

Disease Control Priorities Project

Working Paper No.21

February 6, 2004

Why Has Infant Mortality Decreased at Such Different Rates in Different Countries?

Dean T. Jamison
University of California, Los Angeles
U.S. National Institutes of Health

Martin E. Sandbu
Columbia University

Jia Wang
University of California, Los Angeles

Corresponding author:

Dean T. Jamison
Disease Control Priorities Project
U.S. National Institutes of Health
16 Center Drive, MSC 6705
Building 16, Room 206
Bethesda, MD 20892-6705
(301) 402-8654
jamisond@mail.nih.gov

The Disease Control Priorities Project is a joint effort of The World Bank, the Fogarty International Center of the National Institutes of Health, the Bill & Melinda Gates Foundation, and the World Health Organization.

CONTENTS

February 6, 2004

ABSTRACT.....	i
I. INTRODUCTION.....	1
II. THE IMPORTANCE OF HETEROGENEOUS TIME TRENDS.....	4
III. MODEL SPECIFICATIONS AND RESULTS.....	9
Selection of models.....	10
Making technical progress country-specific.....	11
Sources of cross-country variation in rates of technical progress.....	17
IV. EXPLAINING VARIATION IN IMR DECLINE.....	23
Decomposing IMR decline.....	24
Variation in country performance.....	24
V. CONCLUSION.....	29
Annex A: Description of Data.....	32
Annex B: Alternative Models.....	34
Annex C: Country-specific Estimates of IMR Change, of Sources of IMR Decline and of Performance.....	41
References.....	49

Why Has Infant Mortality Decreased at Such Different Rates in Different Countries?

ABSTRACT

Controlling for socioeconomic and geographic factors, infant mortality (IMR) has been declining at about 1.6% per year, a high rate of ‘technical progress’. This paper adduces theoretical and empirical reasons for rejecting the standard assumption of equal technical progress across countries. Allowing heterogeneity sharply reduces the income elasticity of IMR and points to differing rates of technical progress (or diffusion) as the principal source of the (large) cross-country variation in rate of IMR decline. The paper decomposes IMR decline into its sources for each country and generates estimates of country performance based on the country-specific component of technical progress.

WHY HAS INFANT MORTALITY DECREASED AT SUCH DIFFERENT RATES IN DIFFERENT COUNTRIES?

by

Dean T. Jamison, Martin E. Sandbu and Jia Wang*

“The rapidity with which the death rate has declined in most of the underdeveloped areas ... has been unprecedented. It has never been matched at any time in the now advanced countries ... it seems clear that the great reduction of mortality in underdeveloped areas since 1940 has been brought about mainly by the discovery of new methods of disease treatment applicable at reasonable cost [and] by the diffusion of these new methods ... The reduction could be rapid because it did not depend on general economic development or social modernization ... Though in the literature on public health there is still great lip service paid to the necessity of general economic improvement and community welfare in the control of disease, the truth is that many scourges can be stamped out with none of this...”

Kingsley Davis

American Economic Review (1956, pp. 306-07 and p. 314).

I. INTRODUCTION

The twentieth century differed dramatically from previous history in two critically important domains. First, the rapid economic growth that had begun in the 19th century in the countries of the North Atlantic diffused widely around the globe while continuing in the countries where it originated (Maddison, 1999; DeLong, 2000). Second, human mortality rates plummeted. Again, the changes began in the North Atlantic countries in the 19th century but remained modest until the 20th century, during which they both accelerated and spread to most of the world (Easterlin, 1996 and 1998). During this period life expectancies typically doubled—entailing major immediate improvements in human welfare, dramatic declines in fertility and, in consequence, transformations of the age structures of populations and of the economic environment.

* Jamison is with University of California, Los Angeles, and the Fogarty International Center of the U.S. National Institutes of Health; Sandbu is with the Earth Institute, Columbia University; and Wang is with the Center for the Study of Evaluation, UCLA. An earlier version of this paper was presented at the 2nd Meeting of the International Health Economics Association, Rotterdam (Jamison and Wang, June 1999). The authors wish to express their appreciation for valuable feedback received at that presentation, at presentations later at the World Bank, Harvard University, Johns Hopkins University, UCLA, the University of North Carolina, and at meetings of Working Group 1 of the WHO Commission on Macroeconomics and Health. We have also received helpful comments from George Alleyne, Alok Bhargava, David Bishai, David Bloom, David Canning, Daniel Cohen, Angus Deaton, Gary King, Mead Over, John Powles, Lant Pritchett and Jeffrey Sachs. Financial support for preparation of this paper was provided by WG-1/CMH, by the Fogarty International Center of the National Institutes of Health, and by the Disease Control Priorities Project.

Subsequent to Solow's (1957) assessment of the long-term determinants of income growth in the United States, investigators have generated a huge literature on both proximate and deeper-seated determinants of economic growth, and on the sources of its variation across countries. Perhaps because the magnitude and rapidity of the mortality transformation remain less widely known — or it is judged to be of a different order of significance — far less attention has been paid to its causes than to the determinants of income growth. Yet, arguably, the welfare significance of mortality change has indeed been of the same order as that of income growth, and understanding the sources of mortality decline is therefore correspondingly important.¹

Most analysts agree that advances in science and technology have underpinned the 20th century transformations of income and mortality levels. Models of economic growth rely heavily on technological progress (*i.e.* changes in total factor productivity) to account for economic change (Solow, 1957; Boskin and Lau, 2000; Easterly and Levine, 2000). Preston (1975, 1980) and Fuchs (1974) provided early quantitative assessments of the central importance of technical progress in accounting for 20th century increases in life expectancy, although the quote from Kingsley Davis at the outset of this paper points to an earlier, similar interpretation. While life expectancy and per capita income correlate across countries at any given time, with a particularly strong relation at low-income levels, Preston stressed how much average life expectancy has been increasing over time at any given level of income. Many middle-income countries today, for example, have per capita income levels close to what the United States had had around 1900. Yet in 1900 life expectancy in the U.S. was only about 49 years whereas in many middle-income countries today life expectancy exceeds 75 years and, indeed, is close to that of the U.S. More recent econometric work, on the other hand, assigns a less central role to technical progress in determining levels of health and suggests a greater explanatory power for income variation (for examples, see Pritchett and Summers, 1996, and Filmer and Pritchett, 1999).

¹ Easterlin (1996) and Crafts (2000) place an emphasis on mortality transformation that is comparable to their emphasis on economic growth in their retrospectives on the unprecedented changes in the human condition during the 20th century, whereas DeLong (2000), for example, places far more exclusive emphasis on the growth of income (and on the availability of altogether new material goods). When reasonable estimates of the dollar value of mortality reduction are added to the value of material output growth, however, 20 to 50 percent of the growth in total economic welfare has been attributed to mortality reductions for different countries in different eras. Usher (1973) provided the first such estimates; Mokyr and Stein (1997) provide estimates for high-income countries in the late 19th and early 20th century; Nordhaus (2003) provides recent estimates for the United States; and Jamison, Sachs and Wang (2001) provide recent estimates for selected African countries, including assessment of the impact of the HIV/AIDS epidemic.

Our purpose in this paper is to illuminate these issues with a closer exploration of the relationship between technical progress and mortality decline. We take the importance of science and technology as a given and assume that in some important sense most scientific and technical knowledge has become globally available². Countries may differ, though, in how close their health systems come to utilizing the technology available at any given time: the rate of adoption of new technologies may be country-specific. Previous research has either given little emphasis to technical progress — in part simply because much of the research is cross-sectional and therefore fails to address developments over time — or it has assumed the rate of technical progress or technology adoption to be constant across countries. Our analysis relaxes the assumption that technical progress is constant across countries and in this regard is built on earlier work by Jamison and Wang (1999). Oeppen (1999) independently applies models closely related to ours to assess (for a smaller group of countries over a much longer time frame) country-specific elasticities of mortality with respect to income levels and country-specific rates of technical progress (although he uses different terminology).³ In the context of modeling determinants of economic growth the work of Lee, Pesaran and Smith (1997) is closest in spirit to our current work in allowing not only for country-specific effects on income levels (fixed effects), but also for country-specific technical progress. This paper goes beyond previous work on mortality decline both in exploring the consequences of relaxing the assumption that the rate of technical progress (or diffusion) is constant across countries and in assessing some of the *determinants* of why the rate of technical progress varies. We view this exploration of potential determinants as suggestive and far from definitive but, that said, a number of factors do appear robustly related to the (very large) cross country differences in the rate of technical progress in mortality decline.⁴

The paper begins with a discussion of the importance of heterogeneity in rates of technical progress. This point established, it then provides generalizations of previous models by calculating country-specific estimates of the IMR elasticity with respect to income, education and time (or “technical progress”). To facilitate estimation of country-specific elasticities we replaced previously used OLS, fixed effects or random-effects models with hierarchical (or multilevel) models. To introduce the hierarchical modeling we start with closely related specifications using more standard methods on first differences. Allowing for cross-country heterogeneity in the rate of technical progress results in much weaker estimated effects of income on IMR than previously found, although education’s estimated effect is robust with respect to this specification change.

² Patent restrictions on products relevant to health do of course entail availability of patented commodities only at prices well above the marginal cost of production and distribution. With the recent (possible) exception of antiretroviral agents, patents are unimportant barriers for access to products capable of influencing major mortality decline.

³ Fuchs (1980) observed some time ago that different groups of countries differ in how their mortality changes relate both to income change and to technical progress. This paper can be viewed as drawing out the consequences of Fuchs’s observation at the level of countries rather than groups of countries.

⁴ In related work we have undertaken a parallel analysis of the determinants of country-specific variation in the rate of change of total factor productivity for explaining differences in economic growth rates across countries (Jamison, Lau and Wang, 2003).

We also find that much of the variation in country performance results from the very substantial cross-country variation in the rate of technical progress, from essentially no IMR decline due to technical progress to reductions of up to 5 percent per year from that source. However technical progress or diffusion may be manifested, the large differences in its magnitude across countries suggests that it must be embodied at the country level.

We then seek to identify potential determinants of technical progress by adding geographical and economic policy variables to income and education as predictors. (These variables were constructed at Harvard University's Center for International Development, where they have been used to generate improved models of the determinants of economic growth rates; see Sachs and Warner [1995] and Gallup, Sachs and Mellinger [1999].) Our results show strong and robust results concerning geography's effect on IMR (tropical areas do poorly, coastal areas do well). An important part of the geography effect works through its influence on a country's rate of technical progress. Our results also suggest that an important economic policy variable, degree of openness, is associated with greater rates of technical progress in mortality decline, although a reasonable interpretation is that openness proxies a range of policy variables.

II. THE IMPORTANCE OF HETEROGENEOUS TIME TRENDS

Standard econometric analyses of the determinants of cross-country variation in health outcomes consist of multivariate cross-sectional or panel regression models. (In particular, this is true of the work done by researchers associated with the World Bank. See Filmer and Pritchett [1999] for a cross-sectional study, and Pritchett and Summers [1996] for panel regressions.)⁵ Since our interest is in investigating the effect of technical progress on health outcomes over time, our focus will be on panel models. Consider, then, the following model of the determinants of health:

$$(1) \quad H_{it} = \alpha_i + \beta' \mathbf{X}_{it} + \gamma t + \varepsilon_{it},$$

where H_{it} is a measure of health outcome in country i at time t , α_i is a country-specific intercept in the production function for health outcomes (modeled as fixed or random effects), \mathbf{X}_{it} is a vector of health determinants (or controls) in country i at time t , t is a measure of time so that γ is the conditional time trend of the health outcome variable (the rate of technical progress), and ε_{it} is a random, i.i.d., normally distributed disturbance. This specification does not allow for heterogeneity in the coefficients, and in particular, it assumes that the (conditional) trend change in the health outcome over time is the same in all countries.

⁵ In a paper dealing with IMR decline in Sweden, the U.K. and the U.S., Bishai (1995) has developed a cointegration approach for dealing with the long time series available for those countries.

As we explained in the introduction, the presence of a dramatic downward trend in mortality in the 20th century, even after controlling for socio-economic determinants of health like education levels and per capita income, most plausibly reflects the diffusion of new and relatively inexpensive technologies which allow countries to improve their health levels even at unchanged levels of input into the “health production function.” But there is little reason *ex ante* to assume that countries are identical in their abilities to avail themselves of the new knowledge and improved techniques coming on stream. Suppose that the true causal model of health outcomes is not the one given by equation 1, but rather:

$$(2) \quad H_{it} = \alpha_i + \boldsymbol{\beta}'\mathbf{X}_{it} + \gamma_i t + v_{it} ,$$

where γ_i is a country-specific time trend and v_{it} is an random, i.i.d., normally distributed disturbance. The question we want to consider in this section is whether important problems arise from using equation 1 to estimate a relationship that is really given by equation 2. To see why this may indeed be the case, note that if the true model is (2), then

(1) can be rewritten as:

$$(3) \quad H_{it} = \alpha_i + \boldsymbol{\beta}'\mathbf{X}_{it} + \gamma t + \eta_{it} ,$$

where $\eta_{it} = (\gamma_i - \gamma)t + v_{it}$. In other words, the error term in (3) will be autocorrelated, and it will be correlated with the time variable in the regression equation and with every other serially correlated variable in the regression equation. So not only do we remain ignorant about cross-country variation in technical progress if we use (1) to estimate (2), we also run the risk of biased estimates of the true coefficients (which in the case of the time trend would be the average of the country-specific time trends).

Several recent papers in both econometric theory and in applied work have investigated how serious the biases may be that arise from imposing coefficient homogeneity when the true model has heterogeneous parameters. Robertson and Symons (1992) consider specifications of dynamic panels which include a serially correlated regressor (the “true” determinant of the dependent variable) and a lagged dependent variable. They find that if the regressor is a random walk, then in both large N , small T and in small N , large T panels the coefficient on the lag is biased upwards (from its true value of zero) and the coefficient on the true determinant is biased downwards when coefficient homogeneity is erroneously imposed. Pesaran and Smith (1995) consider various estimators for large N , large T panels and find that imposing slope homogeneity yields inconsistent estimates of the true average coefficient in fixed effects or random effects panel regressions when the regressors are serially correlated. Sandbu (2003) finds that imposing a homogeneous time trend will lead to inconsistent estimates of the coefficients on regressors whose trend rate of change or whose initial values are correlated with the country-specific time trend. There is, therefore, a strong theoretical reason to worry about the consistency of the parameter estimates produced by studies which do not allow for slope heterogeneity. Additionally, this theoretical result has been shown to be quantitatively significant in several empirical applications of panel

regressions. Lee, Pesaran and Smith (1997, 1998) show that the slow rate of per capita income convergence between countries found in econometric studies of economic growth is due to the imposition of a homogeneous rate of technology growth across countries, which biases the coefficient on lagged income towards unity. When they let technological growth vary across countries, they estimate a much more rapid speed of convergence. Another application is found in Imbs et al. (2002) who conclude that the Purchasing Power Parity puzzle (the unexpected persistence of the real price level after exchange rate shocks) is largely due to ignoring parameter heterogeneity. When they allow price autocorrelation estimates to vary across industries, they find that the estimate of aggregate price level persistence becomes sufficiently small that it is no longer puzzling.

We propose that a similarly important bias is at work in the extant literature on cross-national determinants of health outcomes. In the remainder of this section we present a number of simple regressions that are intended as diagnostic, and conclude that it is necessary to use models in which the rate of technical progress is allowed to vary between countries. The data set is the one we use for the full model in the next section, and is fully explained in the Annex A. It contains observations for 94 countries for up to five five-year periods between 1962 and 1987. Of the 94 countries, 24 are classified by the World Bank as high-income and 70 as low- or middle-income.

Consider a model of the health production function of the form of equation (1), where the health outcome is the log of the infant mortality rate (IMR) in country i at time t , and where the regressors include the log of real income per capita in country i at time t (a five-year average, LY5), the average number of years of education in the adult female population in country i at time t (FEDUC), the log of the number of physicians per 10^5 population in country i at time t (LDOC), and a time trend (TIME _{t} , the number of years since 1962):

$$(4) \quad \text{IMR}_{it} = \alpha_i + \beta_1 \text{LY5}_{it} + \beta_2 \text{FEDUC}_{it} + \beta_3 \text{LDOC}_{it} + \gamma \text{TIME}_t + \varepsilon_{it} .$$

Columns A and B in Table 1 report the coefficient estimates obtained from estimating this model with Generalised Least Squares (GLS), treating the country-specific intercept terms as random or fixed effects, respectively. The coefficient estimates are similar with the two estimation methods, and are very close to those found in the previous literature, *e.g.* Pritchett and Summers (1996). In particular, the elasticity of IMR with respect to income is around -0.3, implying that a 10 percent percent increase in real per capita GDP would reduce IMR by 3 percent percent. Given the rates of GDP growth in the 1960-1990 periods, this puts IMR improvements due to income growth and IMR improvements due to technical progress (roughly 1.4 percent percent per year in the random effects specification) at roughly the same magnitude.

As the discussion above suggested, the imposition of parameter heterogeneity on serially correlated variables may make the estimates inconsistent. It is also well known that when one regresses two variables which are not covariance stationary on one another, spurious relationships may be found (Granger and Newbold 1974). Given the persistence over time of both IMR levels and its determinants, we should therefore worry

Table 1.
Determinants of Infant Mortality Rate: Diagnostic Results (robust t-statistics in parentheses)

	Levels Models		1st Difference Models		
	A	B	C	D	E
	Random effects	Fixed effects	OLS	Random effects	Fixed effects
Constant	7.523 (30.36)	7.063 (23.30)	-0.103 (10.81)	-0.11 (9.41)	-0.119 (10.68)
LDOC	-0.086 (3.53)	-0.07 (2.44)	-0.053 (2.39)	-0.049 (2.48)	-0.044 (2.16)
LY5	-0.326 (8.48)	-0.29 (6.60)	-0.211 (4.01)	-0.154 (3.34)	-0.071 (1.35)
FEDUC	-0.133 (9.39)	-0.089 (4.65)	-0.12 (4.75)	-0.124 (6.45)	-0.128 (6.00)
TIME	-0.014 (13.06)	-0.019 (11.51)			
Number of observations	477	477	383	383	383
Number of countries	94	94	93	93	93
R ² (overall)	0.85	0.83	0.20	0.20	0.15

Dependent variable: logarithm of the infant mortality rate (LIMR).

about the consistency of these estimates. A simple diagnostic check is to first-difference the variables and regress their period-to-period changes on each other, rather than their levels:

$$(5) \quad \Delta \text{IMR}_{it} = \beta_1 \Delta \text{LY5}_{it} + \beta_2 \Delta \text{FEDUC}_{it} + \beta_3 \Delta \text{LDOC}_{it} + \gamma' + \Delta \varepsilon_{it} ,$$

where $\Delta x_{it} = x_{it} - x_{it-1}$, and $\gamma' = \gamma \Delta t = 5\gamma$. The results from the first-differenced regression are given in column C of Table 1. The period-to-period change in the log of IMR remains statistically significantly related to that of log per capita income, although the relationship is quantitatively somewhat weaker. The same is true for the other two explanatory variables. We note again that even without any changes in the explanatory variables, the infant mortality rate is estimated to fall at about two percent per year (the intercept in the differenced regression implies a 10 percent percent reduction of IMR over each 5-year period).

The three specifications above all assume that the rate of technical progress (the time trend) is the same in all countries. Another simple diagnostic exercise is to check whether this is a source of significant bias in the context of IMR regressions by letting the intercept in the differenced equation vary across countries:

$$(6) \quad \Delta \text{IMR}_{it} = \beta_1 \Delta \text{LY5}_{it} + \beta_2 \Delta \text{FEDUC}_{it} + \beta_3 \Delta \text{LDOC}_{it} + \gamma_i + \Delta \varepsilon_{it} .$$

Since the intercept is the conditional rate of change of the dependent variable, this specification allows each country to have its own rate of technical progress in the production of infant health (although at the cost of losing potential information about country-specific effects on levels of IMR, since these have been differenced out). Columns D and E report the results from modelling this country-specific intercept in the difference equation as random or fixed effects, respectively. It turns out that relaxing the assumption of homogeneous time coefficients has a negligible effect on the estimated effect of education or of doctor coverage. There is a noticeable change in the estimated elasticity of per capita income, however, which in the random effects specification is estimated at only -0.15, less than one-half of what it was in the original level specification. If we run the last regression with fixed instead of random country effects, the estimated income coefficient is only -0.07 and not statistically significantly different from zero.

Clearly whether or not we allow parameter heterogeneity matters for the results. Formal tests corroborate this claim. A Breusch-Pagan test strongly rejects the hypothesis that the intercept is the same for all the countries in the differenced regression ($\chi^2(1) = 26.54$). We can also test the hypothesis that the coefficient on the time variable is the same for all countries in the level regression. Greene (1993, p. 673) shows that this is equivalent to a Wald test of the assumption that all the time coefficients are equal in an OLS regression which contains a separate time variable for each country (essentially an interaction of time with a country indicator variable). From a regression of the log of IMR on the log of doctors per capita, the log of income per capita, years of female education and the country-specific time variables, the Wald F-statistic for the hypothesis

that all the time coefficients are equal is 137.39, far above the critical level of 1.44 for the $F(93, 380)$. This rejects the hypothesis of equal time coefficients at any significance level.

To summarise: There are no *ex ante* reasons to believe that rates of technical progress are the same for all countries. Econometric theory shows that imposing slope homogeneity when slopes in reality are country-specific leads to inconsistent estimates with conventional methods when the variables are serially correlated. And a cursory examination of data on infant mortality rates and their determinants reveals that this inconsistency may lead to a serious misunderstanding of the relationships between per capita income, technical progress and health outcomes. In the next section, we use a randomly varying coefficients model that allows us to take seriously the possibility of country-specific rates of technical progress and to investigate the sources of differences in these rates, while (unlike the differenced regressions) not throwing away any of the cross-sectional information in the data set.

III. MODEL SPECIFICATIONS AND RESULTS

The previous section provided an overview of the strong intuitive, theoretical and empirical reasons for relaxing the assumption of slope homogeneity in the econometric analysis of cross-country variations in health outcomes. We now proceed to analysing a model of the determinants of infant mortality rates which relaxes that assumption but which is otherwise very similar to earlier approaches. The generic model we estimate is given by equation (7):

$$(7) \quad \text{LIMR}_{it} = \beta_{0i} + \beta_{1i} \text{TIME}_t + \beta_2 \text{LY5}_{it} + \beta_3 \text{FEDUC}_{it} + \beta_4 \text{LDOC}_{it} + \varepsilon_{it} ,$$

where the variables are defined in Annex A and the coefficients signify:

- β_{0i} : the intercept in country i 's production function for infant mortality rate over time;
- β_{1i} : the yearly effect of time (yearly technical progress) in reducing infant mortality in country i ;
- β_2 : the elasticity of infant mortality with respect to per capita income;
- β_3 : the responsiveness of infant mortality in percent with respect to a one-year change in female education;
- β_4 : the elasticity of infant mortality with respect to number of physicians per 100,000 inhabitants;
- ε_{it} : unexplained residual for country i at time t , assumed to be i.i.d normally distributed with mean 0.

All the results we report below come from regressions that use different specifications of the country-specific coefficients β_{0i} , β_{1i} . The benchmark model allows for a random country-specific intercept shift and imposes the constraint that the time slope is the same for all countries. This benchmark model is very similar to the specification in Pritchett

and Summers (1996).⁶ As we relax the homogeneity assumption, we let both the intercept and the time slope be influenced by country-level characteristics and/or a randomly varying idiosyncratic term. In order to estimate the different models, we use the maximum-likelihood procedure of Hierarchical Linear Modeling (for the econometric details of the estimation method, see Bryk and Raudenbusch [1992] and Kreft and De Leeuw [1998]).

Selection of models

Before presenting our results, we need to address three potential sources of concern with our modeling choice. They regard the functional form of our estimating equations, the choice of randomly varying coefficients over a dummy variable approach, and the choice of retaining the assumption of coefficient homogeneity for the independent variables other than time. We discuss each of these in turn.

Functional form of the estimating equation. Since one of our goals is to point out a problem of misspecification in earlier studies — the imposition of a common time trend across countries — it makes sense for us to choose a functional form that makes our results comparable with extant findings. Using the log of infant mortality rates on the left-hand side (instead of absolute levels), moreover, has a theoretical and a practical advantage. The theoretical advantage is that we would expect it to take more resources to reduce IMR by a given absolute amount the lower is the current level of IMR. The log form allows for this, since a predicted effect of given changes in the determinants will be a given percentage change in IMR. The practical advantage is the ease of interpreting the coefficients.⁷ The time coefficient is the (conditional) yearly percentage change in IMR, the LY5 and LDOC coefficients are the (conditional) elasticities of IMR with respect to income or physician coverage, and the coefficient on FEDUC is the (conditional) percentage change in IMR attributable to one more year of education in the female population.

Randomly varying coefficients or indicator variables. As we noted above, and as we show in the detailed models of β_{0i} and β_{1i} below, we model the country-specific part of the intercepts and time slopes as random disturbances. An alternative modeling approach would be to use indicator (dummy) variables for each country. In the case where only the intercept is allowed to vary, this comes down to the familiar choice between a random effects and a fixed effects GLS model. In the case of the country-specific time trend, the difference is one between a randomly varying coefficients approach and estimating individual coefficients on a set of interaction terms between time

⁶ One difference is that they model the intercept shift as a fixed effect; we model it as a random effect. The difference in the other coefficients is negligible, however, and we explain in the main text why the random effects specification is better for our purposes.

⁷ Bishai (2003) points to shortcomings in using a logarithmic transformation in IMR and suggests consideration of a more comprehensive class of transformations. The literature has almost universally used a logarithmic transformation and, to maintain comparability of our results with earlier work, we continue with this specification.

and an indicator variable for each country. It turns out that the choice between these approaches has little effect on the results we are interested in, which is how the estimated effects of socio-economic variables on health change when we allow different countries to have different rates of technical progress. In the case of the intercept shift, we showed in the previous section that there is very little difference in the coefficient estimates whether we use random or fixed effects. In the case of the time slope, using indicator variables produces estimates that make our case even stronger (this can be seen in the differenced estimates reported in Table 1, and also shows up in hierarchical level regressions, the results from which are available upon request). By using the random variation approach, therefore, we conservatively choose the approach that is less favorable to our conclusions. These considerations makes the choice between randomly varying coefficients approach and an indicator variable approach a largely pragmatic one, and here the randomly varying coefficients approach has two main advantages. First, in these short time series (a maximum of six time periods per country) estimating coefficients on two interaction terms per country (for the intercept and for the time slope) would use up many of our degrees of freedom. Second, we are interested not just in allowing the intercept and the time slope to vary across countries, but also to model this variation as a function of time-invariant country characteristics. This we cannot do with an indicator variable approach, since the coefficient on an indicator interacted with time will pick up all the cross-country variation in time trends. The randomly varying coefficient approach, we conclude, is much better suited for our purposes.

Remaining slope homogeneity. If we think that coefficients vary across countries, why do we content ourselves with relaxing the homogeneity assumption for the time coefficient, without allowing country-specific estimates for the other determinants? We do report results from such estimations in Annex B. However, as a first step towards relaxing the assumption of slope homogeneity, allowing country-specific rates of technical progress is a natural and parsimonious approach, and it is conceptually very close to the conventional practice of letting intercepts vary. The log specification of the production function with level effects assumes that countries differ in how well they put to use a given set of inputs by a multiplicative productivity parameter (additive in the log form). The inclusion of a time trend assumes that this multiplicative productivity parameter changes over time. Heterogeneous time trends, then, simply mean that countries that are already assumed to have different productivity parameters may also change that parameter at different speeds, which is hardly a great conceptual leap. Allowing different countries to have different exponents on the inputs in the production function, on the other hand, is conceptually a much greater departure. We therefore think it is useful to begin by concentrating on the narrower modification to current practice. Moreover, as Annex B shows, allowing the time trend to vary has much greater implications for the estimated effects of the other variables (and contributes more to model fit) than has the inclusion of country-specificity in the other coefficients.

Making technical progress country-specific

Our benchmark regression is one where none of the coefficients except the

intercept varies across countries, that is, where equation (7) is supplemented with the following specification of β_{0i} and β_{1i} :

$$(8a) \quad \beta_{0i} = \gamma_{00} + \gamma_{01} \text{TROPICS}_i + \gamma_{02} \text{COASTAL}_i + \mu_{0i} ,$$

$$(8b) \quad \beta_{1i} = \gamma_{10} ,$$

where μ_{0i} is assumed to be normally distributed with mean zero and independent of the unexplained disturbance for the country-time observation ε_{it} : $\text{Cov}(\mu_{0i}, \varepsilon_{it}) = 0$. This simple specification is similar to many of the models in the existing literature in that it imposes a common health production function across countries except for the intercept shift (or country-specific effect). With the error structure given in equations (8a) and (8b), it is equivalent to a GLS random effects model. As mentioned above, however, we estimate all the models using a maximum-likelihood algorithm of Hierarchical Linear Modeling (HLM), which is we can also use to estimate the models with the more complex error structures below.

The estimates for our benchmark model are reported in Table 2 (model 1), and the point estimates are very close to those using GLS reported in Table 1. (The differences are due to the addition of geographical variables.) The benchmark model is consistent with previous studies that find substantial income effects. Other things equal, the infant mortality rate falls by about 1.6 percent percent per year. The elasticity of IMR with respect to income is -0.31, which is only somewhat smaller (in absolute magnitude) than previous estimates, e.g. Pritchett and Summers (1996) and Filmer and Pritchett (1999). A 10 percent percent (or \$353 at the sample mean) increase in income is associated with a 3.3 percent percent fall in infant mortality, or about 2.5 fewer deaths per thousand births at the sample mean. Education, as is usually found, is also important: One additional year of female education is associated with about a 12 percent fall in infant mortality (or about 7 fewer deaths per thousand at the sample mean). A 10 percent increase in the number of physicians per capita would reduce infant mortality by 0.9 percent.⁸

Model 1 also includes geographical variables that measure the fraction of a country's land area situated within the geographical tropics, and the fraction of the country's land area located within 100 km of the coast or an navigable waterway. Model 1 shows that the geography indicators contribute to explaining cross-country differences in the intercept. For example, a completely tropical country ($\text{TROPICS} = 1$) has, on average, a 19 percent higher infant mortality rate ($e^{.17} = 1.19$) than a non-tropical one ($\text{TROPICS} = 0$). A country whose entire land surface lies within 100 km of the coast or a navigable river ($\text{COASTAL} = 1$) has, on average, a 25 percent lower infant mortality rate ($e^{-.29} = 0.75$) than a completely landlocked one ($\text{COASTAL} = 0$). These effects of geography could, of course, result from multiple factors, for example through its effect on the disease environment or the relatively low productivity of tropical agriculture.

⁸ Time series data on public or total health expenditures per capita are unavailable, whereas data on numbers of physicians are available, hence our choice of this variable. Cross-sectional studies of the effects of public spending on health outcomes have produced mixed results, but an important recent study (Gupta, Verhoeven and Tiongson, 2002) found a clear effect of public spending on health outcomes, with a particularly strong effect on health outcomes of the poor.

Table 2. Determinants of Infant Mortality: The Effects of Income, Education, Physician Coverage, Geography and Technical Progress (robust t-statistics in parentheses)

Independent Variables/Model Parameters	Models					
	(1)	(2)	(3)	(4)	(5) model 4 for low- and middle- income countries	(6) model 4 for high- income countries
Level-1 Model: Determinants of LIMR (equation 7)						
Average value of country-specific intercepts (sample mean of β_{0i})	7.32	5.83	5.68	5.64	5.28	5.33
Average value of country-specific time trend (sample mean of β_{1i})	-0.016	-0.020	-0.021	-0.021	-0.022	-0.023
LY5 (β_2)	-0.31 (5.57)	-0.11 (2.48)	-0.10 (2.12)	-0.09 (1.92)	-0.02 (0.34)	-0.17 (1.51)
FEDUC (β_3)	-0.12 (5.91)	-0.12 (6.76)	-0.11 (6.29)	-0.11 (6.42)	-0.12 (6.12)	-0.03 (1.48)
LDOC (β_4)	-0.065 (1.89)	-0.068 (3.39)	-0.07 (3.59)	-0.07 (3.55)	-0.06 (2.84)	-0.11 (1.71)
Level-2 Model: TIME coefficient (β_{1i})						
Coefficient on TIME (common value across countries, γ_{10})	-0.016 (9.04)	-0.020 (11.32)	-0.020 (6.68)	-0.012 (4.69)	-0.017 (5.38)	-0.013 (1.97)
TROPICS (γ_{11})			0.011 (4.05)	0.005 (1.78)	0.009 (2.67)	-0.0002 (0.04)
COASTAL (γ_{12})			-0.015 (4.16)	-0.008 (2.32)	-0.012 (2.64)	-0.005 (0.74)
OPEN6590 (γ_{13})				-0.019 (6.67)	-0.010 (2.23)	-0.021 (5.33)
Variance of country-specific time trend μ_{1i}		0.0002 (6.33)	0.0001 (6.50)	0.0001 (5.50)	0.0001 (5.00)	0.0001 (3.50)

Table 2. Continued

Independent Variables/Model Parameters	<i>Models</i>					
	(1)	(2)	(3)	(4)	(5) model 4 for low- and middle- income countries	(6) model 4 for high- income countries
Level-2 Model: Country-specific intercept (β_{0i})						
Intercept (common value across countries, γ_{00})	7.37 (19.12)	5.84 (19.49)	5.67 (19.03)	5.63 (18.10)	5.33 (17.89)	5.42 (4.75)
TROPICS (γ_{01})	0.17 (1.62)	0.27 (2.74)	0.30 (3.01)	0.31 (3.09)	0.02 (0.28)	-0.24 (1.70)
COASTAL (γ_{02})	-0.29 (2.65)	-0.31 (2.81)	-0.32 (2.87)	-0.32 (2.82)	-0.14 (1.44)	0.08 (0.42)
Variance of country-specific level effect μ_{0i}		0.12 (6.58)	0.13 (6.61)	0.13 (6.61)	0.06 (5.49)	0.09 (3.37)
Correlation between country-specific level effect μ_{0i} and time trend μ_{1i}		0.004	0.060	-0.329	-0.156	-0.754
Estimation Statistics						
Number of observations	477	477	477	477	355	122
Number of countries	94	94	94	94	70	24
Number of parameters estimated	9	11	13	14	14	14
Log-likelihood value	97.4	255.0	271.8	285.0	250.0	83.56
Likelihood-ratio tests:						
Comparison model		1	2	3		
Test degrees of freedom		2	2	1		
Chi-square value		315.08	33.58	26.42		
p-value		0.000	0.000	0.000		

Dependent variable: logarithm of the infant mortality rate (LIMR).

Our next step is to modify the benchmark models to allow for country-specific rates of technical progress. As explained above, we model differences in technical progress by including a country-specific random term in the coefficient on time. Thus model 2, which is an extension of model 1, models the intercept as in equation (8a), but adds a country-specific term to the equation for the time coefficient β_{1i} :

$$(9) \quad \beta_{1i} = \gamma_{10} + \mu_{1i} .$$

The random term in equation (9) is assumed to be normally distributed with mean zero and independent of ε_{it} , but potentially correlated with μ_{0i} , the random IMR level (intercept) effect.

Substituting equations (8a) and (9) into equation (7) gives us the following model:

$$(10) \quad \text{LIMR}_{it} = \gamma_{00} + \gamma_{10}\text{TIME}_t + \beta_2 \text{LY5}_{it} + \beta_3 \text{FEDUC}_{it} \\ + \beta_4 \text{LDOC}_{it} + (\mu_{0i} + \mu_{1i} * \text{TIME}_t + \varepsilon_{it}) .$$

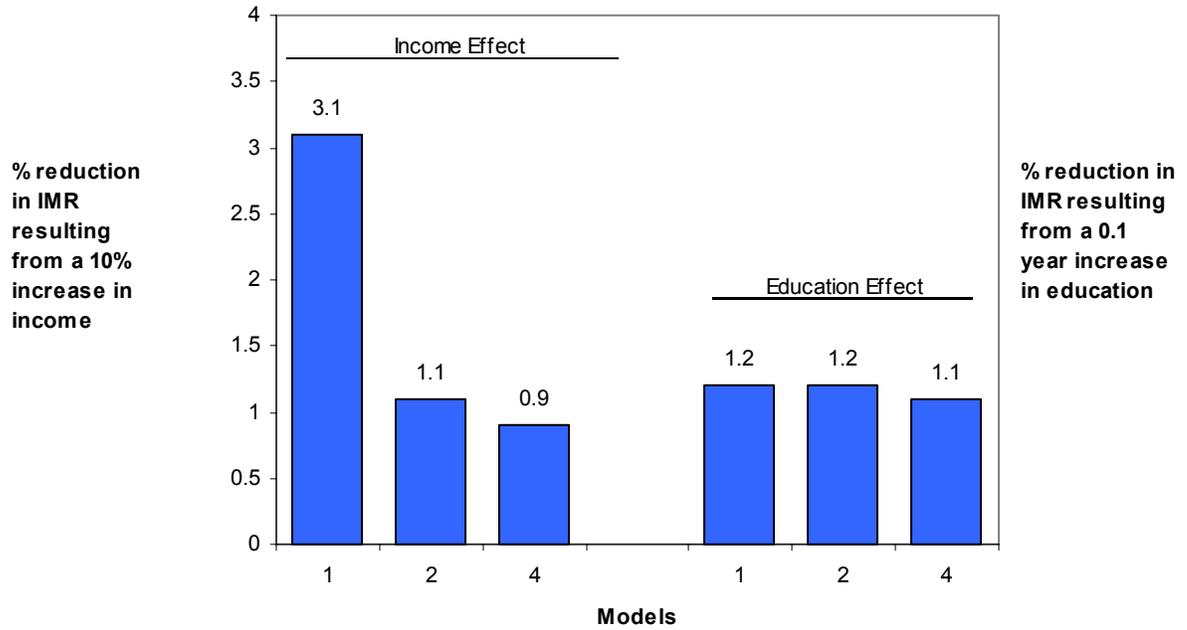
As discussed in the previous section, the complex error structure makes least squares methods biased. The HLM maximum-likelihood procedure, on the other hand, consistently estimates the variable coefficients, the variance of the observation error ε_{it} , the variances of the two country-specific random effects μ_{0i} and μ_{1i} , and the covariance between them, $\text{Cov}(\mu_{0i}, \mu_{1i})$.⁹ This means that the models without a randomly varying time slope are constrained versions of the equivalent model that allows this random variation (the constraints being $\text{Var}(\mu_{1i}) = 0$ and $\text{Cov}(\mu_{0i}, \mu_{1i}) = 0$).¹⁰ Model 1 is thus a restricted version of model 2. A likelihood ratio test can be applied to see if the restriction is valid. The bottom row in Table 2 reports the results of a likelihood ratio comparison of model 2 with model 1. The hypothesis that the constraint is valid is decisively rejected, corroborating the tests in the previous section which suggested that the time slope does indeed vary across countries.

The results reported in models 1 and 2 of Table 2 show that the coefficient estimates change little from letting the time coefficient vary across countries, with the notable exception that the effect of income falls dramatically — to about a third of its previous magnitude. Not only does the point estimate of the income effect become much smaller in model 2, the associated t-statistic also decreases. Clearly health, income, and a country's rate of technology adoption are interrelated in complex ways that the simpler regression of model 1 fails to capture. Any satisfactory account of cross-country variation in infant mortality declines must attempt to explain these relationships. Figure 1 illustrates the impact on both the income and education coefficients of allowing the time coefficient to be country-specific.

⁹ We use the HLM5 software package (Raudenbusch, Bryk, Cheong and Congdon 1999).

¹⁰ The variances and covariances should be understood to be the conditional moments given the independent variables. We omit the conditions for notational simplicity.

**Figure 1:
Sensitivity Analysis for Relaxing the Assumption that the Rate of
Technical Progress is the Same for All Countries**



Note:

Estimates of models 1, 2, and 4 appear in Table 2. In model 1, the coefficient on time -- the rate of technical progress -- is constrained to be equal for all countries. In models 2 and 4, this assumption is relaxed.

Furthermore, it should be noted that the cross-country variation in technical progress is itself quantitatively important. The standard deviation of μ_{1i} is .014 (i.e. 1.4 percentage points per year). Figure 2 displays the distribution across countries of the rate of technical progress. As the histogram shows, there is a considerable spread across countries, from one country with *adverse* technical change to 9 countries with remarkable rates of technical progress of above 4 percent per year. The importance of a 1.4 percentage point better (more negative) rate of technical progress is illustrated by a simple calculation: After 25 years, IMR in a country that has a one standard deviation faster rate of technical progress is a full 30 percent lower than what it would be in an otherwise identical country ($e^{-.014*25} = .70$). This quantifies the importance of gaining a better understanding of the determinants and the role of differential technical progress across countries.

Sources of cross-country variation in rates of technical progress

This large variation in the rates of technical progress of different countries, together with the reduced magnitude of the coefficient on income, suggests that technical progress is a key determinant of why infant mortality has declined at such different rates in different countries. We elaborate on this finding in the next section, but it is immediately clear that an investigation of why some countries have fast technical progress while others progress only slowly is an extremely important area of further research. In the remainder of the section, we make an initial contribution to this task by estimating a set of models designed to assess some of the sources of the cross-country variation of technical progress. Models 3 and 4 of Table 2 are designed to assess how much of the variation can be explained by the influence of certain country characteristics. Thus we have the following model specification for model 3:

$$(11a) \quad \beta_{0i} = \gamma_{00} + \gamma_{01} \text{TROPICS}_i + \gamma_{02} \text{COASTAL}_i + \mu_{0i} \text{ , and}$$

$$(11b) \quad \beta_{1i} = \gamma_{10} + \gamma_{11} \text{TROPICS}_i + \gamma_{12} \text{COASTAL}_i + \mu_{1i} \text{ .}$$

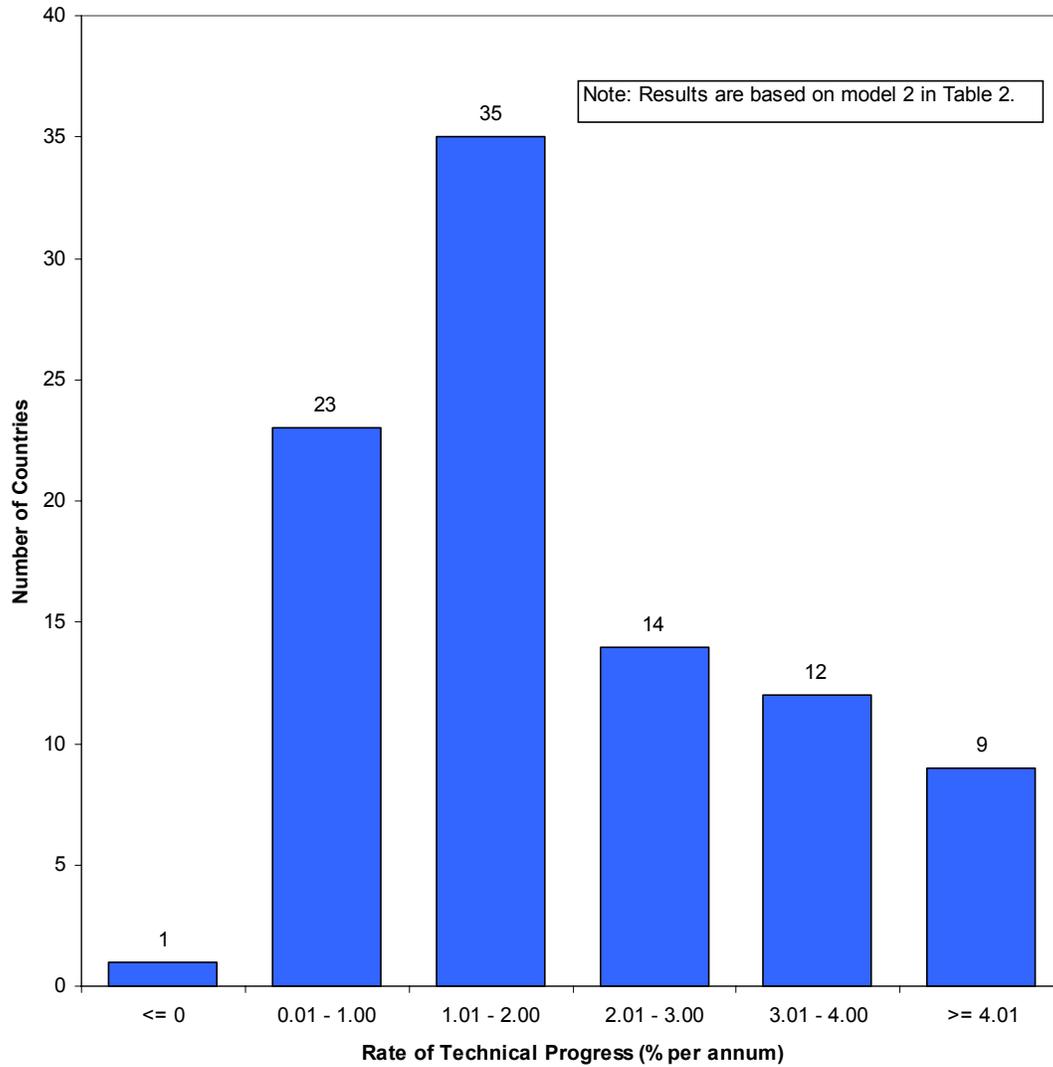
Model 4 has the same determinants for β_{0i} as in model 3 but adds a measure of economic openness as a determinant of β_{1i} :¹¹

$$(12) \quad \beta_{1i} = \gamma_{10} + \gamma_{11} \text{TROPICS}_i + \gamma_{12} \text{OPEN6590}_i + \gamma_{13} \text{COASTAL}_i + \mu_{1i} \text{ .}$$

The results from Table 2 show that geographic variables operate both through their effect on the intercept *and* through their effect on the time slope. We see in models 3 and 4 of Table 2 that the coefficients in the model of the time slope are both statistically

¹¹ We do not include openness as a determinant of the intercept. This is because the intercept gives a measure of how well or badly the country was doing at the beginning of the period (1962), while the openness variable measures certain aspects of economic policy over the subsequent period. It is therefore not clear whether any meaning could be attributed to a coefficient on the openness variable included as a determinant of the intercept.

Figure 2:
**Country-specific Variation in Technical Progress as a
Determinant of IMR Decline**



significant and quantitatively important (they are reported under the heading ‘Level-2 Model: TIME coefficient (β_{1i})’). From model 3, for example, we can calculate that a temperate, coastal country (TROPICS = 0 ; COASTAL = 1) on average reduces its IMR at a rate of 3.5 percent per year, a rate that is almost *four times as fast (ceteris paribus)* as that of a tropical and landlocked country (TROPICS = 1; COASTAL = 0), which reduces its IMR by 0.9 percent per year on average. OPEN6590 has a highly significant and quantitatively important effect on the time slope (model 4). Thus an economically open country is calculated to reduce its IMR at a rate that is around 1.9 percentage points per year faster than an economically closed, but otherwise similar country. In 25 years, this substantial differential accumulates to an additional 38 percent reduction in IMR relative to what it would have been ($e^{-0.019*25} = .62$). Prasad, Rogoff, Wei and Kose (2003) find a similarly important impact of trade integration on mortality reduction. Countries that are not open to the world economic system miss out not only on gains from trade and specialization in production, but also on information flows and the benefits of technological diffusion. Note that modeling the country-specific rate of technical progress as a function of country characteristics has the same effect on the other coefficients as in the random coefficient approach of model 2. Relative to model 1, the education and physician coverage coefficients change only slightly, while the income coefficient falls from -0.31 to -0.10 when the geographical variables are included as determinants of a randomly varying time slope, and further to -0.09 when the openness variable is also included.

If we are right that the time slope may be interpreted as absorption of technical progress, then it is not clear why a tropical country should be less effective in introducing low cost technologies of mortality reduction than are temperate countries. One possibility is that development of attractive technologies was more rapid for conditions relatively more prominent in temperate zones. Another reason could be the debilitating effects of the tropical diseases that have been discussed in other work (see Gallup and Sachs, 2001). A related explanation would lie in a high correlation of TROPICS with being in Africa, which for some reason might be more prone to poor health than other tropical regions. Table 3, model 8, reports a specification including an indicator variable for Africa which suggests that the explanation must lie elsewhere, a finding consistent with the more general findings of Hoeffler (2002) in the context of economic growth. All this said, model 4 shows that the coefficient on TROPICS becomes half as large and statistically insignificant (at the 5 percent level) when the openness variable is introduced. Thus the apparent effect of tropical location on the time slope in model 3 is in part simply due to omitted variable bias.

The country characteristics with which we modeled technical progress capture only a part of the entire cross-country variation. The differences in the time slope that remain unexplained, captured by the random term μ_{1i} of equations (11b) and (12), are quantitatively very important. For many countries, the magnitude is comparable to the effects of the geographic and openness variables. Note that even in model 4, which includes our richest specification for the country-specific time slope, the variance of the random component is .0001. This implies a standard deviation as high as .01, or one percentage point per year, which is substantial compared to the magnitude of the other

Table 3.
Variants on Determinants of LIMR, Model 4

Independent Variables/Model Parameters	Models		
	(7) Model 4 without 'LDOC'	(8) Model 4 with 'AFRICA'	(9) Model 4 with ly5 growth rate
Level-1 Model: Determinants of LIMR (equation 7)			
Average value of country-specific intercepts (sample mean of β_{0i})	5.56	5.58	5.63
Average value of country-specific time trend (sample mean of β_{1i})	-0.022	-0.022	-0.021
LY5 (β_2)	-0.11 (2.32)	-0.08 (1.80)	-0.09 (1.88)
FEDUC (β_3)	-0.13 (7.10)	-0.11 (6.22)	-0.11 (6.42)
LDOC (β_4)		-0.07 (3.45)	-0.07 (3.55)
Level-2 Model: TIME coefficient (β_{1i})			
Coefficient on TIME (common value across countries, γ_{10})	-0.013 (5.11)	-0.014 (5.26)	-0.012 (4.22)
TROPICS (γ_{11})	0.004 (1.71)	0.004 (1.20)	0.005 (1.66)
COASTAL (γ_{12})	-0.008 (2.12)	-0.007 (2.06)	-0.008 (2.30)
OPEN6590 (γ_{13})	-0.019 (6.50)	-0.019 (5.45)	-0.019 (6.41)
AFRICA (γ_{14})		0.003 (1.15)	
RATE (γ_{15})			-0.00005 (0.06)
Variance of country-specific time trend μ_{1i}	0.0001 (5.50)	0.0001 (5.50)	0.0001 (5.50)

Table 3. Continued

Independent Variables/Model Parameters	Analogous Models		
	(7) Model 4 without 'LDOC'	(8) Model 4 with 'AFRICA'	(9) Model 4 with ly5 growth rate
Level-2 Model: Country-specific intercept			
Intercept (common value across countries, γ_{00})	5.558 (17.56)	5.558 (17.68)	5.63 (17.66)
TROPICS (γ_{01})	0.378 (3.74)	0.310 (2.94)	0.308 (3.06)
COASTAL (γ_{02})	-0.372 (3.27)	-0.320 (2.63)	-0.320 (2.74)
AFRICA		0.033 (0.36)	
Variance of country-specific level effect μ_{0i}	0.136 (6.68)	0.135 (6.61)	0.132 (6.61)
Correlation between country-specific level effect μ_{0i} and time trend μ_{0i}	-0.331	-0.316	-0.33
Estimation Statistics			
Number of observations	477	477	477
Number of countries	94	94	94
Number of parameters estimated	13	16	15
Log-likelihood value	276.5	285.6	185.0
Likelihood-ratio tests:			
Comparison model		4	4
Test degrees of freedom		2	1
Chi-square value		1.22	0.0028
p-value		>0.5	>0.5

Dependent variable: logarithm of the infant mortality rate (LIMR).

coefficients (*e.g.* the average time trend implied by the model 4 estimates is -2.1 percent per year, and the average difference between a totally landlocked and a completely coastal country is 0.8 percentage points).

Models 5 and 6 of Table 2 divide the sample between the 70 low- and middle-income countries and the 24 high-income countries using the same specification as model 4. Several differences emerge. For the low-income countries the coefficient on income drops to close to zero and the effect of TROPICS appears relatively more important as a determinant of the time coefficient than of the intercept. For the high-income countries the estimated effect of education drops markedly and, not surprisingly, the geographical variables become unimportant. (Most high-income countries – Hong Kong and Singapore excepted – are in the temperate zones and have good access to ocean trade.) Model 7 (Table 3) is the same as model 4 except that it excludes the doctor variable. The effect is to increase the importance of income and education somewhat. We use model 7 in our discussion of country performance in Section IV.

We now return to the sensitivity of the coefficient on income to a relaxation of the assumption that technical progress is constant across countries. The effect of income that we find is much smaller than what has previously been found in cross-country regressions, and it is indeed so small that it seems of little use in a policy-making context. An IMR-elasticity with respect to income of -.09 (model 4) implies that a doubling of GDP, *ceteris paribus*, is associated with a fall in the infant mortality rate of only about 6 percent ($e^{-.09(\ln(2))} \approx .94$). This suggests that for reducing infant mortality, purely growth-oriented policies may not be particularly effective. Instead it may be much more important to understand the cross-country differences in adoption of low-cost, life-saving technologies. This qualitative pattern of findings is strengthened if the analysis is restricted to only the low- and middle-income countries in the sample (shown in model 5, Table 2). Indeed the estimated elasticity of IMR with respect to income drops from a just significant -0.09 for the full sample to a statistically insignificant -0.02 for the 70 low- and middle-income countries.¹² Easterly (1999) finds a broadly similar pattern of findings on the importance of income for other social indicators.

In regression models of this type, there is always a worry about potential reverse or common causation. If health outcomes influence the regressors, or if they are jointly influenced by an omitted variable, then the coefficients cannot be interpreted as the causal impact of the independent variables on health. Summers and Pritchett (1996) use an instrumental variable approach to check whether the high coefficient on income does indeed reflect causal influence. Their instruments are the investment to GDP-ratio, the black market exchange rate premium, terms of trade shocks and price level distortions. All of these could arguably be influenced by the quality of a country's institutions, which could have an independent effect also on health. Nevertheless, we tried to supplement

¹² Much empirical evidence points, however, to a strong within-country correlation of income and health (*e.g.* Wagstaff, 1999). Deaton (2001) points to one interpretation, which is that an individual's health may be affected by her standing relative to a salient reference group (rather than her income level *per se*), which in this case would be the country. This is logically consistent with a much weaker relationship between income and health across countries (as opposed to within them).

our analysis with instrumentation along the lines they use. We replicated all the regressions described in the paper, but instead of using actual income per capita numbers, we substituted the predicted income from an ordinary least squares-regression of GDP per capita on lagged investment to GDP-ratios. The main result from this admittedly crude exercise was that across all the models, the income coefficient was stable but very small, around -.03, and statistically significant only at the 10 percent-level. The other coefficients were unchanged. The results were therefore compatible with what we find in the models where we let the time trend vary across countries without instrumenting. We did not pursue this analysis further, partly because the tentative analysis did not suggest omitted variables affected our main results, and partly because our conclusions are not undermined by the possibility that the income coefficient not reflect a causal effect. Since our main analysis suggests precisely that income per capita does *not* have a strong causal role in the determination of infant mortality rates, we do not have a causality claim to prove. If an instrumental variable analysis showed that even our estimates are too high, then that would merely strengthen our case.

Another possible reading of our results could be that income differences at a business cycle frequency do not affect health, but that long-term changes in income do. On this interpretation, the time variable may simply be a proxy for these long-term income changes. If the coefficient on time really reflected the influence of long-term per capita GDP growth on health, then that coefficient should be strongly influenced by the average income growth rate. We checked whether this was the case by including the country's average 1960-1990 GDP per capita growth as a determinant of the time slope (model 9 in Table 3). The results showed that the effect of average income growth on the time coefficient is numerically small and statistically insignificant.^{13, 14}

IV. EXPLAINING VARIATION IN IMR DECLINE

Three main results emerged in the previous section. First, the annual rate of technical progress varies enormously across countries with a range of 0 to 5 percent per year around a mean of 2 percent per year. Second, when rates of technical progress are modeled explicitly as varying across countries, the estimated effect of income on IMR is substantially reduced, although our estimates of substantial effects from education and doctor coverage remain unchanged. Third, there are clear correlations between geographic and policy variables and the estimated rate of technical progress. In this section we use results from the previous section to do two things. First we decompose for each country — and for our sample as a whole — the sources of IMR decline into four components: the amount due to changes in that country's income level, its education level, its doctor supply and its rate of technical progress. We then assess how the

¹³ The points made in this paragraph were suggested by Daniel Cohen, Angus Deaton and Mead Over.

¹⁴ A complementary approach to the one adopted here involves detailed studies of why mortality has changed from specific diseases (e.g. Cutler and Kadinyala, 2003) or particular technologies (e.g. Lichtenberg, 2003). Both these studies conclude that technical progress has been a driving force for health improvements.

magnitude of differences in country ‘performance’ contributes to differences in IMR levels. To do this we integrate the country-specific component of the intercept term with the country-specific component of the coefficient on time from equation 7.

Decomposing IMR decline

Just as the literature on economic growth reports decompositions of growth into elements associated with increased levels of inputs and technical progress (total factor productivity growth) so, too, can IMR declines be decomposed. IMR declined dramatically in the period 1962-87 – from 99 per thousand to 54. The average per capita income increased by 78 percent (to \$4,700) and the average length of education of females increased from 3.3 to 4.8 years. How much did each of these factors contribute to IMR decline? And how much of the decline remains unaccounted for by these factors and, by convention, can be attributed to technical progress? The answers to these questions are country-specific both because the input changes are country-specific and because the calculated rate of technical progress is.

We use model 4 of Table 2 for the decomposition. We use the percentage change in each of the inputs, the estimated effects of these inputs, and the total country-specific technical progress $25\beta_{li}$ to calculate a predicted change in the log of IMR. The decomposition shows the amount of change in predicted IMR due to each factor divided by the total.

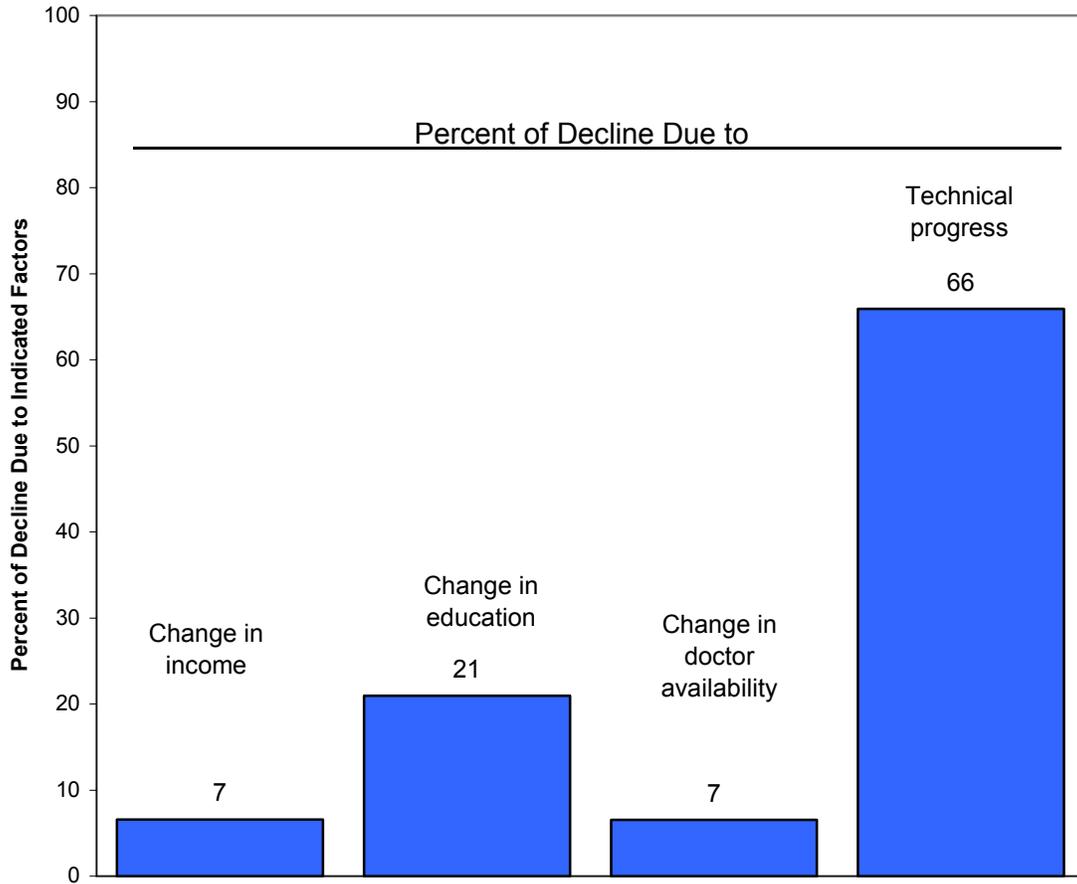
For our sample as a whole our approximation attributes 7 percent of the IMR decline to increases in per capita income, 21 percent to improvements in female education, 7 percent to the increased number of physicians and 66 percent to technical progress. Annex Table C.1 reports the decomposition for each country in our sample, and Figure 3 illustrates – as examples – the results for India and South Korea, as well as for the entire sample.

Variation in country performance

We have interpreted the coefficient on the time variable as technical progress widely construed. Country differences in the time-coefficient can be seen as countries’ differential ability to harness technological progress and the development of new ideas for policies. Some countries are better than others at absorbing ideas and technology from the world and at implementing new solutions as they become available, and this is an important measure of the country’s performance. In this subsection, we make use of the regression results to create an index of country performance in IMR reduction. We use model 7 (Table 3) to generate the performance measures, so that we do not control for health system resources (proxied by the number of doctors). If a country achieves better health outcomes by increasing doctor coverage, that should be counted as improved performance, whereas the same does not hold for health determinants completely outside of the health system such as GDP per capita and especially geography. So the performance measures are calculated after controlling for income, geography, and

Figure 3:
Sources of Predicted Decline in IMR, 1962-87

Panel A: All Countries
(Level of IMR in 1962 = 97; Decline, 1962-87 = 43)

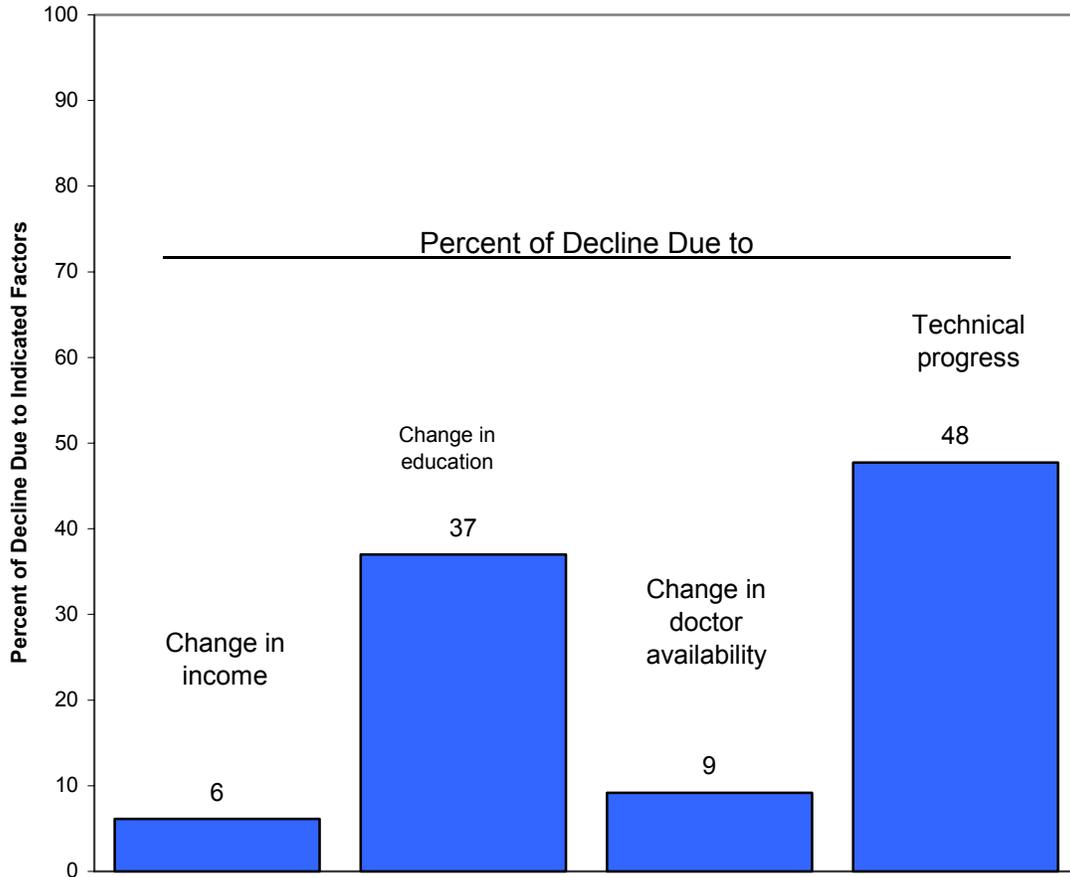


Note:

The calculation is based on Model 4 in Table 2. Average income in the sample increased by 77% in the period of 1962 to 1987; average years of female education increased from 3.3 to 4.8 years; average doctor availability increased from 1962's 53 to 110 per 100,000 people in 1987.

Figure 3:
Sources of Predicted Decline in IMR, 1962-87

Panel B: India
(Level of IMR in 1962 = 157 Decline, 1962-87 = 64)

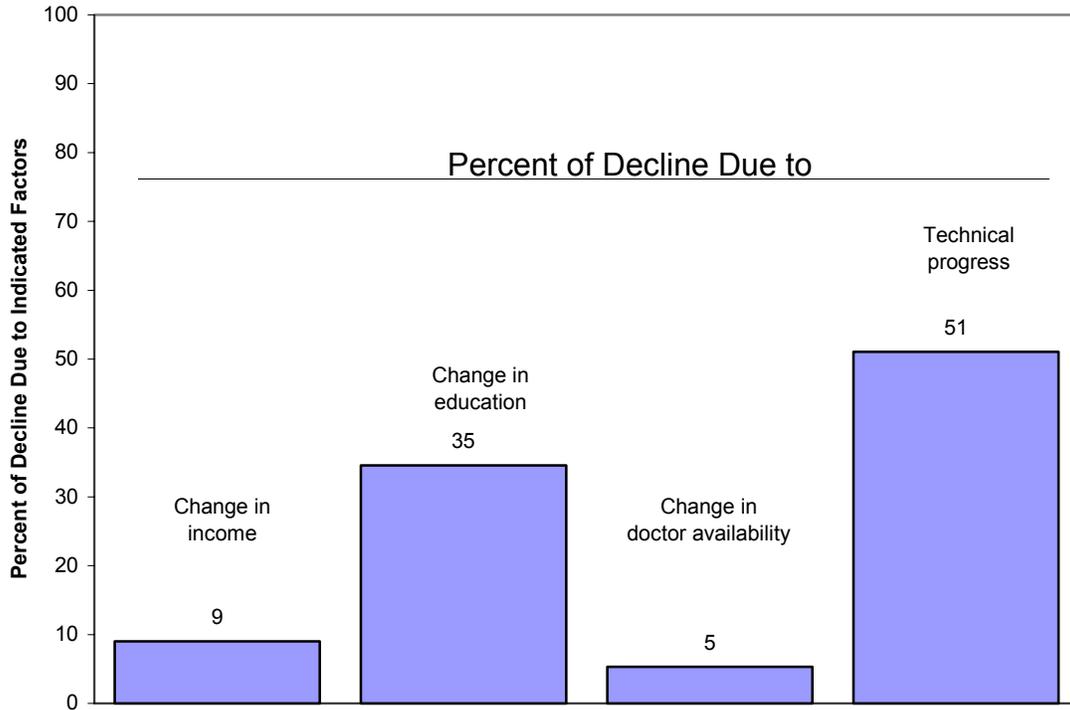


Note:

The calculation is based on Model 4 in Table 2. Average income in India increased by 42% in the period of 1962 to 1987; average years of female education increased from 0.8 to 2.5 years; average doctor availability increased from 1962's 21 to 41 per 100,000 people in 1987.

Figure 3:
Sources of Predicted Decline in IMR, 1962-87

Panel C: South Korea
(Level of IMR in 1962 = 70 Decline, 1962-87 = 56)



Note:

The calculation is based on Model 4 in Table 2. Average income in South Korea increased by 371% in the period of 1962 to 1987; average years of female education increased from 3.6 to 8.4 years; average doctor availability increased from 1962's 28 to 89 per 100,000 people in 1987.

openness, but not for the number of doctors. The latter quantity should instead be seen as an explanation *why* countries differ in performance.

The *country-specific* component of technical progress is given by μ_{1i} (equation 12), and Annex Table C.2 provides its value for all countries. Countries with a negative value for μ_{1i} have a rate of technical progress better than would be predicted from the country's characteristics and in that sense can be said to perform well. Over the 25-year period we are considering the cumulative effect would be on its IMR relative to what would be predicted from the average value of μ_{1i} (*i.e.*, $\mu_{1i} = 0$) by the amount $\exp(25\mu_{1i})$. To take an example, for Senegal $\mu_{1i} = -.016$ and $e^{(-.016*25)} = .67$, indicating that Senegal's IMR in 1987 was 67 percent of what would have been expected had it had an average value of μ_{1i} . Put differently, Senegal's IMR was 33% better than expected from the model. We label the quantity $1-\exp(T * \mu_{1i})$ the *within-period performance* of country i . This number gives the percentage by which the country over- (positive numbers) or underperforms (negative numbers) the average country (performance score of zero) within the period.

In addition to varying in their performance with respect to technical progress, countries vary in the value of their intercept term, β_{0i} in equation 7. Part of this variation we explain by whether the country is coastal or in the tropics, but there remains an unexplained country-specific contribution to the intercept term (μ_{0i}). Factors influencing μ_{0i} after controlling for the geographical variables in equation (11a) might include aspects of infrastructure such as long-standing high levels of water supply and sanitation, or long-standing aspects of health policy such as high levels of immunization coverage throughout the period. It could also reflect the cumulative amount of technical progress in the country prior to the beginning of the period. These antecedent differences in countries will be reflected in μ_{0i} , and can in some sense be viewed as 'initial conditions' for the country in 1962. To continue with the Senegal example, its value for $\mu_{0i} = .29$, indicating a substantial adverse initial effect. The result of this alone would be to increase its IMR level by 34 percent ($e^{.29} = 1.34$), that is, an IMR level 34% worse than what the model predicts. A number of previous efforts to assess country performance on health have focused, essentially, on μ_{0i} . [See, for example, Wang, Jamison, Bos, Preker and Peabody (1999).] We label $1-\exp(\mu_{0i})$ the *beginning-of-period performance* of country i .

A more comprehensive measure of country performance would combine the country-specific components of performance on both level and on rate of technical progress. The ratio by which Senegal's IMR differs from what would have been expected in 1987 — because of its technical progress in the preceding 25 years and its initial (upward) shift in mortality level — is then given to be $e^{(.29-25*.016)} = .90$, or 10% better than the model prediction. We label the composite, $1-\exp(\mu_{0i} + T * \mu_{1i})$, the *end-of-period performance* of country i over the period T . As the length of the period becomes small the end-of-period performance becomes close to the beginning-of-period value. Annex Table C.2 shows all three measures of performance and the rank order of each country by each measure. (The rank orderings are within either the low- and middle-income group of 70 countries or the high-income group of 24 countries.) Table 4

shows the best and worst performing members of each group in terms of the composite (end-of-period) measure, which we view as the most comprehensive measure. For both groups of countries μ_{1i} correlates slightly negatively with μ_{0i} . One interpretation is that countries with low μ_{0i} (good beginning-of-period performance) have implemented attractive new methods earlier and that the potential for further technical progress (or for good within-period performance) is somewhat diminished.

V. CONCLUSION

The 20th century witnessed huge and unprecedented declines in mortality rates at all ages and in most parts of the world. Understanding the sources of these changes is important not only for understanding one of the defining events of world history but, also, to devise policies to address the needs of the perhaps 25 percent of the world's population whose mortality rates remain far higher than those of the rest of humanity. Several approaches shed light on the sources of mortality decline. Epidemiologists and demographers have carefully tracked specific communities for many years to assess what causes of mortality decline, and for what reasons. An interesting example of this approach found, in rural Senegal, that much of the rapid mortality decline there could be traced to the introduction of interventions addressing specific conditions (Pison et al, 1993). Another approach is historical. Easterlin (1998, 1999), for example, examines the interplay of economic growth, urbanization and mortality in 19th and 20th century Europe. He finds little correlation between the timing of periods of economic growth and mortality decline and concludes that income growth in the 19th century probably had a real but modest impact on reducing mortality through its influence on food availability and environmental conditions. Fogel (1997) has also stressed the importance of increases in food availability during this period. These positive factors were partially offset by increased infectious disease transmission resulting from urbanization. Easterlin concludes that 20th century mortality decline, which was much more rapid than that of the 19th century, had its origin in technical progress, and Powles (2001) has pointed to the importance and nature of the institutional changes required to translate technical change and economic improvements into mortality reduction.

Increasingly good time series data have become available on country-specific demographic and economic conditions for the period from around 1960. These data have allowed statistical assessment of relations among income, education, technical progress and mortality, a line of work initiated by Preston (1975, 1980). This paper adds to that literature by continuing to explore of the role of geographical variables (work begun by Bloom and Sachs, 1998) and, more importantly, by allowing for heterogeneity across countries in the rate of technical progress in mortality decline. We find that there is high variation across countries in the rate of technical progress and that taking account of that variation leads to estimates of the effect of income on health that are less than a quarter of those of previous assessments (including some of our own). Even in a period of rapid economic growth income changes can account for only a modest fraction of the changes in infant mortality in most countries. Technical progress and educational improvements

Table 4.
 Countries Ranked by their End-of-Period Performance in Reducing IMR
 (Listed alphabetically within groups)

Low- and Middle-Income Countries (N = 70)	High-Income Countries (N = 24)
Top Ten	Top Five
Bulgaria	Finland
Central African Republic	Hong Kong
Columbia	Singapore
Costa Rica	Spain
Kenya	Sweden
Malaysia	
Sri Lanka	
Sudan	
Venezuela	
Zimbabwe	
Bottom Ten	Bottom Five
Bangladesh	Belgium
Bolivia	Israel
Ecuador	New Zealand
Gambia	United Kingdom
Guinea Bissau	United States
Indonesia	
Lesotho	
Philippines	
Sierra Leone	
Turkey	

Source: Annex Table C.2, based on rank ordering number (3).

are far more important in explaining why infant mortality has declined at such different rates in different countries.

Drawing on Mosk and Johansson's (1986) assessment of the interplay between income and mortality in Japan, it may be an instructive simplification to categorize mortality history into 3 or 4 epochs. Epoch I, extending up to the late 18th century, was a period of ups and downs in mortality rates unaccompanied by any upward trend. Epoch II, in the 19th century, witnessed slow but real mortality reductions among the North Atlantic countries that resulted from improved diets and other consequences of income growth, but that were partially counterbalanced by the adverse effects of urbanization. Epoch III, in the 20th century, was a period of very rapid mortality decline in much of the world that was based on the generation and diffusion of inexpensively applied new knowledge and specific technologies embodying that knowledge. A possible Epoch IV, in the first quarter of the 21st century, may involve convergence of all communities' mortality rates to the levels technology has made possible even at low levels of income.¹⁵

¹⁵ See Jha, Mills and others (2002) for assessment of the priority diseases to be addressed, the relevant technologies and the probable costs.

Annex A: Description of Data

We obtain our data on infant mortality rates from the United Nations Population Division 1998 Series.¹⁶ Income per capita is the real gross domestic product (GDP) per capita adjusted for purchasing power parity and is expressed in 1985 US dollars (Heston and Summers, 1996; Summers and Heston, 1991). The educational measure is the average number of years of education for the female population, aged 15 years and above (Barro and Lee, 1986).¹⁷ We also included a variable on the number of physicians per 1,000 population in our analysis based on the CD version of *World Development Indicators 2001* (World Bank, 2001). In order to have the natural logarithm of physicians be a positive number, we re-calculated and redefined the variable to represent the number of physicians per 100,000 population. The geographical variables are from Gallup, Sachs and Mellinger (1999). These variables measure the percentage of a country's land area situated in the geographical tropics and the percentage of the land area within 100 km of the coast or a navigable waterway. The economic policy variable measures the percentage of years between 1965 and 1990 that the country's economy was considered open, as described in Sachs and Warner (1995).

The findings of this paper are based on 94 countries with a total of 477 observations from the period 1962-87. The countries are alphabetically listed in Annex Table C.1. Definitions and descriptive statistics of the variables used are reported in Annex Table A.1. Across all observations, the average infant mortality rate is 77 deaths per thousand live births; income per capita is \$3,525; and the average education level of adult females is 3.9 years. Table A.1 also presents the means and standard deviations of each variable for 1962 and 1987. As shown, between 1962 and 1987 income per capita almost doubled, from \$2,626 to \$4,685, infant mortality almost halved, from 97 per thousand to 54 per thousand, and the average female education level increased from 3.3 years to 4.8 years.

¹⁶ The correlation coefficients between the United Nations data and the IMR data from the 1999 World Development Indicators by year range from 0.994 to 0.998 depending on the year. Ahmad, Lopez and Inoue (2000) and Hill et.al. (n.d.) provide thoughtful discussions and assessments of the difficulties in measuring IMR, how those can be addressed and current estimates.

¹⁷ Krueger and Lindahl (2001) provide an extensive discussion of the properties of alternative education series and conclude that all contain extensive measurement error but that the Barro-Lee series has important advantages over alternatives.

Annex Table A.1.
Definitions, Means, and Standard Deviations (in Parenthesis) of the Variables Used

Variable	Definition	All years	t = 1962	t = 1987
Time-varying variables				
Y5 _{it}	GDP per capita of country <i>i</i> averaged over the 5-year period from (t - 2) to (t + 2)	3,525 (3,465)	2,626 (2,426)	4,686 (4,562)
LY5 _{it}	Natural logarithm of Y5 _{it}	7.71 (1.0)	7.46 (0.9)	7.95 (1.1)
FEDUC _{it}	Average numbers of years of education in the female population aged 15 and above for country <i>i</i> in year <i>t</i>	3.88 (2.8)	3.32 (2.7)	4.81 (3.0)
IMR _{it}	Infant mortality rate (deaths prior to age 1 per 1000 live births) for country <i>i</i> in year <i>t</i>	76.9 (52.9)	97.3 (59.0)	53.6 (42.0)
LIMR _{it}	Natural logarithm of IMR _{it}	4.00 (0.9)	4.32 (0.8)	3.55 (1.1)
DOC _{it}	Number of physicians (per 100,000 people) for country <i>i</i> in year <i>t</i>	70.2 (77.6)	52.9 (53.9)	109.5 (110.9)
LDOC _{it}	Natural logarithm of number of physicians (per 100,000 people) for country <i>i</i> in year <i>t</i>	3.48 (1.4)	3.25 (1.4)	3.91 (1.5)
TIME _t	Calendar year of observation minus 1962 (= t - 1962)	12.55 (8.66)	0.00	25.00
Number of observations		477	80	82
Time-invariant variables				
TROPICS _i	Fraction of land area situated in the geographical tropics for country <i>i</i>	0.54 (0.48)		
COASTAL _i	Fraction of land area located within 100km of the seacoast or an ocean-navigable waterway for country <i>i</i>	0.49 (0.37)		
OPEN6590 _i	Fraction of years between 1965 and 1990 that country <i>i</i> is deemed to have had an open economy	0.36 (0.43)		
AFRICA _i	Indicator for countries in Africa (takes value 1 for African countries and 0 otherwise)	0.29 (0.45)		
Number of countries:		94		

Annex B: Alternative Models

All the models discussed in the main text share the characteristic that they do not allow for any cross-country variation in the coefficients on income, education or physicians per capita. As explained above, our main focus is on cross-country differences in technical progress, but there is no *a priori* reason to think that there may not be important cross-country variation in the use of the other inputs into the health production function. Indeed Oeppen (1999) has found substantial cross-country variation in the income elasticity. To check whether our focus on country-specific time slopes was warranted, we estimated twelve more models that are equivalent to models 1 to 4 of Table 2 except that they let either the income, education, or physicians per capita slope vary in the same way the time slope was allowed to vary in models 2 - 4. The results are reported in Annex Table B.1 (for income), Annex Table B.2 (for education), and Annex Table B.3 (for physicians per capita). Each column reports the coefficient results and the same model statistics as the table for the main models. For easy reference each table's column 1 repeats column 1 of Table 2, *i.e.* the baseline model that results from the imposition of the constraint of equal coefficients across countries.

As the tables show, the log-likelihood and chi-squared values are uniformly better in all the models that allow for parameter heterogeneity. That said, Table 2 and Annex Tables B.1 - B.3 collectively show that the fit is much better improved by relaxing the assumption of time slope homogeneity than by relaxing the homogeneity assumption for the other coefficients.

If we move from measures of goodness of fit to the coefficient estimates, we also find that making the time slope heterogeneous is more informative. The tables show that while varying the time slope across countries has dramatic effects on the income slope, there is no similar effect when we make the other coefficients heterogeneous. Across all the models in the Annex B tables, the slopes on the determinants whose effect we keep homogeneous are stable. Finally, while the variation in the time slope is only somewhat correlated with the country level shift, the correlations between the country intercept shift and the variation in the other slopes are very high, suggesting that the inclusion of a country-specific time slope is more useful than varying the other slopes.

Allowing country-specific time slopes simply means allowing each country's health production function to shift down at different rates, which is theoretically not a great leap from allowing different levels (intercepts) for different countries. Allowing country-specific coefficients on the socio-economic determinants, on the other hand, is tantamount to saying that the shape of the production function is different. Such a move would require us to rethink what we are doing when we estimate health production functions with cross-country data. All of this leads us to believe that while country variation in the effect of income, education and doctor coverage on health may be important subjects of future research, understanding the role of differential rates of technical progress is particularly important at this stage.

Annex Table B.1.
 Robustness Check: Cross-Country Variation in the Income Slope (robust t-statistics in parentheses)

Independent Variables/Model Parameters	Analogous Models			
	(1)	(2)	(3)	(4)
Level-1 Model: Determinants of IMR (modified equation 7)				
Average value of country-specific intercepts (sample mean of β_{0i})	7.32	6.85	6.84	6.76
Average value of country-specific LY5 coefficient (sample mean of β_{2i})	-0.311	-0.214	-0.210	-0.204
TIME (β_1)	-0.02 (9.04)	-0.02 (9.92)	-0.017 (10.79)	-0.018 (11.34)
FEDUC (β_3)	-0.12 (5.91)	-0.11 (5.61)	-0.099 (5.30)	-0.089 (4.89)
LDOC (β_4)	-0.06 (1.89)	-0.11 (4.10)	-0.118 (4.53)	-0.116 (4.32)
Level-2 Model: Country-specific LY5 coefficients (β_{2i})				
Coefficient on LY5 (common value across countries, γ_{20})	-0.31 (5.57)	-0.21 (4.12)	-0.120 (1.26)	-0.097 (1.06)
TROPICS (γ_{21})			0.314 (3.71)	0.293 (3.62)
COASTAL (γ_{22})			-0.524 (5.13)	-0.504 (5.41)
OPEN6590 (γ_{23})				-0.048 (3.68)
Variance of country-specific income effect μ_{2i}		0.1411 (5.27)	0.0745 (4.61)	0.0589 (4.38)

Annex Table B.1, continued

	(1)	(2)	(3)	(4)
Level-2 Model: Country-specific intercept (β_{0i})				
Intercept (common value across countries, γ_{00})	7.37 (19.12)	7.01 (18.96)	6.35 (9.22)	6.25 (9.48)
TROPICS (γ_{01})	0.17 (1.62)	0.018 (0.19)	-2.29 (3.61)	-2.19 (3.58)
COASTAL (γ_{02})	-0.29 (2.65)	-0.348 (2.74)	3.50 (4.60)	3.45 (4.95)
Variance of country-specific level effect μ_{0i}		7.79 (5.23)	4.08 (4.53)	3.35 (4.34)
Correlation between country-specific level effect μ_{0i} and income effect μ_{2i}		-0.99	-0.99	-0.99
Estimation Statistics				
Number of observations	477	477	477	477
Number of countries	94	94	94	94
Number of parameters estimated	9	11	13	14
Log-likelihood value	97.4	173.5	193.3	200.2
Likelihood-ratio tests:				
Comparison model		1	2	3
Test degrees of freedom		2	2	1
Chi-square value		152.20	39.58	13.8
p-value		0.000	0.000	0.000

Dependent variable: logarithm of the infant mortality rate (LIMR).

Annex Table B.2.

Robustness Check: Cross-Country Variation in the Education Slope (robust t-statistics in parentheses)

Independent Variables/Model Parameters	Analogous Models			
	(1)	(2)	(3)	(4)
Level-1 Model: Determinants of IMR (modified equation 7)				
Average value of country-specific intercepts (sample mean of β_{0i})	7.32	7.11	6.94	6.72
Average value of country-specific FEDUC coefficient (sample mean of β_{3i})	-0.311	-0.094	(0.08)	(0.07)
TIME (β_1)	-0.02 (9.04)	-0.02 (9.76)	-0.018 (10.42)	-0.019 (11.07)
LY5 (β_2)	-0.12 (5.91)	-0.27 (4.56)	-0.239 (4.17)	-0.211 (3.79)
LDOC (β_4)	-0.06 (1.89)	-0.09 (3.32)	-0.097 (3.79)	-0.103 (4.04)
Level-2 Model: Country-specific FEDUC coefficients (β_{3i})				
Coefficient on FEDU (common value across countries, γ_{30})	-0.31 (5.57)	-0.09 (3.54)	-0.028 (0.73)	0.020 (0.52)
TROPICS (γ_{31})			0.105 (3.14)	0.071 (2.27)
COASTAL (γ_{32})			-0.227 (5.00)	-0.182 (4.34)
OPEN6590 (γ_{33})				-0.1155 (5.70)
Variance of country-specific education effect μ_{3i}		0.0262 (5.73)	0.0167 (5.33)	0.0131 (1.00)

Annex Table B.2, continued

	(1)	(2)	(3)	(4)
Level-2 Model: Country-specific intercept (β_{0i})				
Intercept (common value across countries, γ_{00})	7.37 (19.12)	7.26 (17.25)	6.88 (16.23)	6.66 (16.35)
TROPICS (γ_{01})	0.17 (1.62)	0.207 (1.83)	-0.17 (1.04)	-0.12 (0.80)
COASTAL (γ_{02})	-0.29 (2.65)	-0.526 (4.04)	0.30 (1.48)	0.27 (1.35)
Variance of country-specific level effect μ_{0i}		0.54 (5.98)	0.37 (5.77)	0.34 (5.74)
Correlation between country-specific level effect μ_{0i} and education effect μ_{2i}		-0.85	-0.77	-0.80
Estimation Statistics				
Number of observations	477	477	477	477
Number of countries	94	94	94	94
Number of parameters estimated	9	11	13	14
Log-likelihood value	97.4	170.5	187.4	199.9
Likelihood-ratio tests:				
Comparison model		1	2	3
Test degrees of freedom		2	2	1
Chi-square value		146.26	33.72	25
p-value		0.00	0.000	0.000

Dependent variable: logarithm of the infant mortality rate (LIMR).

Annex Table B.3.

Robustness Check: Cross-Country Variation in the LDOC Slope (robust t-statistics in parentheses)

Independent Variables/Model Parameters	Analogous Models			
	(1)	(2)	(3)	(4)
Level-1 Model: Determinants of IMR (modified equation 7)				
Average value of country-specific intercepts (sample mean of β_{0i})	7.32	7.43	7.40	7.17
Average value of country-specific LDOC coefficient (sample mean of β_{4i})	-0.311	-0.167	-0.178	-0.174
TIME (β_1)	-0.02 (9.04)	-0.02 (9.58)	-0.016 (9.96)	-0.017 (10.91)
LY5 (β_2)	-0.12 (5.91)	-0.27 (4.91)	-0.258 (4.87)	-0.232 (4.58)
FEDUC (β_3)	-0.06 (1.89)	-0.10 (4.70)	-0.095 (4.59)	-0.085 (4.40)
Level-2 Model: Country-specific LDOC coefficients (β_{4i})				
Coefficient on LDOC (common value across countries, γ_{40})	-0.31 (5.57)	-0.17 (3.79)	-0.140 (2.07)	-0.094 (1.53)
TROPICS (γ_{41})			0.250 (4.14)	0.207 (3.64)
COASTAL (γ_{42})			-0.349 (4.29)	-0.302 (4.12)
OPEN6590 (γ_{43})				-0.121 (5.07)
Variance of country-specific LDOC effect μ_{4i}		0.0861 (5.49)	0.0418 (4.72)	0.0278 (4.24)

Annex Table B.3, continued

	(1)	(2)	(3)	(4)
Level-2 Model: Country-specific intercept (β_{0i})				
Intercept (common value across countries, γ_{00})	7.37 (19.12)	7.57 (18.76)	7.41 (17.31)	7.18 (17.88)
TROPICS (γ_{01})	0.17 (1.62)	0.096 (0.90)	-0.84 (3.58)	-0.77 (3.56)
COASTAL (γ_{02})	-0.29 (2.65)	-0.389 (3.14)	0.89 (2.95)	0.83 (3.02)
Variance of country-specific level effect μ_{0i}		1.37 (5.59)	0.64 (4.91)	0.46 (4.59)
Correlation between country-specific level effect μ_{0i} and physician coverage effect μ_{4i}		-0.96	-0.92	-0.91
Estimation Statistics				
Number of observations	477	477	477	477
Number of countries	94	94	94	94
Number of parameters estimated	9	11	13	14
Log-likelihood value	97.4	152.8	171.4	183.8
Likelihood-ratio tests:				
Comparison model		1	2	3
Test degrees of freedom		2	2	1
Chi-square value		110.81	37.16	24.8
p-value		0.00	0.000	0.000

Dependent variable: logarithm of the infant mortality rate (LIMR).

Annex C: Country-specific Estimates of IMR Change, of Sources of IMR Decline and of Performance

For each country, as well as for the entire sample of 94 countries, we decomposed the sources of the country's IMR decline between 1962 and 1967 into the amount due to changes in its income level, its education level, its number of physicians and its (country-specific) technical progress. We further assessed the amount of the technical progress for the country that was due to geographical location, the openness of its economy and a residual country-specific element. Annex Table C.1 conveys these decompositions for each country.

Annex Table C.2 provides information, for each country, on the size of each country's rate of technical progress and the country-specific level effect, based on model (7) of Table 3. It then orders countries by the three measures of performance described in Section IV of the text.

Annex Table C.1:
Percent of IMR Decline due to Technical Progress and to Improvements in Income and Education Levels for 94 Countries.^a

Country	IMR			Percent of IMR Decline Due to				Factors Influencing Technical Progress ^b			
	level in 1962	level in 1987	percent decline, 1962 to 87	income improvement	education improvement	Increase of physicians	technical progress	tropical location	coastal location	open economic policies	country-specific effect
Total Sample (94 countries)	99	44	56	7	21	7	66	-8	13	21	39
Algeria	160	67	58	7	25	8	60	-2	1	0	61
Argentina	60	27	55	2	34	7	57	0	5	0	53
Australia	20	9	56	6	11	4	79	-5	5	53	26
Austria	32	9	71	6	20	2	72	0	10	38	24
Bangladesh	150	110	27	4	26	39	31	-10	41	0	-1
Belgium	27	9	66	6	8	6	81	0	18	41	22
Bolivia	164	90	45	17	-3	-108	194	-54	2	169	77
Botswana	113	57	49	18	30	17	35	-12	0	30	18
Brazil	109	55	50	11	7	13	69	-16	7	0	79
Cameroon	154	92	40	14	29	13	44	-23	5	0	62
Canada	26	7	72	5	0	4	91	0	1	38	52
Central African Republic	167	104	38	-3	22	11	70	-26	0	0	97
Chile	109	18	83	1	13	-21	107	-1	10	20	78
Colombia	92	41	55	7	30	8	56	-15	8	12	51
Costa Rica	81	16	80	2	9	4	85	-7	13	4	75
Denmark	20	8	60	6	5	5	84	0	21	48	14
Dominican Republic	118	55	53	7	24	20	48	-15	27	0	36
Ecuador	119	57	52	23	114	-98	60	-43	30	122	-49

Annex Table C. 1, continued

	IMR			Percent of IMR Decline Due to				Factors Influencing Technical Progress			
	level in 1962	level in 1987	percent decline, 1962 to 87	income improve- ment	education improve- ment	Increase of physicians	technical progress	tropical location	coastal location	open- economic policies	country- specific effect
El Salvador	123	54	56	3	21	12	65	-15	28	3	50
Finland	19	6	69	6	14	8	72	0	5	39	28
France	25	8	69	6	15	6	73	0	15	39	20
Germany	29	8	72	5	5	3	87	0	15	37	34
Ghana	127	82	36	-2	36	0	67	-25	9	24	60
Greece	50	11	78	6	20	4	70	0	13	31	25
Guatemala	127	65	49	4	22	4	70	-19	14	9	65
Haiti	176	100	43	0	26	4	70	-22	40	0	52
Honduras	136	53	61	3	16	17	64	-12	15	0	61
Hong Kong	33	7	79	9	31	5	55	-8	14	31	18
India	157	93	41	6	37	9	48	-12	10	0	49
Indonesia	133	75	44	14	49	22	15	-19	26	63	-54
Iran	163	53	68	3	23	2	72	0	2	0	70
Ireland	28	8	71	5	11	2	82	0	15	35	31
Israel	29	11	64	19	70	-95	107	0	47	26	33
Italy	40	10	75	5	11	6	78	0	12	33	33
Jamaica	61	27	56	4	38	-45	102	-20	36	31	55
Japan	25	5	80	8	10	2	80	0	13	31	36
Jordan	125	44	65	13	47	-31	71	0	4	58	9
Kenya	118	73	38	6	42	8	44	-25	4	12	53
Korea, Republic of	70	14	80	9	35	5	51	0	12	27	12
Lesotho	145	107	26	29	22	11	39	0	0	0	39
Liberia	180	104	42	5	35	-51	111	-41	50	0	102

Annex Table C. 1, continued

	IMR			Percent of IMR Decline Due to				Factors Influencing Technical Progress			
	level in 1962	level in 1987	percent decline, 1962 to 87	income improvement	education improvement	Increase of physicians	technical progress	tropical location	coastal location	open-economic policies	country-specific effect
Malawi	204	153	25	9	35	-5	61	-46	0	0	107
Malaysia	63	17	73	8	29	5	58	-10	14	39	15
Mali	208	145	30	0	8	22	70	-29	0	15	84
Mauritius	61	24	61	3	24	8	65	-11	20	46	10
Mexico	88	40	55	7	42	6	45	-7	10	11	31
Mozambique	185	125	32	-9	12	-10	106	-26	17	0	115
Myanmar	150	101	33	14	35	18	34	-29	15	0	48
Nepal	189	109	42	7	11	15	67	0	0	0	67
Netherlands	16	7	55	7	39	6	49	0	24	54	-29
New Zealand	21	10	50	6	29	4	61	0	31	14	17
Nicaragua	131	65	50	1	24	4	72	-18	20	0	69
Niger	186	135	28	1	16	-5	88	-51	0	0	139
Norway	17	8	54	9	26	7	58	0	12	56	-10
Pakistan	155	100	35	13	39	10	38	0	4	0	34
Papua New Guinea	155	70	55	2	10	22	66	-13	16	0	62
Paraguay	62	47	25	17	59	5	19	-23	24	13	5
Peru	136	68	50	4	50	7	39	-17	7	8	41
Philippines	76	54	30	9	86	-1	6	-31	57	15	-34
Portugal	76	14	82	5	14	4	77	0	9	28	40
Romania	60	26	56	14	28	3	55	0	11	0	45
Senegal	168	76	55	1	8	-16	107	-18	19	0	106
Sierra Leone	215	180	16	6	237	-254	110	-266	235	0	141
Singapore	30	7	75	10	17	4	69	-8	14	32	31

Annex Table C. 1, continued

	IMR			Percent of IMR Decline Due to				Factors Influencing Technical Progress			
	level in 1962	level in 1987	percent decline, 1962 to 87	income improvement	education improvement	Increase of physicians	technical progress	tropical location	coastal location	open-economic policies	country-specific effect
South Africa	87	62	28	6	11	45	38	-1	6	0	33
Spain	42	9	80	5	17	5	74	0	6	29	38
Sri Lanka	80	24	70	4	20	-2	79	-10	17	9	62
Sweden	15	6	60	5	19	8	68	0	7	51	11
Switzerland	20	7	66	4	21	1	74	0	6	44	24
Syrian Arab Rep.	125	49	61	8	34	10	48	0	3	2	43
Tanzania	143	92	36	9	-11	-4	106	-26	4	0	128
Thailand	95	39	59	10	21	3	66	-12	6	50	22
Togo	170	96	44	9	31	18	42	-21	6	0	58
Trinidad & Tobago	48	20	59	12	78	-69	80	-30	55	0	55
Tunisia	155	49	68	7	23	10	60	0	9	3	48
Turkey	176	81	54	8	25	7	60	0	11	5	44
Uganda	125	124	1	18	131	-71	22	-232	0	114	141
United Kingdom	22	9	59	8	18	-58	131	0	36	83	12
United States	25	10	60	5	31	4	60	0	6	49	6
Uruguay	48	23	53	1	32	6	61	0	15	3	43
Venezuela	73	27	63	0	32	6	62	-13	13	4	58
Zambia	130	85	35	-3	48	5	51	-29	0	0	79
Zimbabwe	106	69	35	4	26	-4	74	-27	0	0	101

^a This decomposition of decline in IMR is based on model 4 (Table 2).

^b These columns shown the amount of the technical progress components of IMR decline that is due to each of the three indicated factors.

Annex Table C.2.

The Country-Specific Components of the Determinants of IMR and Country Performance

	Country-specific components of IMR			Rank order among low- and middle-income countries based on column		
	(1)	(2)	(3)	(1)	(2)	(3)
Low- and Middle-Income Countries	μ_{0i}^b	μ_{1i}^c	total country-specific effect on IMR ^d			
Algeria	-47%	1%	-18%	14	60	25
Argentina	-23%	0%	-9%	29	54	36
Bangladesh	-53%	-1%	-114%	12	4	1
Benin	7%	0%	13%	48	46	53
Bolivia	-61%	0%	-81%	9	19	8
Botswana	20%	-1%	7%	61	17	46
Brazil	-7%	1%	18%	40	63	58
Bulgaria	27%	0%	25%	63	35	64
Cameroon	8%	0%	9%	49	38	50
Central African Republic	12%	1%	23%	50	55	62
Chile	-138%	3%	-10%	1	69	34
China	28%	-1%	3%	64	7	41
Colombia	14%	0%	21%	55	49	61
Congo	-10%	0%	-14%	38	31	30
Costa Rica	-24%	4%	52%	27	70	70
Dominican Republic	-36%	0%	-32%	19	41	20
Ecuador	-15%	-2%	-79%	35	3	9
Egypt	-91%	1%	-61%	3	57	13
El Salvador	-40%	0%	-26%	16	53	24
Gambia	-70%	-1%	-103%	6	12	2
Ghana	15%	0%	8%	57	23	48
Guatemala	-3%	0%	6%	44	48	44
Guinea Bissau	-66%	-1%	-95%	8	13	6
Haiti	-55%	0%	-61%	11	29	12
Honduras	-24%	1%	14%	26	64	54
Hungary	-70%	2%	-16%	5	66	27
India	-24%	0%	-31%	28	27	21
Indonesia	-11%	-2%	-100%	36	1	3
Iran	-73%	2%	-15%	4	68	29
Jamaica	24%	0%	21%	62	30	60
Jordan	-28%	-1%	-63%	23	9	11
Kenya	29%	0%	23%	65	24	63
Korea, Republic of	-22%	-1%	-42%	30	15	17
Lesotho	-59%	-1%	-95%	10	10	5
Liberia	-39%	0%	-43%	18	33	16
Malawi	-19%	0%	-26%	31	28	23

Annex Table C.2, continued

	Country-specific components of IMR			Rank order among low- and middle-income countries based on column		
	(1)	(2)	(3)	(1)	(2)	(3)
	μ_{0i}	μ_{1i}	total country-specific effect on IMR			
Low- and Middle-Income Countries						
Malaysia	37%	-1%	27%	70	16	65
Mali	-16%	0%	-10%	34	43	35
Mauritius	14%	-1%	-3%	56	11	38
Mexico	-5%	0%	-14%	42	25	31
Mozambique	-27%	0%	-16%	25	50	28
Myanmar	13%	0%	4%	52	22	43
Nepal	-45%	0%	-32%	15	51	19
Nicaragua	-28%	1%	-12%	24	56	32
Niger	2%	0%	4%	45	40	42
Pakistan	-31%	-1%	-53%	22	14	15
Papua New Guinea	-11%	1%	15%	37	61	55
Paraguay	29%	-1%	2%	66	5	40
Peru	-31%	0%	-39%	21	26	18
Philippines	-9%	-2%	-78%	39	2	10
Poland	-7%	0%	-11%	41	32	33
Romania	3%	0%	9%	47	44	49
Rwanda	12%	0%	10%	51	34	51
Senegal	-34%	2%	10%	20	67	52
Sierra Leone	-47%	-1%	-93%	13	8	7
South Africa	-39%	0%	-55%	17	20	14
Sri Lanka	-4%	1%	28%	43	65	66
Sudan	32%	0%	36%	68	45	69
Syrian Arab Rep.	-18%	0%	-7%	32	52	37
Tanzania	2%	1%	21%	46	59	59
Thailand	14%	-1%	0%	53	18	39
Togo	14%	0%	16%	54	42	57
Trinidad & Tobago	15%	0%	6%	58	21	45
Tunisia	-68%	1%	-29%	7	62	22
Turkey	-104%	0%	-100%	2	39	4
Uganda	32%	-1%	7%	69	6	47
Uruguay	-16%	0%	-18%	33	36	26
Venezuela	18%	1%	33%	60	58	67
Zambia	17%	0%	15%	59	37	56
Zimbabwe	30%	0%	35%	67	47	68

Annex Table C.2, continued

High-Income Countries	Country-specific components of IMR			Rank order among high-income countries based on column		
	(1)	(2)	(3)	(1)	(2)	(3)
	μ_{0i}	μ_{1i}	total country-specific effect on IMR			
Australia	37%	0%	31%	16	10	14
Austria	31%	0%	29%	15	13	13
Belgium	-5%	0%	-7%	4	14	5
Canada	8%	1%	36%	8	23	15
Denmark	8%	-1%	-7%	7	8	6
Finland	46%	0%	49%	18	15	22
France	39%	0%	36%	17	12	16
Germany	-13%	1%	1%	1	19	8
Greece	-13%	0%	-6%	2	16	7
Hong Kong	55%	0%	52%	21	11	23
Ireland	16%	0%	22%	12	17	11
Israel	9%	-1%	-15%	9	5	3
Italy	2%	1%	20%	5	20	10
Japan	30%	1%	43%	14	21	19
Netherlands	52%	-2%	14%	20	1	9
New Zealand	2%	-1%	-21%	6	6	1
Norway	60%	-2%	41%	24	2	17
Portugal	-12%	1%	23%	3	24	12
Singapore	60%	0%	65%	23	18	24
Spain	26%	1%	46%	13	22	20
Sweden	56%	-1%	46%	22	7	21
Switzerland	48%	0%	42%	19	9	18
United Kingdom	15%	-1%	-8%	11	4	4
United States	11%	-1%	-20%	10	3	2

^a These results are based on Model 7 of Table 3 estimated without inclusion of doctor availability, LDOC.

^b This column shows μ_{0i} , the calculated value of the country-specific component of the intercept (equation 11a) by $[1 - \exp(\mu_{0i})]$.

^c This column shows μ_{1i} , the calculated value of the country-specific component of the coefficient on time (equation 12b) as by $[1 - \exp(\mu_{1i})]$.

^d This column shows the total country-specific effect over the 25 years, i.e., it is the upward (or downward) shift for a given country, relative to its expected level (μ_{0i}) plus the cumulative effect over 25 years of the country-specific component of the rate of technical progress $25\mu_{1i}$. To express in terms of IMR (rather than its logarithm), we exponentiate and express the result as a percent of what the country's expected IMR would be if its value of the country-specific effects were average, i.e. 0. The column 3 value for country i is, therefore, given by $[1 - \exp(\mu_{0i} + 25\mu_{1i})]$.

References

- Adams, P., M. D. Hurd, D. McFadden, A. Merrill and T. Ribiero.** “Healthy, Wealthy and Wise? Tests for Direct Causal Paths between Health and Socioeconomic Status.” *Journal of Econometrics*, 2003, *111(1)*, pp. 3-56.
- Ahmad, Omar B., Alan D. Lopez, & Mie Inoue.** “The Decline in Child Mortality: A Reappraisal.” *Bulletin of the World Health Organization*, 2000, *78(10)*, pp. 1175-1191.
- Anand, Sudhir, & Ravallion, Martin.** “Human Development in Poor Countries: On the Role of Private Incomes and Public Services.” *Journal of Economic Perspectives*, Winter 1993, *7(1)*, pp. 133-50.
- Barro, Robert, & Lee, J.W.** “International Measures of School Years and Schooling Quality.” *American Economic Review, Papers and Proceedings*, 1996, *86*, pp. 218-223.
- Bishai, David M.** “Infant Mortality Time Series are Random Walks with Drift: Are They Cointegrated with Economic Variable?” *Health Economics*, 1995, *4*, pp.157-67.
- Bishai, David M.** “The Hazards of Transforming Infant Mortality with Logs: Astonishing Variability in the Pattern of 20th Century Infant Mortality Decline in 22 Countries.” Unpublished paper, Johns Hopkins University School of Public Health, September 2003.
- Bloom, David E., & Sachs, Jeffrey D.** “Geography, demography, and economic growth in Africa.” *Brookings Papers on Economic Activity*, 1999, *2*, pp. 207-295.
- Bryk, Anthony S., & Raudenbusch, Steven W.** *Hierarchical Linear Models*. Newbury Park, CA: Sage Publications, 1992.
- Crafts, Nicholas.** “Globalization and Growth in the Twentieth Century”. Washington, D.C.: International Monetary Fund, Working Paper WP/00/44, March 2000.
- Cutler, David M., & Srikanth Kadinyala.** “The Return to Biomedical Research: Treatment and Behavioural Effects.” In Kevin M. Murphy and Robert H. Topel (eds.), *Measuring the Gains from Health Research: An Economic Approach*. Chicago: University of Chicago Press, 2003, pp. 110-162..
- Davis, Kingsley.** “The Amazing Decline of Mortality in Underdeveloped Areas.” *American Economic Review (Papers and Proceedings)*, May 1956, *46(2)*, pp. 305-18.

- Deaton, Angus.** *Relative Deprivation, Inequality, and Mortality*. Working Paper 8099. Cambridge, MA: National Bureau of Economic Research, 2001
- DeLong, J. Bradford.** “Cornucopia: The Pace of Economic Growth in the Twentieth Century.” Cambridge, MA: National Bureau of Economic Research, Working Paper 7602, March 2000.
- Easterlin, Richard A.** *Growth Triumphant*. Ann Arbor: The University of Michigan Press, 1996.
- Easterlin, Richard A.** *How Beneficent is the Market? A Look at the Modern History of Mortality*. *European Review of Economic History*, 1999, 3, pp. 257-294.
- Easterly, William.** “Life During Growth.” *Journal of Economic Growth*, 1999, 4, pp. 239-26.
- Filmer, Deon, & Pritchett, Lant.** “The Impact of Public Spending on Health: Does Money Matter?” *Social Science and Medicine*, 1999, 49, pp. 1309-1323.
- Fogel, Robert William.** “New Findings on Secular Trends in Nutrition and Mortality: Some Implications for Population Theory.” In Mark Rosenzweig and Oded Stark (Eds.), *Handbook of Population and Family Economics, Volume 1A*. Amsterdam: Elsevier Science B.V., 1997, pp. 433-481.
- Fuchs, Victor.** “Comment”. In Easterlin, Richard (Ed.), *Population and Economic Change in Developing Countries*. Chicago and London: University of Chicago Press, 1980, pp. 348-351.
- Fuchs, Victor.** “Some Economic Aspects of Mortality in Developed Countries”. In Perlman, Mark (Ed.), *The Economics of Health and Medical Care*. London: Macmillan, 1974, pp. 174-93.
- Gallup, John Luke, & Sachs, Jeffrey D.** “The Economic Burden of Malaria.” *American Journal of Tropical Medicine and Hygiene*, 2001, 64 (supplement), pp. 85-96.
- Gallup, John Luke, Sachs, Jeffrey D., & Mellinger, A.** “Geography and Economic Development,” CID Working Paper No. 1, Center for International Development, Harvard University, 1999. Available on www.cid.harvard.edu .
- Granger, C. W. J., & P. Newbold.** “Spurious regressions in econometrics.” *Journal of Econometrics*, 1974, 2(2), pp. 111-20.
- Greene, William H.** *Econometric Analysis*. 2nd Edition. 1993. New York: MacMillan.

- Gupta, Sanjeev, Verhoeven, Marjin and Tiongson, Erwin.** “Public Spending on Health Care and the Poor.” *Health Economics*, 12, pp. 685-696.
- Heston, Alan, & Summers, Robert.** “International price and quantity comparisons: Potentials and pitfalls.” *International Macro- and Microeconomic Data*, 1996, 86, pp. 20-24.
- Hill, Kenneth, Rohini Pande, Mary Mahe, & Gareth Jones.** *Trends in Child Mortality in the Developing World: 1960 to 1996*. New York: UNICEF, unpublished paper, n.d.
- Hoeffler, Anke.** “The Augmented Solow Model and the African Growth Debate.” *Oxford Bulletin of Economics and Statistics*, 2002, 64(2), pp. 135-158.
- Imbs, Jean, Haroon Mumtaz, Morton O. Ravn, & Helene Rey.** “PPP Strikes Back: Aggregation and the Real Exchange Rate.” National Bureau of Economic Research working paper no. 9372. Cambridge, MA, 2002.
- Ingram, Gregory K.** “Social Indicators and Productivity Convergence in Developing Countries.” In Baumol, William J., Nelson, Richard, R., and Wolff, Edward N. (Eds.), *Convergence of Productivity*. Oxford and New York: Oxford University Press, 1994, pp. 316-333.
- Jamison, Dean T., Jeffrey D. Sachs, & Jia Wang.** “The Effect of the AIDS Epidemic on Economic Welfare in Sub-Saharan Africa.” Geneva: World Health Organization, Working Paper No. WG1:13, Commission on Macroeconomics and Health, 2001.
- Jha, Prabhat, Anne Mills, & 11 others.** “Improving the Health of the Global Poor.” *Science*, 2002, 295, pp. 2036-2039.
- Kreft, Ita, & de Leeuw, Jan.** *Introducing Multilevel Modeling*, London: Sage Publications, 1998.
- Krueger, Alan B., & Lindahl, Mikael.** “Education for Growth: Why and for Whom?” *Journal of Economic Literature*, 2001, 39, pp. 1101-1136.
- Lee, Kevin, Pesaran, M. Hashem, & Smith, Ron.** “Growth and Convergence in a Multi-Country Empirical Stochastic Growth Model”. *Journal of Applied Econometrics*, 1997, 12, pp. 357-392.
- Lichtenberg, Frank R.** “Pharmaceutical Innovation, Mortality Reduction and Economic Growth.” In Kevin M. Murphy and Robert H. Topel (eds.), *Measuring the Gains from Health Research: An Economic Approach*. Chicago: University of Chicago Press, 2003, pp. 74-109.

- Maddison, Angus.** “Poor Until 1820.” *The Wall Street Journal Europe*, January 11, 1999.
- Mokyr, Joel, & Stein, Rebecca.** Science, Health and Household Technology: The Effect of the Pasteur Revolution on Consumer Demand. In Gordon, Robert, J. and Bresnahan, Timothy (eds.), *The Economics of New Goods*. Chicago: University of Chicago Press and NBER, 1997, pp. 143-200.
- Mosk, Carl, & Johannson, S. Ryan.** “Income and Mortality: Evidence from Modern Japan.” *Population and Development Review*, 1986, 12, pp. 415-440.
- Nordhaus, William.** “The Health of Nations: The Contributions of Improved Health to Living Standards.” In Kevin M. Murphy and Robert H. Topel (eds.), *Measuring the Gains from Health Research: An Economic Approach*. Chicago: University of Chicago Press, 2003, pp. 9-40.
- Oeppen, Jim.** “The Health and Wealth of Nations Since 1820.” Paper presented at the 1999 Social Science History Conference, Fort Worth Texas, November, 1999.
- Pesaran, M. Hashem, & Smith, Ron.** “Estimating long-run relationships from dynamic heterogeneous panels.” *Journal of Econometrics*, 1995, 68, pp. 79-113.
- Pison, G., Trape, J.F., Lefebvre, M., & Enel, C.** “Rapid Decline in Child Mortality in a Rural Area of Senegal.” *International Journal of Epidemiology*, 1993, 22(1), pp. 72-80.
- Powles, John.** Healthier Progress: Historical Perspectives on the Social and Economic Determinants of Health.” In Eckersly, Richard, Dixon, Jane and Douglas, Bob (eds.), *The Social Origins of Health and Well-being*. Cambridge: Cambridge University Press, 2001, pp. 3-24.
- Prasad, Eswar, Kenneth Rogoff, Shang-Jin Wei and M. Ayhan Kose.** *Effects of Financial Globalization on Developing Countries: Some Empirical Evidence*. Washington, D.C.: International Monetary Fund, Occasional Paper 220, September 2003.
- Preston, Samuel H.** “Causes and Consequences of Mortality Declines in Less Developed Countries during the Twentieth Century”. In Easterlin, Richard (Ed.), *Population and Economic Change in Developing Countries*. Chicago and London: University of Chicago Press, 1980, pp. 289-360.
- Preston, Samuel H.** “The Changing Relation between Mortality and Level of Economic Development.” *Population Studies*, 1975, 29(2), pp. 231-248.
- Preston, Samuel H., & Haines, M.R.** *Fatal Years: Child Mortality in Late Nineteenth Century America*. New Jersey: Princeton University Press, 1991.

- Pritchett, Lant, & Summers, Lawrence H.** “Wealthier is Healthier,” *The Journal of Human Resources*, 1996, 31(4): pp. 841-868
- Raudenbusch, Steven, Bryk, Anthony, Cheong, Yuk F., & Congdon, Richard.** *HLM5: Hierarchical Linear and Nonlinear Modeling*. Lincolnwood, IL: Scientific Software International, Inc, 1999.
- Robertson, D., & J. Symons.** “Some strange properties of panel data estimators.” *Journal of Applied Econometrics*, 1992, 7, pp. 175-189.
- Rodríguez, Francisco, & Dani Rodrik.** “Trade Policy and Economic Growth: A Skeptic’s Guide to the Cross-National Evidence.” *NBER Macroeconomics Annual 2000*, pp. 1-90. Cambridge, MA: MIT Press.
- Sachs, Jeffrey D., & Warner, Andrew M.** “Economic Reform and the Process of Global Integration.” *Brookings Papers on Economic Activity*, August 1995, 1, pp. 1-118.
- Sandbu, Martin E.** “Bias in Panel Regressions with Heterogeneous Time Trends.” Unpublished paper, Harvard University, 2003.
- Solow, Robert.** “Technical Change and the Aggregate Production Function”. *Review of Economics and Statistics*, 1957, 39, pp. 312-320.
- Summers, Robert, & Heston, Alan.** “The Penn World Table (Mark 5): An expanded set of international comparisons, 1950-1988.” *Quarterly Journal of Economics*, 1991, 106: 327-368.
- United Nations.** *World Population Prospects: The 1998 Revision*. New York: The United Nations, 1999.
- United Nations, Department of Social & Economic Affairs.** *Socio-Economic Differentials in Child Mortality in Developing Countries*. New York: United Nations, 1985.
- Usher, Dan.** “An Imputation to the Measure of Economic Growth for Changes in Life Expectancy.” In Moss, Milton (ed.) *The Measurement of Economic and Social Performance*. Chicago: Columbia University Press for the National Bureau of Economic Research, 1973, pp. 193-226.
- Wagstaff, Adam, Flavia Bustreo, Jennifer Bryce, Mariam Claeson and Henrik Axelsson.** “Inequalities in Child Health: Are We Narrowing the Gap?” *American Journal of Public Health*, December 2003 (forthcoming).

Wang, Jia, Jamison, Dean T., Bos, Eduard, Preker, Alexander, & Peabody, John.
(In print). *Measuring Country Performance on Health: Selected Indicators for 115 Countries, 1960-90*. Washington, DC: The World Bank, Health, Nutrition and Population Technical Series, 1999.

World Bank. *World Development Indicators 2001*. Washington: D.C.: The World Bank, 2001.