortality occurred.

Using micro-level data from Malaysia between 1946 and 1975, DaVanzo and Habicht (1986) find that mother's education and piped water were the factors most closely associated with improvements in infant mortality, while sanitation was also marginally relevant. Another important determinant of infant mortality in Malaysia was breastfeeding, which seemed to reduce the negative effect of lack of access to treated water. Merrick (1985) and Macinko et al. (2006) find similar evidence for Brazil. Merrick (1985) uses census and household survey data between 1970 and 1976 to determine the effects of an extensive effort by the Brazilian government in the early 1970s to improve urban water supply and sanitation. He finds that parents' education and access to piped water were most closely related to child mortality in both 1970 and 1976. Access to piped water explained about 20 percent of the regional differentials in child mortality. Macinko et al. (2006), in their evaluation of the family health program described above, also show that access to water and female literacy were closely related to reduction in mortality.

Jain (1985), analyzing data for 1973–78 in rural India, shows that, together with mother's literacy, type of birth attendant and triple vaccination were closely related to regional variations in child mortality. Breaking down child mortality in different periods of the child's life, he shows that level of poverty and medical care received at birth were particularly crucial for neonatal mortality, while availability of medical facilities in the village and the extent of triple vaccination during infancy were most important for post-neonatal mortality.

Caldwell (1986) analyzes three exceptional declines in mortality—Kerala (India 1956–66), Sri Lanka (1946–53), and Costa Rica (1970–80)—and argues that these experiences were also exceptional in their social and political environments, and in the effectiveness of government inputs in the areas of education, health services, and nutrition. He highlights the role of cultural factors—female autonomy, intrinsic value attached to education, open political system (competition), large civil society without rigid class structure, and national consensus on policies—as important in facilitating the adoption of new health inputs and the absorption of new technologies. In this interpretation, education and a demanding public were key factors in the implementation and success of interventions. As other evidence has shown, results in these three settings did not depend on the use of particularly expensive technologies.

In Sri Lanka, cholera was contained starting in the 1870s through quarantine measures (for arrivals from India) and later construction of a piped water system, while neonatal tetanus was reduced by the reliance on midwives during childbirth. Starting in 1910, successful campaigns against diarrhea, respiratory infections, and hookworm (supported by the Rockefeller Foundation) promoted public health measures, sanitation, and personal hygiene. Other important events included the malaria campaign started immediately after World War II (which led to near eradication through the use of DDT spraying) and the popularization of penicillin and sulfa drugs. Health expenditures over this period never exceeded 1.5 percent of GDP, despite a major enhancement in public health infrastructure and programs (ibid.).

The mortality breakthrough in Kerala took place between 1956 and 1966. During this period, deaths from cholera and smallpox, which accounted for 17 percent of all deaths at the end of the nineteenth century, were drastically reduced. After World War II, these causes of death never again accounted for more than 3 percent of all deaths. Extension of public health programs and immunization through provision of community-level services seem to have been the immediate causes of much of the mortality reduction. Similarly, Costa Rica increased expenditure on health services, leading to a breakthrough period between 1970 and 1980. As in Kerala, easy access and community-level services—coupled with immunization campaigns—were very important in reducing infant and child mortality (ibid.).

Riley (2005b) describes the exceptional reduction of mortality in Jamaica, which attained life expectancy above 75 years in 2000, and compares that experience to the three cases analyzed by Caldwell (1986). He argues that in Jamaica, as in Kerala, Sri Lanka, and Costa Rica, women have historically been more independent (although for different reasons), public schooling developed early, and there was a tradition of open discussion of political and social issues. On the other hand, widespread corruption and organized crime in Jamaica have greatly undermined the institutional effects of political freedom. Also, substantial government investments in health and widespread use of the school system to deliver public health education to the population—both dating back to British colonial times—seem to have been particularly important. School teachers were trained to be health educators, instructing people how to recognize and protect themselves against specific diseases and vectors. Riley concludes that reductions in mortality in Jamaica up to the end of the twentieth century were driven mostly by improvements in public health, individual behavior, and schooling.

The evidence from within-country mortality studies is diverse in nature, focus, and methodology. Nevertheless, it addresses some concerns raised in the demographic literature and reveals some surprisingly consistent results.

First, the evidence indicates that interventions targeted at particular diseases have shown substantial and sustained success in reducing mortality. Therefore, concerns that narrow approaches focused on specific technologies end up simply increasing mortality from competing causes of death do not seem to be empirically relevant. Hill and Pebley (1989) discuss evidence from malaria and measles eradication programs in Guyana, Kenya, Sri Lanka, Tanzania, and Zaire that suggests exactly the opposite: in the implementation of targeted programs, reductions in mortality seem to be systematically larger than the direct reductions in cause-specific mortality that were the initial goal. There seem to be synergistic benefits: reductions in mortality from one cause of death lead to reduced mortality from other causes. The evidence also supports the idea that family health programs, implemented at the community level, can be very effective in reducing mortality. This was the case with successful programs implemented in Bangladesh and Brazil, and also to a degree in Jamaica. Thus, in general, there is no need for an a priori choice between disease-specific interventions and broad interventions focused on health practices and the cultural context within the community or family. Both strategies are potentially effective in reducing mortality.

Second, in relation to relative contributions of different factors, overwhelming evidence points to the importance of education, particularly mother's education, in determining infant and child mortality. The association between these variables reflects an income effect on health, but studies controlling for socioeconomic status still find robust correlations between mother's education and child mortality. This relationship is not yet well understood. Haines and Avery (1982) and Haines et al. (1983) hypothesize that better-educated mothers may seek medical care more actively; may be more aware of sanitary precautions, nutritional information, and health services; and may be better able to recognize serious child health conditions. Jain (1985) shows that mother's literacy improves the type of medical care used during birth and the use of preventive and curative measures during the post-neonatal period. Other authors view the effect of schooling as being one of modernization and indoctrination of the target population (Caldwell 1986; Riley 2005b). According to this interpretation, schooling would familiarize the population with Western values and institutions, reducing people's reluctance to seek medical attention or use modern medicines. Hobcraft (1993), reviewing evidence on the channels through which maternal education affects child mortality, shows that educated mothers are better informed about and more likely to use medical facilities and other health technologies, are more likely to have their children immunized and to have received prenatal care, and are more likely to have their deliveries attended by trained personnel. He identifies several channels linking mother's education to child mortality but is unable to quantify the relative importance of each. The channels include greater cleanliness among better-educated women, increased use of health services, greater emphasis on child quality, and enhanced female empowerment (including an increased feeling of control over the outside world, closer identification with modern institutions, greater self-confidence, and increased bargaining power within the family).

The role of access to clean water and sanitation suggested by the aggregate data is also supported by the micro-evidence. Different micro-studies tend to emphasize one of these dimensions and, given the high degree of correlation between the two, have rarely been able to identify their independent effects. But numerous studies cited above identify a significant correlation between either sanitation (Haines and Avery 1982; Haines et al. 1983; Alves and Belluzzo 2004) or access to clean water (DaVanzo and Habicht 1986; Merrick 1985; Macinko et al. 2006) and mortality. Also, anecdotal evidence from Cuba and Kerala confirms the importance of infrastructural factors in triggering mortality reduction.

Conclusion: Understanding mortality changes across and within countries

Bringing together the evidence on the increase in life expectancy across countries and on the correlates of mortality decline within countries can help us understand the determinants of mortality improvements and their implications for the reduction of health inequality. If we consider the recent process of global health improvement as one of discoveries, diffusion, and absorption of new ideas, technologies, and practices, this process will be mirrored by changes in the distribution of health outcomes across and within countries, according to the nature of the new technologies and their gradual transmission throughout the world.

Studies based on micro data, by revealing the within-country pattern of mortality inequality and its change over time, shed light on the nature of the technological changes driving the reduction in mortality. In this respect, Haines et al. (1983) notice that mortality differentials (e.g., urban–rural, by educational level) increased in Guatemala while mortality was reduced. In addition, the interaction of different dimensions seemed to enhance inequality, so that educational level tended to be more advantageous in the capital city than elsewhere. Along the same lines, DaVanzo and Habitch (1986) find that the effect of mother's education on infant mortality in Malaysia increased through time, while the influence of water and sanitation became less important. They also find evidence that the effect of mother's education was particularly strong in more developed areas.

Historical evidence from the United States also suggests that the educational gradient of mortality has increased over time (Preston and Haines 1991). At the end of the nineteenth century, just before the germ theory of disease became widely accepted and applied, mortality differentials in the United States across occupations or social classes were rather small. Professional and literate people had a minor advantage when compared to the rest of the population, and even children of doctors faced mortality rates that were only 6 percent below the national average. By 1925, children of teachers and doctors had mortality rates corresponding to only 65 percent of the average, suggesting that progress and scientific knowledge tended to increase health inequalities along educational lines. Consistent with this pattern, countries today at a development level comparable to that of the United States in 1900 typically have higher life expectancies and steeper mortality–education gradients than did the United States at that time.

But results related to the effect of development on health inequality are not robust across different studies. Haines and Avery (1982), for example, find that education and urban residence were associated with lower mortality in Costa Rica, but the educational gradient was higher in rural than urban areas, and the urban mortality advantage disappeared for high levels of education. They also find that the response of mortality to education was higher among women with low education and tended to disappear as educational level increased. Merrick (1985) finds similar evidence for Brazil. He shows that improved and increased water supply attenuated mortality differentials associated with education and income. Macinko et al. (2006), also for Brazil, show that female literacy and access to water were particularly important determinants of mortality in the poorer regions of the country and that the effect of family health programs tended to be three times larger in these same regions than in the country as a whole.

Still, a large body of evidence indicates that within-country mortality inequality may increase as average mortality is reduced. For the United States, Britain, and Western Europe, evidence suggests that health inequalities increased in recent years (Glied and Lleras-Muney 2003). For developing countries, in addition to the cases of Guatemala and Malaysia mentioned above, Minujin and Delamonica (2004) look at Demographic and Health Surveys from 18 developing countries and show that inequality in under-five mortality seems to have increased during the 1990s in at least eight of them (Bangladesh, Colombia, Dominican Republic, Indonesia, Kazakhstan, Philippines, Uganda, and Zimbabwe).

Caldwell (1986) hypothesizes that development and technology might increase the educational gradient of mortality, but his argument—as well as that of more recent studies—seems to hinge on an implicit assumption about the nature of the technology being considered. Technologies related to individual-level inputs in the production of health seem to be subject to the effectiveness with which individuals can use the inputs. Evidence indicates that better-educated individuals have higher survival advantage in diseases for which medical progress has been particularly important, and this advantage is greater for recent technologies (Glied and Lleras-Muney 2003). Better-educated individuals are also more likely to use recently developed drugs, above all in situations where individuals repeatedly purchase the same drug, suggesting that education increases the capacity of individuals to learn from experience (Lleras-Muney and Lichtenberg, forthcoming). Studies on the AIDS epidemic in Africa suggest that schooling is closely related to the adoption of protective behaviors, such as use of condom, recourse to counseling and testing, and discussion among spouses; educated individuals are evidently more responsive to information campaigns (de Walque 2004, 2006). New technologies associated with individual actions can therefore offer an advantage to the more educated if they are better able to comprehend and adopt the technology. In these cases, diffusion of new technology might increase mortality inequality within countries.

On the other hand, technology adoption is sometimes incorporated within public goods. In these cases, provision of a new technology (as with clean air and water) may affect particular outcomes independently of individual actions, and may reduce the relevance of personal behavior in determining health outcomes. The evidence presented on malaria control in Ceylon, family health programs in Brazil, and access to urban public health infrastructure in Costa Rica, Malaysia, and Brazil indicates that all these "technologies" seem to reduce the salience of individual behavior—and, therefore, of individual characteristics—in determining health outcomes. In these cases, one would expect introduction of new technologies to be associated with reduced health inequality within countries.

Therefore, contrary to the case of cross-country mortality, it is difficult to specify unequivocally the effect of recent technological diffusion on within-country inequality in health and mortality. It seems to depend on two dimensions: the character of the technology (private versus public) and its degree of diffusion. Diffusion of new private technologies to relatively small portions of the population is likely to lead to increasing inequality, as relatively better-educated and well-off people benefit disproportionately. With time, as use of the private technology becomes widespread throughout the population, inequality in health starts to decline. This sequence of events mimics the process of international diffusion of medical technologies and reproduces its impact on the dynamics of inequality.

With public technologies, however, as long as the population of a certain area can universally benefit from the public good, the effect should reduce mortality irrespective of individual characteristics and in some cases even reduce the effect of specific individual traits (such as education) on mortality. Still, adoption of public good technologies also varies within a country, and the timing of adoption may depend on the political influence of different groups. In this case, the effect of a new technology on inequality would also depend on its degree of penetration. Although introduction of clean water distribution systems may reduce health inequality between the wealthy and poor within a single city, it may increase inequality across different cities in the same country, as long as cities benefiting from the new system are initially better off.

The long-term evolution of life expectancy inequality across countries is closely linked to this same pattern of technological innovation and diffusion. Despite the almost monotonic trend toward reduced inequality after World War II, history has not always been uniform. Bourguignon and Morrisson (2002), for example, show that inequality in life expectancy across countries increased consistently between 1820 and 1930, then started falling. Vallin and Meslé (2004) suggest that the notion of an epidemiological transition, characterized by a fixed sequence of events, is inadequate for understanding the improvements in life expectancy observed across countries in the last 200 years. They suggest that the evolution of life expectancy across countries, and therefore the evolution of life expectancy inequality, are driven by new knowledge and by the gradual absorption of this new knowledge by different societies. Typically, as new knowledge emerges and some countries take advantage of the technologies developed as a result, health inequality increases, reflecting the differential access to the new benefits across countries. If the technology becomes accessible to a large number of countries, its subsequent widespread diffusion eventually leads to reduced inequality. Absorption capacity across countries depends on the nature of the technology and on institutional aspects of the country—its infrastructure, provision of health public goods, and political responsiveness.

This paradigm is based on the dynamics of technological shocks and their international diffusion: speed and penetration depend on the type of technology and on the characteristics of different countries. Vallin and Meslé (2004) prefer the concept of "health transition" to Omran's "epidemiological transition." They identify three technological shocks that marked the dynamics of health inequality during the twentieth century: the conquest of mortality from infectious diseases, which Omran characterized as an epidemiological transition and which is still diffusing throughout the developing world; the cardiovascular revolution, which started in the mid-1960s and is still mostly restricted to the developed world; and progress against mortality at very old ages, which at present benefits only a handful of countries. Associated with each of these breakthroughs is an initial period of increasing inequality, as a few leading countries take advantage of the progress. If the technology spreads through other parts of the world, there follows a reduction in inequality. This sequence of events has almost come to completion with respect to infectious diseases, where the initial increase in international health inequality in the nineteenth century was followed by a reduction in inequality starting in the mid-twentieth century. With cardiovascular diseases, we are still observing increasing international inequality, as shown by the evidence presented in Becker, Philipson, and Soares (2005) and the discussion in Vallin and Meslé (2004). Finally, the advance against aging is still at the initial stages, with a very few leading countries taking advantage of the new technologies (Vallin and Meslé 2004).

Based on the evidence discussed above, the effect of these waves of technological diffusion on mortality reduction and on inequality within countries depends on the nature of the technologies and on the within-country pattern of geographical diffusion. But it is not difficult to imagine that patterns similar to those observed across countries would emerge across different regions of the same country, as more developed areas are better able to take advantage of certain types of technological improvements. At the same time, broad health projects—taking place at the national level—would probably lead to more homogeneous reductions in mortality and to rapid reductions in overall health inequality. Still, the recent waves of technological advance—related to cardiovascular diseases and aging—seem to be more closely related to private health technologies than were the breakthroughs in the fight against infectious diseases. Reductions in mortality from cardiovascular diseases require radical changes in personal behavior and expensive medical intervention. These technologies seem to have much less of a public goods component than the early technologies associated with reductions in mortality from infectious diseases. Therefore, once the conquest of mortality from infectious diseases is complete in most of the developing world, diffusion of the second and third waves of the health transition may be accompanied by a long period of rising inequality in life expectancy, both within and between countries.

Notes

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1 Both of these trends have been noticed before in the literature. In relation to income, see, for example, Barro and Sala-i-Martin (1995), de la Fuente (1997), Mankiw, Romer, and Weil (1992), Quah (1996), Parente and Prescott (1993), and Sala-i-Martin (2002). In relation to life expectancy, see Bourguignon and Morrisson (2002), Goesling and Firebaugh (2004), Neumayer (2003), Sap and Smith (2002), Younger (2001), and Kenny (2005).

2 Ezzati et al. (2003), for example, estimate that 25 percent of all deaths in sub-Saharan Africa are caused by conditions (respiratory infections, diarrheal diseases, low birth weight, and malaria) for which effective interventions already exist, with an additional 9 percent of deaths attributable to AIDS.

3 The basic profile of the shift in these curves does not depend on the functional forms adopted. Logarithmic curves would lead to qualitatively similar results.

4 As discussed by Mosley (1984), infection can hinder absorption of nutrients, being under certain circumstances a cause rather than a consequence of malnutrition. Obviously, the interaction between these two dimensions is complex, with each one reinforcing the other.

5 Today, the sequence of events described by Omran (1971) is not regarded as fixed, but rather as a consequence of technological advances taking place at different points in time. Nevertheless, because it gives an accurate description of events in the historical experiences of mortality reduction discussed in this section, I retain Omran’s definition for now and save discussion of its merits for later in this article.

6 In addition to specific medical innovations, reductions in adult mortality can be also caused by previous reductions in

child mortality and morbidity. For example, heart problems in adulthood may be associated with childhood rheumatic fever. In this sense, part of the reductions in adult mortality observed during the later stages of the epidemiological transition may simply be dynamic implications of early improvements in child health.

7 Mokyr (1998) discusses the process of advances in knowledge in medical sciences and the technological innovations induced by it. Elsewhere, Mokyr (2000) analyzes final acceptance of the germ theory at the end of the nineteenth century, and the implications it had for changes in personal and public health practices. He points out that the beginning of the health revolution, related to the early recognition of "cleanliness" as a way to prevent diseases, dates back to the empirically based sanitary and hygienic movement from the early nineteenth century, well before the advent of the germ theory.

8 The mortality data are from the World Bank's *World Development Indicators*. Health-related data presented in the *World Development Indicators* are from the United Nations Statistics Division's *Population and Vital Statistics Report*, from national statistical offices, from the Demographic and Health Surveys, and from UNICEF. A word of caution is called for here. Although most of the primary vital statistics used in these calculations come from national civil registration systems, the degree of coverage and information detail of the systems vary from country to country. When these statistics are not available or are incomplete, periodic surveys, projections, and censuses are used to complement the data (United Nations 2005). Most importantly, detailed age-specific mortality rates are frequently not available, and indirect estimates based on auxiliary data or demographic models are often used. This is not a major concern in relation to child and infant mortality, for which estimation based on survey data on number of children ever born and number of children alive gives quite accurate estimates (Brass 1975), but it can be a problem for mortality at older ages. In these cases, absence of data is usually overcome by the use of model life tables.

Model life tables allow the estimation of mortality rates at adult and old ages based on the observation of a few age-specific mortality rates and on the classification of a given population within a specific "family" of model life tables (United Nations 1983). Although the use of indirect data in the comparison and analysis of mortality changes has been strongly criticized by some researchers (Musgrove 2003), others have argued that it is an integral part of the process of evolution in the measurement of health systems performance, and it reflects the best use of the information and knowledge currently available (Bruntland et al. 2003). Public health researchers have also highlighted the importance of analyzing various dimensions of health performance, not only child and infant mortality, even if only with the limited existing information, in order to draw an adequate picture of the health status of different populations (Mathers et al. 2003a; Mathers et al. 2003b; Bruntland et al. 2003).

Even though the application of model life tables to estimate mortality rates at certain ages may lead to inaccurate measures for a particular country, I believe that the use of such model tables does not systematically bias the estimates and thus, on average, produces good descriptions of the mortality profiles observed in the world today. Keeping this limitation in mind, I consider the mortality estimates presented by the *World Development Indicators* as reasonable approximations to the average patterns of mortality observed in different world regions.

9 Adult mortality for Europe and Central Asia increased slightly between 1960 and 2000 owing to the presence of former Communist countries in the sample. In these countries, the collapse of the Soviet Union was associated with significant increases in adult and old-age mortality. If we look at western Europe alone, reductions in mortality during this period were also substantial between ages 15 and 60.

10 The data used in Tables 6 and 7 come from the *World Development Indicators*. The main source of the numbers from the *World Development Indicators* is the World Health Organization. Public expenditure data are supplemented by information from the Organisation for Economic Co-operation and Development, the International Monetary Fund, and the World Bank itself. Data on private expenditure in developing countries,

on the other hand, are drawn largely from household surveys conducted by governments and international organizations. Information on hospital beds also uses data from OECD, UNICEF's TransMONEE, and individual countries. Immunization data are supplemented by information from UNICEF and from the Demographic and Health Surveys (World Bank 2005).

11 For example, in the case of immunization, Murray et al. (2003) show that the cross-country correlation coefficient between officially reported rates and rates calculated from the Demographic and Health Surveys (DHS) is only 0.45 (for DPT3 coverage in 41 countries, between 1985 and 1998). And, even though the coefficient of a regression of the officially reported rate on the DHS rate is 1.02, the constant term is equal to 0.21, indicating that official rates overestimate coverage rates by, on average, 20 percent. Murray et al. also show that this relationship seems to be nonlinear, with countries with lower coverage having official and DHS rates more closely related than countries with high coverage (where the overestimation in official rates is larger). More seriously, there is no clear pattern to the association between official and DHS rates when changes over a five-year period are analyzed (regression coefficient of 0.21, with R^2 equal to 0.02).

12 "Good governments" may implement good economic and social policies. Good economic policies may lead to openness, while good social policies may lead to reductions in mortality. This would generate a correlation between openness and mortality in the data, even though there would be no causal relationship between the two variables.

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