COMMISSION ON MACROECONOMICS AND HEALTH
A WHO commission examining the interrelations among investments in health, economic growth and poverty reduction

CMH Working Paper Series

Paper No. WG1 : 4

Cross-Country Variation in Mortality Decline, 1962-87: The Role of Country-Specific Technical Progress

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Date: April 2001

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April 2001

Background Paper for Working Group 1,
WHO Commission on Macroeconomics and Health

Note: This is a preliminary draft, for comments only.

Contents

ABSTRACT

Mortality rate at all ages declined dramatically in the 20th Century and, in particular, the decline extended to most of the developing world in the period following 1960. One widely held interpretation of this decline is that it resulted from economic growth throughout much of the world. The income gains resulting from growth allow consumption of the increased quantity and quality of food as well as access to water supplies, sanitation, and more recently family planning services. An alternative view is that while income change has played some role, the decisive factor has been the degeneration and diffusion of new scientific knowledge and technology. Most statistical analyses of the determinants of variation in infant mortality rate (IMR) decline across countries have concluded that income differences have indeed played a major role. Technical progress and the education level of populations have also been found influential, but the emphasis has been on the importance of income.

This paper extends previous analyses by relaxing the previously maintained hypothesis that the rate of technical progress is the same for all countries. It concludes both that there is a marked heterogeneity across countries in the rate of technical progress and that when the heterogeneity is expressively modeled, the effect of income levels on IMR declines sharply. Perhaps because of the complimentarity between education with new knowledge, the estimated effect of education levels on IMR is a little affected by allowing for cross-country variation in the rate of technical progress, equivalently, the diffusion of the new technology.

Given the apparent central role of variation in the rate of technical progress, this paper initiates an attempt to identify the determinants of such variation. The methods of hierarchical linear modeling are employed to conclude that both geographical factors and aspects of the economic policy environment strongly effect technical progress.

Implications for policy are mixed. On the one hand, it seems clear that non-controllable geographical factors on average hinder the diffusion of new technology. On the other hand, low levels of income appear to impose no constrains on a country's capacity to rapidly reduce IMR. A number of low-income countries in adverse geographical circumstances have achieved rapid rates of IMR reduction, suggesting that adverse geography can be overcome with appropriate public policies.

CROSS-COUNTRY VARIATION IN MORTALITY DECLINE, 1962-87:
THE ROLE OF COUNTRY-SPECIFIC TECHNICAL PROGRESS[1]

By
Dean T. Jamison, Martin Sandbu, and Jia Wang[2]

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 (and somewhat earlier) in the countries of the North Atlantic diffused widely around the globe while continuing in the countries where it originated (Maddison, de Long, Easterlin, JMF). 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 also spread to most of the world (Easterlin, WHO). Life expectancies doubled entailing major immediate improvements in human welfare, dramatic declines in fertility and, in consequence of fertility declines, transformations of the age structures of populations away from being predominantly young. Understanding the origins of these revolutions – and the relations between them – forms the subject of much work in demography, economics and history.

Most analysts agree that advances in science and technology have underpinned these 20th Century transformations. Models of economic growth rely heavily on technological progress (or in changes in total factor productivity) to account for economic change (Solow, Lau and Boskin; Easterly and Levine). That said, short periods of rapid growth can result from high rates of savings and investment (Lau on East Asia; Krugman on the Soviet Union and Eastern Europe). Preston (1975?) first pointed to the similar importance of technical progress in accounting for 20th Century increases in life

[1] An earlier version of this paper was presented at the 2nd Meeting of International Health, Economics Association, Rotterdam (Jamision and Wang, June 1999). The authors wish to express their appreciation for valuable feedback received at that presentation, at a presentation later at the World Bank, and at a meeting of Working Group 1 of the WHO Commission on Macroeconomics and Health. We have also received helpful comments from George Alleyne, David Bloom, David Canning, Angus Deaton, Lant Pritchett and Jeffrey Sachs.
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expectancy. Although 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 at any given level of income. Middle-income countries today, for example, have reached per capita income levels close to that of the United States 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.

Our purpose in this paper is to explore 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 available[3]. Countries may differ, though, in how close their health systems come to utilizing the technology available at any given time: Technical progress may be country-specific. Previous research has either given little emphasis to technical progress – in part simply because much of it is cross-sectional – or it has assumed the rate of technical progress to be constant across countries. Our analysis relaxes the assumption that technical progress is constant across countries and attempts a very preliminary account of some of the reasons for cross-country variation in the rate of technical progress. (In related work with L.J. Lau we are undertaking a parallel analysis of the importance of country-specific variation in changes in total factor productivity for explaining differences in economic growth rates across countries.)

The paper begins with generalizations of previous models by allowing for *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 random-effects models with hierarchical linear models. Models allowing country-specific estimates of the effect of technical progress performed the best, find much weaker effects of income on IMR than previously estimated, and find that much of the variation in country performance results from the very substantial cross-

[3] 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 exception of high-activity anti-retroviral agents, patents are relatively unimportant barriers to products capable of influencing major mortality decline.

country variation in the rate of technical progress (from essentially no IMR decline from technical progress to reductions of up to 5% per year from that source). Whatever technical progress may be, the country-specific nature of its magnitude suggests that it must be embodied at the country level.

We next add geographical and economic policy variables to income and education as predictors of IMR; these variables were constructed by Jeffrey Sachs and his colleagues at Harvard who have used them to generate improved models of the determinants of economic growth rates. 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 is 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 technical progress, although a reasonable interpretation is that openness proxies a range of policy variables.

II. DATA AND METHODS

Data

We obtain the infant mortality rate data from the 1999 World Development Indicators from the World Bank (1999). Income per capita is the real gross domestic product (GDP) per capita adjusted for purchasing power parity 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). 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 ocean-navigable waterway. The 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 532 observations. The countries are listed in appendix A. Descriptive statistics of the variables used are reported in Table 1. Across all observations, the average infant mortality rate is 75 deaths per thousand, income per capita is $3,721, and the average female education level is 4 years. Table 1 also presents the means and standard deviations of each variable for every five-year period between 1960 and 1990. As shown, between 1960 and 1990 income per capita almost doubled, from $2,586 to $4,585, infant mortality almost halved, from 98 per thousand to 55 per thousand, and the average female education level increased from 3.3 years to 4.8 years.

Model Specifications and Results

Our purpose in this paper is to re-examine the empirical evidence on cross-country variation in infant mortality. Most of the previous literature has used specifications that impose common coefficients across countries, but as explained in the introduction, we believe that this may obscure some of the most important sources of cross-country differences, which we think originate less in the levels of the inputs that enter countries' "health production functions" as in how well different countries make use of the inputs they have. In order to capture this phenomenon, the general description of our model of infant mortality is given by equation (1):

$$(1) \qquad LIMR_{it} = \beta_{0i} + \beta_{1i}\, TIME_t + \beta_2\, LY5_{it} + \beta_3\, FEDUC_{it} + \varepsilon_{it}$$

where the variables and coefficients signify:

$LIMR_{it}$: the natural log of the infant mortality rate in country *i* at time *t*

$TIME_t$: the number of years lapsed since 1962 (*t*-1962)

$LY5_{it}$: the natural log of average per capita GDP in country *i* over a five-year period from *t*-2 to *t*+2;

$FEDUC_{it}$: the average number of years of education in the female population of country *i* aged over 15 at time *t*;

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 income;

β_3: the responsiveness of infant mortality with respect to changes in female education; and

ε_{it}: unexplained residual for country *i* at time *t*, assumed to be normally distributed with mean 0.

The different regressions we report and interpret below use different models of the country specific coefficients β_{0i}, β_{1i}.

Benchmark models

We first estimated a regression where none of the coefficients except the intercept vary across countries, that is where equation (1) is supplemented with:

(1a) $\beta_{0i} = \beta_0 + \mu_{0i}$

(1b) $\beta_{1i} = \beta_1$

where μ_{0i} is assumed to be normally distributed with mean zero and uncorrelated with the unexplained residual for the country ε_{it}, in other words, the covariance among them is zero [$Cov(\mu_{0i}, \varepsilon_{it}) = 0$]. This simple specification (which we label model 1) 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). With the error structure given in equations (1) and (1a), it is equivalent to a Generalized Least Squares (GLS) random effects model. The more complicated error structures of the models to be discussed below make us choose maximum-likelihood estimation of all the models, including model 1. Instead of using GLS, therefore, we chose to use the Hierarchical Linear Modelling (HLM) technique developed by Bryk and Raudenbusch (1992). The econometric approach will be further described below.

We also need to justify our modeling of country intercept shift as random rather than fixed effects. Our principal reason for not using fixed effects is the high cost in terms of degrees of freedom that we would incur by including indicator variables for each country. This would be all the more serious given that the models below will incorporate country-specific effects in determining technical progress as well as in the intercept. With a maximum of six observations per country in this panel, we are constrained in degrees of freedom. Moreover, any omitted variable bias would presumably cause the estimates of the coefficients on income and education to be too high rather than too low. Since our most important conclusion about the income coefficient will be that conventional estimates are biased upwards because of model misspecifications, it seems that any downward adjustment to a possible bias in our own estimation would only strengthen that conclusion. As for the education coefficient, we will not discuss its magnitude beyond noting its stability across our different models. These considerations make us believe that the random-effect specification is warranted.

The estimates for model 1 are reported in table 2. As that table shows, the benchmark model is consistent with previous literature described above. All three coefficients are statistically and quantitatively significant. On average, the infant mortality rate falls by about 2% per year. The elasticity of IMR with respect to income is -.35, which is comparable to the numbers found by Pritchett and Summers (1996). An increase in income of 10% (or $372 at the sample mean) is associated with a fall of 3.5% in infant mortality (or about 2.5 fewer deaths per thousand infants at the sample mean). Education, as is usually found, is also important: One additional year of female education is associated with about a 15% fall in infant mortality (or about 12 fewer deaths per thousand at the sample mean).

We also estimated a simple modification of the benchmark model. In this model, model 2, we included a set of geographical variables as determinants of a country's level of IMR. Thus model 2 supplements equation (1) with the specification:

(2a) $\beta_{0i} = \gamma_{00} + \gamma_{01}\ \text{TROPICS}_i + \gamma_{02}\ \text{COASTAL}_i + \mu_{0i}$

(2b) $\beta_{1i} = \beta_1$

As explained above and in table 1, these two variables denote the fraction of a country's land area situated within the geographical tropics or within 100 km from the seacoast or a sea-navigable waterway, respectively.

The estimation results are reported in table 2, which shows that including geography indicators contributes to explaining cross-country differences in the intercept. For example, a tropical country (TROPICS = 1) has, on average, a 28% higher infant mortality rate than a non-tropical one ($e^{.25} = 1.28$). A country whose entire land surface lies within 100 km of the coast or a navigable river (COASTAL = 1) has, on average, a 30% lower infant mortality rate ($e^{-.35} = 0.70$) than a completely landlocked one

(COASTAL = 0). Of course these effects of geography could reflect a host of different factors. Geography could itself be a determinant of IMR through its effect on the disease environment, or it could be an important correlate of omitted factors that are also important determinants of IMR, e.g. the relatively low productivity of tropical agriculture. The key point is that whatever the geography effects reflect here, these factors are different from those of income and education, since the coefficients on these variables hardly change when we move from model 1 to model 2. Thus the geography variables capture something separate and important, but the other variables remain significant factors in explaining infant mortality.

Allowing cross-country variation in technical progress

Our next step is to modify the two benchmark models to allow for country-specific rates of technical progress. We model differences in technical progress by including a random term in the coefficient on time. Thus model 3, which is an extension of model 1, models the coefficients in equation (1) as:

(3a) $\beta_{0i} = \beta_0 + \mu_{0i}$

(3b) $\beta_{1i} = \beta_1 + \mu_{1i}$

whereas model 4, which the equivalent extension of model 2, replaces (3a) with

(4a) $\beta_{0i} = \gamma_{00} + \gamma_{01}\ \mathrm{TROPICS}_i + \gamma_{02}\ \mathrm{COASTAL}_i + \mu_{0i}$

and is otherwise identical to model 3, so (4b) = (3b). The random term in (3b) and (4b) is assumed to be normally distributed, uncorrelated with ε_{it}, but potentially correlated with μ_{0i}, the random IMR level effect.

As mentioned above, this specification takes us away from the simple GLS framework. Substituting (3a-b) into equation (1) gives us the following model:

$$\mathrm{LIMR}_{it} = \beta_0 + \beta_1\ \mathrm{TIME}_t + \beta_2\ \mathrm{LY5}_{it} + \beta_3\ \mathrm{FEDUC}_{it} + \mu_{0i} + \mu_{1i}\cdot\mathrm{TIME}_t + \varepsilon_{it}$$

with an equivalent expression for model 4 (and, below, models 7 and 8).
The key feature of these models is their complex error structure. To estimate the parameters, we chose to use a multi-level modeling technique, specifically, the Hierarchical Linear Modelling (HLM) technique developed by Bryk and Raudenbusch

(1992). This maximum likelihood procedure generates estimates for the coefficients and for the variance of the country-and-time-specific random term, $Var(\varepsilon_{it}|TIME, LY5, FEDUC)$, the variances of the two country-specific (but time-invariant) random effects, $Var(\mu_{0i}|TIME, LY5, FEDUC)$ and $Var(\mu_{1i}|TIME, LY5, FEDUC)$, and the covariance of the country-specific random terms, $Cov(\mu_{0i}, \mu_{1i}|TIME, LY5, FEDUC)$. In models 3 and 4 this amounts to 8 and 10 parameters, respectively. Country-specific estimates of intercept and slope then are calculated from the model as residuals. This gives us a measure of the cross-country differences in rates of technical progress without including indicator variables for each country.[4]

When we modify models 1 and 2 to allow for country-specific technical progress (randomly varying time coefficients), we get the results reported in columns 3 and 4 of table 2. As that table shows, the results are not significantly affected, with the notable exception that the effect of income falls dramatically to about a third of its previous magnitude. Thus in model 3 all the other coefficients are similar to those in model 1, but the income coefficient is only -.09. The education slope decreases only slightly (See Figure 1). (The time coefficient reported is the average across countries, *i.e.* the constant in equation (3b).) Model 4 exhibits the same changes relative to model 2 – the coefficients are fairly stable (although the coefficients on the geography variables increase slightly), except the coefficient on income which falls to -.08. Not only does the income effect become much smaller in models 3 and 4, it also borders on statistical insignificance at conventional levels. Clearly health, income, and a country's use of technical progress are interrelated in important ways that the simpler regressions of models 1 and 2 fail to capture. Any satisfactory account of cross-country variation in infant mortality must be able to explain these relationships.

Furthermore, it should be noted that the cross-country variation in technical progress is itself quantitatively important. The variance of μ_{1i} is .0002, which means a standard deviation of .014. Figure 2 shows the distribution across countries of the rate of technical progress. The importance of a 1.4 percentage point higher (more negative) rate of technical progress is illustrated by a simple calculation: After 30 years, IMR is 34%

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[4] The HLM modelling and estimation techniques are explained in Bryk and Raudenbusch (1992), in Raudenbush, Bryk, Cheong, and Congdon (1999), and in Kreft and de Leeuw (1998).

lower than what it would otherwise be ($e^{-.014*30} = .66$). This shows the importance of gaining a better understanding of the determinants and the role of differential technical progress across countries.

To illustrate the magnitude of cross-country variation of technical progress, we include a histogram of the country-specific time-slopes in figure 2 (the values come from the model 3 estimates). As the histogram shows, there is a considerable spread across countries, from countries with *adverse* technical change to a few countries with a rate of technical progress above 5% per year.

Sources of cross-country variation in rates of technical progress

Our next set of models, whose results are reported in table 3, are designed to assess some of the sources of variation in country-specific rates of technical progress. The first two models, 5 and 6, attempt to account for this effect by modeling the time slope as a function of country-level variables instead of a random error. Model 5 makes the time coefficient a function of the geography variables that also affect the country's intercept, and model 6 adds to these an indicator of economic openness over the period 1965-1990. Thus models 5 and 6 consist of equation (1) supplemented with:

(5a) $\beta_{0i} = \gamma_{00} + \gamma_{01}\,\text{TROPICS}_i + \gamma_{02}\,\text{COASTAL}_i + \mu_{0i}$

(5b) $\beta_{1i} = \gamma_{10} + \gamma_{11}\,\text{TROPICS}_i + \gamma_{12}\,\text{COASTAL}_i$

for model 5, and

(6a) $\beta_{0i} = \gamma_{00} + \gamma_{01}\,\text{TROPICS}_i + \gamma_{02}\,\text{COASTAL}_i + \mu_{0i}$

(6b) $\beta_{1i} = \gamma_{10} + \gamma_{11}\,\text{TROPICS}_i + \gamma_{12}\,\text{OPEN6590}_i + \gamma_{13}\,\text{COASTAL}_i$

for model 6.[5]

We can observe from table 3 that geographic variables operate both through their effect on the intercept *and* through their effect on the time slope. We see in the first two

[5] We chose not to include the openness variable as a determinant of the country-specific intercept. This is because we think of the intercept as a country's starting point (setting TIME = 0) in terms of IMR, controlling for initial values of income and education. It is therefore unclear how one would interpret the coefficient on a variable measuring policy stance over the next 25 years. We do include it in the time coefficient, however, since the time slope captures a country's rate of technical progress over the 1960-1990 period, which it makes sense to think of as potentially determined by policy stance over that same period.

columns of table 3 that the coefficients in the model of the time slope are both statistically significant and quantitatively important. From model 6, for example, we can calculate that a non-tropical, coastal country (TROPICS = 0; COASTAL = 1) on average reduces its IMR at a rate of 2.5% per year, a rate that is *two and a half times as large* as that of a tropical and landlocked country (TROPICS = 1; COASTAL = 0), which reduces its IMR by 1% per year on average

OPEN6590 has a highly significant and quantitatively important effect on the time slope. Thus an economically open country seems to reduce its IMR at a rate that is 1.5 percentage points per year faster than an economically closed, but similarly situated country. In 30 years, this substantial differential accumulates to an additional 36% reduction in IMR relative to what it would have been ($e^{-.015*30} = .64$), see Figure 3. Another important observation about the economic openness variable is that omitting it (in model 5, relative to model 6) has the effect of substantially increasing the apparent effect of income (from -.15 to -.24). This buttresses our suspicion that previous findings on the effects of income on health were partly caused by model misspecifications. Models 7 and 8 expand on models 5 and 6 by also including a random error in the model of the time slope to see if there is any variation in rates of technical progress left unexplained by the geography and openness variables. Thus we have the following model specifications for model 7:

(7a) $\beta_{0i} = \gamma_{00} + \gamma_{01}\ \text{TROPICS}_i + \gamma_{02}\ \text{COASTAL}_i + \mu_{0i}$

(7b) $\beta_{1i} = \gamma_{10} + \gamma_{11}\ \text{TROPICS}_i + \gamma_{12}\ \text{COASTAL}_i + \mu_{1i}$

and we have:

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

(8b) $\beta_{1i} = \gamma_{10} + \gamma_{11}\ \text{TROPICS}_i + \gamma_{12}\ \text{OPEN6590}_i + \gamma_{13}\ \text{COASTAL}_i + \mu_{1i}$

for model 8.

The results, presented in the last two columns of table 3, show that even when we modeled technical progress as a function of country-level variables, we did not capture all the cross-country variation in the time slope. Models 7 and 8, which include a randomly varying component of the time slope, perform better than models 5 and 6, which do not. The criterion of comparison is a likelihood-ratio test; we compared model 7 to model 5, and model 8 to model 6. Including the random error in equations (7b) and (8b) involves estimating two additional parameters; the variance of μ_{0i} and its covariance with the random country intercept shift (μ_{0i}). Thus the ratio of the maximized likelihood functions in the two specifications is asymptotically distributed as χ^2 with two degrees of freedom. The p-values of less than 0.01 shows that allowing random variation in the time slope contributes to a statistically significant (at the .01 level) improvement in the goodness of fit.

Moreover, one should note the quantitative importance of the idiosyncratic differences in the time slope, captured by the random term. They are frequently comparable to the effects of the geographic and openness variables. Note that in even in model 8, which includes our richest specification of the country-specific time slope, the variance of the random component is .0001, *i.e.* its standard deviation is .01, which is substantial compared to the magnitude of the other coefficients (*e.g.* the constant in the time slope function, γ_{10} in equation (8b), is -.015, and the average difference between a totally landlocked and a completely coastal country is .009).

We now return to the sensitivity of the coefficient on income to relaxation of the assumption that technical progress is constant across countries. As can be seen in models 5 and 6, explicitly modeling potential determinants of cross-country variation of technical progress reduces the income coefficient relative to the benchmark models (models 1 and 2). From a magnitude of -.35, the income elasticity of IMR falls to -.24 and -.15 in models 5 and 6, respectively. Models of technical progress allowing for more variation in the country-specific effects (models 7 and 8) reduce the apparent effect of income even more markedly, as can be seen in figure 1. Thus in model 7, the income elasticity becomes vanishingly small at -.01, whereas in model 8, it is at -.07. In neither of the latter two models is the income coefficient statistically significant. This qualitative pattern of findings is strengthened if the analysis is restricted to only the low- and middle-income countries in the sample. This again points to the need of rethinking the importance of income as a determinant of health[6].

[6] Much empirical evidence points to a strong within-country correlation of income and health (Gwathin and Wagstaff, others). 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, which in this case would be the country.

Hypothesis and model selection

The t-values for individual coefficients are given in parentheses in each table. All the coefficients in models 1 through 8 are statistically significant, with two exceptions. The first is the income coefficient, which becomes insignificant at the 0.05 level in all the models with country-specific technical progress (modeled with the random term in the time slope), except the simplest specification, model 3. The reduced magnitude and statistical significance of the income coefficient is one of the chief observations of our analysis and is further discussed in the next section. The second parameter that loses statistical significance is the coefficient on TROPICS as a determinant of the time slope when OPEN6590 is included (model 8). The t-statistic is 1.85, which is statistically significant at the 10% level but not the 5% level. This simply suggests an absence of links between tropical location and technical progress in the production of health, once appropriate controls are included.

We further tested the appropriateness of our models by checking the improvement in goodness of fit from each new specification. Tables 2 and 3 report the results of likelihood ratio tests of the improvement in fit as we include more variables (we compared model 2 with model 1, model 5 with model 2, and model 6 with model 5), and they all show that the more comprehensive specifications are warranted – the increase in the likelihood values are all statistically significant at the 0.01 level. We performed similar tests of the improvement due to letting the time slope include a randomly varying component (this adds two parameters to the specification, *i.e.* the variance of the random component of the time slope, μ_{1i}, and its covariance with the intercept-shifting random effect, μ_{0i}). Thus tables 2 and 3 report the likelihood ratio test results from comparing model 3 with model 1, model 4 with model 2, model 7 with model 5, and model 8 with model 6. Again, specifications with randomly varying time slopes are statistically better than the equivalent specification without random time slope variation (every test gives a p-value below 0.01). Thus we conclude that the best specification is model 8.

III. DISCUSSION

Three main results emerge from the observations listed in the previous section. First, the rate of technical progress varies enormously across countries with a range of 0 to 5% per year around a mean of 2%. Second, when rates of technical progress are modeled explicitly as varying across countries, the estimated effect of income is substantially reduced. Third, there are clear correlations between geographic and policy variables and the time slope. These results both pose a challenge to previous analyses and suggest an alternative interpretation of the wealth-health relationship.

The second result suggests that previous studies have mistakenly attributed a large causal role to national income in the determination of cross-country differences in infant mortality. The challenge that our results present to the literature is that they show hardly any effect of income on health within a country over time, or between countries. The effect that we do find is much smaller than what has previously been found, 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 -.07 implies that a doubling of GDP, *ceteris paribus*, is associated with a fall in the infant mortality rate of only about 4.8% ($e^{-.07(\ln(2))} \approx .952$). This suggests that if we want to reduce infant mortality, it is much more important to understand the cross-country differences in the time coefficient. That latter question is the focus of the rest of this section.

We interpret the coefficient on the time variable as technical progress widely construed. As time goes by, the adoption of technology and the benefit of experience both contribute to a country’s ability to deal with health policy problems and other challenges. The country differences in the time-coefficient, then, could 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, harnessing technological and intellectual developments outside their country to boost those within it, and implementing new solutions as they become available. The results in models 5-8 help us tell a story about what determines the ability to absorb technical progress. It intuitively fits the view we are proposing that countries whose economic policies make them open to the world, and countries within easy geographical reach of world trade routes both have a higher rate of technical absorption than other countries. 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. The importance of openness in affecting the rate of technical progress is illustrated in figure 3.

We are harder pressed to explain the effect of tropical location on the time coefficient. 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 worse at making use of this progress. One reason one might suggest could be the debilitating effects of the tropical diseases that have been discussed in other work (see Gallup and Sachs 2000). Our lack of a story may not be a great problem, however, since the results of model 8 show that the coefficient on TROPICS becomes statistically insignificant (at the 5% level) when other explanatory variables are introduced. Thus the effect of tropical location on the time slope in the other model may simply be due to omitted variable bias.

If this reading of the econometric results makes sense, then not only does it suggest an alternative explanation of the variations in IMR across countries, but also of the correlation found between income and health in previous studies. Such an account of *why* previous studies got it wrong will buttress our claim that they indeed did. Since enriching the way we model technical progress has the effect of sharply reducing the estimated effect of income, it seems that there is a close connection between our notion of technical progress and income. This is not surprising: On our interpretation of the time slope, it is an indicator of a country's ability to harness technical progress and put that progress to use in the effort to improve health. But a country that is capable of incorporating new knowledge and technology in that way is also likely to be capable of using the same resources to improve its economy. Rather than differences in income and economic growth rates affecting levels and reduction rates of infant mortality, it may therefore be that the ability to absorb technological and intellectual developments from the outside world (which depends, *inter alia*, on a country's integration into the global economic and social system) enables a country to be more efficient at reducing its IMR *and* to be more efficient in increasing its wealth. So there may be common causation: The correlation between health and income holds in underspecified models because health and wealth are influenced by the same underlying factors – the ability to harness technical progress widely construed. This is both consistent with our results and a plausible story. Whether it stands up to more extensive scrutiny, of course, is an important subject for future research.

IV. CONCLUSION: THE SOURCES OF MORTALITY DECLINE

The 20th Century witnessed extraordinary and unprecedented declines in mortality rates at all ages. Understanding the sources of these changes is important not only for understanding one of the defining events of world history but, also, to shed light on policies to address the needs of perhaps 25% of the world's population whose mortality rates remain far higher than those of the rest of the world's population.

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 (Pison, et al 1993) found, in rural Senegal, that much of the rapid mortality decline there could be traced to introduction of interventions addressing specific conditions. An approach is historical. Easterlin (1998), 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 probably had a modest impact on reducing mortality through its influence on food availability and environmental conditions. This modest effect was partially offset by increased infectious disease transmission resulting from urbanization.

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. This paper adds to this literature by continuing exploration of the role of geographical variables (work begun by Bloom and Sachs, 1998) and by relaxing the assumption that technical progress occurs at the same rate in all countries. We find strong inter-country variation in the rate of technical progress and that taking account of inter-country 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). Figure 4 shows a decomposition , for four countries, of mortality decline between 1962 and 1987 into the constituents we have assessed. Even in a period of rapid economic growth income changes can account for only modest changes in infant mortality. Technical progress is far more important.

It may be instructive to categorize mortality history into 3 or 4 epochs. Epoch I, extending up to the late 18^{th} Century, was a period of ups and downs in mortality rates unaccompanied by any upward trend. Epoch II, in the 19^{th} Century, witnessed very slow but real mortality reductions that resulted from the consequences of income growth, but that were partially counterbalanced by the effects of urbanization. Epoch III, in the 20^{th} Century, was a period of very rapid mortality decline based on the generation and utilization of new knowledge. A possible Epoch IV, in the first quarter of the 21^{st} Century, would involve bringing all communities' mortality rates to the levels technology has made possible even at low levels of income.

Annex A: Alternative Models

All of these models (1-8) share the characteristic that they do not allow for any cross-country variation in either the income or the education coefficient. 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 two inputs in the health production function (equation 1). To check whether our focus on country-specific time slopes was warranted, we estimated ten more models that are equivalent to models 4-8, but that let either the income or the education slope vary in the same way the time slope varies in model 4-8. The results are reported in tables A1 (for income) and A2 (for education). Each column reports the coefficient results and model statistics for comparing whether the model performs better than the equivalent model where the variation was in the time slope.

As the tables show, the deviance values (-2 times the maximized value of the log likelihood function) are uniformly better in the models that allow the time slope to vary. (The deviance is a measure of fit; the lower, the close the model fits the data.) Table A1 also shows that having the income slope vary randomly across countries actually increases the unexplained variation in the outcome variable: the variation reduction values turn negative. (The variation reduction measures how much of the unexplained variation in a model without regressors is reduced in the richer models.) The within-country and between-country variation reduction values in Tables A1 and A2 are smaller than the ones reported for the corresponding models in Tables 2 and 3.

We observe, moreover, that the other coefficients are stable across the different models of country-specific income or education slopes. Variations in the time slope, on the other hand, caused a dramatic reduction in the income coefficient. All of this leads us to believe that while country variation in the use of wealth and education may be important subjects of future research, understanding the role of differential rates of technical progress is particularly important at this stage.

Annex B: Instrumental Variable Specifications

As we stated in our discussion of the previous literature above, the existence of a relationship between per capita income and country-level health outcomes is well established. Notwithstanding, there has been less formal analysis of the causal nature of that relationship. The positive correlation between income and health could mean that higher income causes better health, that better health causes higher income, or that there are third factors that cause both better health and higher income. There are intuitive reasons for believing that each of these causal relationships may be true. To disentangle the directions of causality, Summers and Pritchett (1996) applied instrumental variable (IV) analysis to the determinants of cross-country variation infant mortality rates. We performed some tentative analysis that incorporated their use of instrumental variables into our multi-level models while recognizing the difficulty of finding credible instruments.

The purpose of instrumental variable analysis is to isolate the effect that runs from income to health from the opposite effect. This is done by using variables that influence income without influencing health variable directly, and that are not determined either by the health variable or jointly determined with the health variable by a third factor. We tried to instrument for per capita income by using the ratio of investment to GDP, a variable that can be expected to affect GDP and that it may be safe to consider exogenous with respect to health outcomes (although not entirely safe: it may be that the risk or return on investment depends on the health status of the country). This is one of the instruments used in by Summers and Pritchett (1996). To make sure that the variation of investment is not due to a variation in income which again may reflect reverse causality from health, we used lagged values of investment-to-GDP ratios (5 year lags).

In order to avoid erroneously interpreting spurious correlations in the regressions discussed in this paper, we did a similar analysis using the value of income predicted from a regression of income on the instrumental variables. Specifically, we regressed the income values on the ratio of investment to GDP five years earlier using a standard OLS regression, and obtained a predicted series of per capita income. In a second stage, we repeated the HLM analysis from above, substituting the predicted income for actual income.

We tried a series of models, similar to the ones reported above. The new estimations produced the following main results. First, the instrumentation almost completely removed the income effect, even in the benchmark model (equivalent to model 1, using predicted income instead of actual income). Second, the new, very low income effect, was very stable across different models, and would hover around -.03 and usually be statistically significant at the 10% level. Third, the coefficients on the other variables were very similar for equivalent models using either the actual or the instrumented income variable.

In sum, our tentative experiments with instrumental variable analysis produced results that were very similar to what we found in the non-instrumented models where we let the time coefficient vary across countries. This suggests that the instability of the income coefficient across models 1 through 8 above is due to a problem of reverse causation or common causation that is controlled for once technical progress is modeled as country-specific. This conclusion lends support to our interpretation of the data: that better health status is not caused by higher incomes, but that both better health status and higher incomes are driven by the same cause, namely differential ability to absorb and use technical progress.

Annex C: Country-specific Decomposition of the Sources of Mortality Decline

[To be added]

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Appendix A. List of countries included and the number of avaible observations for each country.

Country Name	# of Observations	Country Name	# of Observations
Algeria	6	Liberia	6
Argentina	6	Malawi	6
Australia	6	Malaysia	6
Austria	6	Mali	6
Bangladesh	6	Mauritius	6
Belgium	6	Mexico	6
Benin	4	Mozambique	6
Bolivia	6	Myanmar	6
Botswana	6	Nepal	6
Brazil	6	Netherlands	6
Bulgaria	2	New Zealand	6
Cameroon	6	Nicaragua	6
Canada	6	Niger	6
Central African Republic	6	Norway	6
Chile	6	Pakistan	6
China	3	Papua New Guinea	6
China, Hong Kong SAR	6	Paraguay	6
Colombia	6	Peru	6
Congo	1	Philippines	6
Costa Rica	6	Poland	4
Denmark	6	Portugal	6
Dominican Republic	6	Republic of Korea	6
Ecuador	6	Romania	6
Egypt	3	Rwanda	4
El Salvador	6	Senegal	6
Finland	6	Sierra Leone	6
France	6	Singapore	6
Gambia	3	South Africa	6
Germany	6	Spain	6
Ghana	6	Sri Lanka	6
Greece	6	Sudan	4
Guatemala	6	Sweden	6
Guinea-Bissau	2	Switzerland	6
Haiti	6	Syrian Arab Republic	6
Honduras	6	Thailand	6
Hungary	4	Togo	6
India	6	Trinidad and Tobago	6
Indonesia	6	Tunisia	6
Iran (Islamic Republic of)	6	Turkey	6
Ireland	6	Uganda	6
Israel	6	United Kingdom	6
Italy	6	United States of America	6
Jamaica	6	United States of Tanzania	6
Japan	6	Uruguay	6
Jordan	6	Venezuela	6
Kenya	6	Zambia	6
Lesotho	6	Zimbabwe	6

Table 1. Definitions, means, and standard deviations (in parenthesis) of the variables used

Variable	Definition	All years	1962	1967	1972	1977	1982	1987
Country- and time-specific variables								
TIME	Year of observation (Year – 1962)	12.9						
		(8.5)						
Y5	GDP per capita, averaged over the 5-year period from year – 2 to year + 2)	3,721	2,586	3,053	3,522	3,999	4,373	4,585
		(3629)	(2393)	(2867)	(3314)	(3740)	(4074)	(4452)
LY5	Natural log of Y5	7.8	7.5	7.6	7.7	7.8	7.9	7.9
		(1.0)	(0.9)	(1.0)	(1.0)	(1.0)	(1.0)	(1.0)
FEDUC	Average numbers of years of education in the female population aged 15 and above	4.0	3.3	3.5	3.8	4.1	4.5	4.8
		(2.9)	(2.7)	(2.7)	(2.8)	(2.9)	(3.0)	(2.9)
IMR	Infant mortality rate (deaths prior to age 1 per 1000 live births)	75.4	98.5	88.9	80.1	71.4	62.7	55.0
		(53.3)	(58.5)	(55.5)	(52.8)	(50.7)	(47.5)	(43.6)
LIMR	Natural log of the infant mortality rate	4.0	4.3	4.2	4.1	3.9	3.7	3.6
		(1.0)	(0.8)	(0.8)	(0.9)	(0.9)	(1.0)	(1.0)
Country-specific variables								
TROPICS	Fraction of the country's land area situated in the geographical tropics	53.63						
		(47.80)						
OPEN6590	Fraction of years between 1965 and 1990 that the country is deemed to have an open economy	35.66						
		(43.50)						
COASTAL	Fraction of the country's land area located within 100km of the seacoast or an ocean-navigable waterway	49.15						
		(37.33)						

Table 2. Determinants of Infant Mortality: The effects of Income, Education, Geography and Technical Progress

	Models				
	0	1	2	3	4
Independent Variable					
Time-invariant determinants of IMR:					
Intercept	3.98	7.52	7.26	5.50	5.36
	(42.88)	(19.04)	(18.53)	(18.66)	(17.16)
TROPICS			0.25		0.41
			(2.56)		(3.88)
COASTAL			-0.35		-0.40
			(3.39)		(3.35)
Time-varying determinants of IMR:					
LY5		-0.35	-0.32	-0.09	-0.08
		(5.83)	(5.46)	(2.06)	(1.79)
FEDUC		-0.15	-0.13	-0.13	-0.12
		(7.62)	(6.24)	(8.04)	(6.08)
TIME (common coefficient across countries)		-0.02	-0.02		
		(9.36)	(9.23)		
TIME (average of country-specific coefficients)				-0.02	-0.02
				(12.55)	(12.07)
Model Statistics					
Within-country Variance Reduction		83%	83%	96%	96%
Between-country Variance Reduction		85%	86%	76%	81%
# of Parameters Estimated	3	6	8	8	10
Deviance	735	-215	-234	-590	-614
Significance Test					
Chi-square value			19	375	380
p-value			0.00	0.00	0.00

Notes:
1. Model 0 has no predictors. 86% of the variation in health outcomes are between countries.
2. Model 1 adds fixed income, education, and time effects to Model 0.
3. Model 2 adds to Model 1 two country varaibles to the intercept.
4. Model 3 lets the time slope in Model 1 randomly vary across countries.
5. Model 4 lets the time slope in Model 3 ramdonly vary across countries.

Table 3. Sources of Cross-Country Variation in Technical Progress

	Models				
	0	5	6	7	8
Independent Variable					
Time-invariant determinants of IMR:					
Intercept	3.98	6.56	5.86	5.21	5.21
	(42.88)	(16.73)	(17.13)	(16.67)	(15.99)
TROPICS		0.286	0.395	0.465	0.466
		(2.81)	(3.96)	(4.25)	(4.32)
COASTAL		-0.270	-0.363	-0.440	-0.433
		(2.50)	(3.13)	(3.55)	(3.46)
Time-varying determinants of IMR:					
LY5		-0.24	-0.15	-0.01	-0.07
		(4.34)	(3.04)	(1.49)	(1.43)
FEDUC		-0.11	-0.11	-0.11	-0.11
		(5.63)	(5.80)	(5.73)	(5.79)
Determinants of country-specific TIME coefficient:					
Intercept (common coefficient across countries)		-0.02	-0.01	-0.02	-0.02
		(5.67)	(5.39)	(7.36)	(5.56)
TROPICS		0.009	0.005	0.011	0.005
		(3.27)	(2.01)	(4.11)	(1.85)
OPEN6590			-0.014		-0.019
			(5.09)		(6.74)
COASTAL		-0.015	-0.011	-0.016	-0.009
		(4.19)	(2.86)	(4.32)	(2.53)
Model Statistics					
Within-country Variance Reduction		87%	89%	97%	97%
Between-country Variance Reduction		83%	83%	80%	80%
# of Parameters Estimated	3	10	11	12	13
Deviance	735	-331	-399	-650	-676
Significance Test					
Chi-square value		97	68	319	277
p-value		0.00	0.00	0.00	0.00

Notes:

1. Model 0 has no predictors. 86% of the variation in health outcomes are between countries.
2. Model 5 adds to Model 0 two country varaibles to both the intercept and time slope.
3. Model 6 adds to Model 5 time slope an additional country variable.
4. Model 7 lets the time slope in Model 5 vary randomly across countries.
5. Model 8 lets the time slope in Model 7 vary randomly across countries.

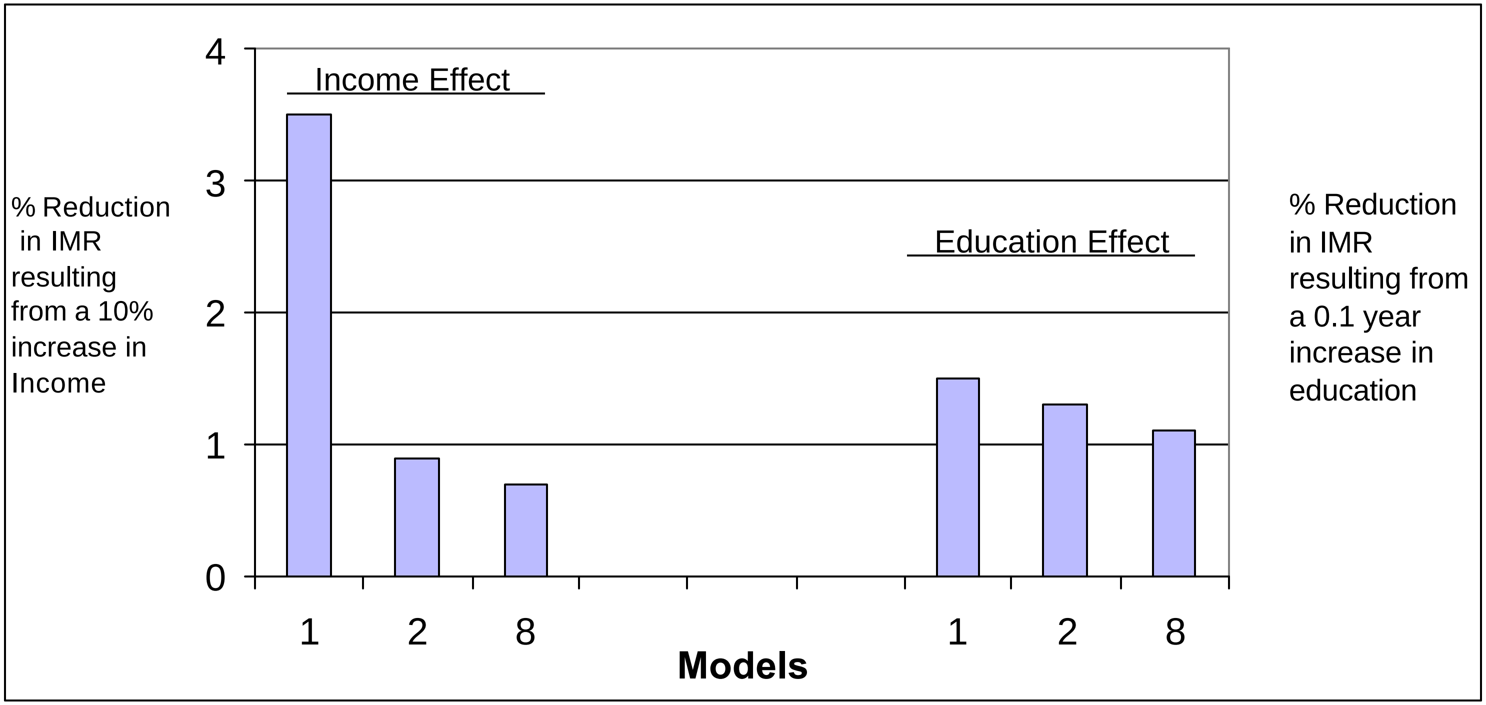
Table A1. Robustness check: Cross-country variation in the income coefficient

	Models					
	1	9	10	11	12	13
Independent Variable						
Time-invariant determinants of IMR:						
Intercept	7.52	6.97	6.56	6.17	6.28	6.17
	(19.04)	(18.04)	(10.63)	(11.44)	(8.96)	(9.33)
TROPICS		0.1427	-1.5690	-1.3006	-1.8300	-1.7256
		(1.47)	(2.99)	(2.77)	(2.91)	(2.88)
COASTAL		-0.4200	2.7600	2.5700	3.1150	-3.0703
		(3.32)	(4.86)	(5.48)	(4.10)	(4.45)
Time-varying determinants of IMR:						
TIME	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
	(9.35)	(9.66)	(10.29)	(11.73)	(10.20)	(10.73)
FEDUC	-0.15	-0.13	-0.11	-0.10	-0.12	-0.11
	(7.62)	(6.43)	(5.85)	(6.22)	(6.33)	(5.90)
Determinants of country-specific LY5 coefficient:						
Intercept (common coefficient across	-0.35	-0.25	-0.22	-0.15	-0.16	-0.13
	(5.83)	(4.62)	(2.52)	(1.94)	(1.63)	(1.45)
TROPICS			0.2400	0.1933	0.2691	0.2451
			(3.54)	(3.16)	(3.20)	(3.09)
OPEN6590				-0.0770		-0.0520
				(6.81)		(4.03)
COASTAL			-0.4180	-0.3740	-0.4818	-0.4600
			(5.32)	(5.90)	(4.75)	(5.04)
Model Statistics						
Within-country Variance Reduction	83%	91%	86%	87%	91%	91%
Between-country Variance Reduction	85%	-856%	86%	90%	-467%	-357%
# of Parameters Estimated	6	10	10	11	12	13
Deviance	-215	-374	-320	-372	-406	-422

Table A2. Robustness check: Cross-country variation in the education coefficient

	Models					
	1	14	15	16	17	18
Independent Variable						
Time-invariant determinants of IMR:						
Intercept	7.52	6.94	7.07	6.52	6.55	6.41
	(19.04)	(16.94)	(17.42)	(18.08)	(15.53)	(15.53)
TROPICS		0.327	-0.023	0.027	-0.004	0.029
		(2.73)	(0.19)	(0.24)	(0.03)	(0.17)
COASTAL		-0.580	-0.018	-0.075	0.259	0.229
		(3.98)	(0.12)	(0.53)	(1.19)	(1.08)
Time-varying determinants of IMR:						
TIME	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
	(9.35)	(10.65)	(9.99)	(11.19)	(11.05)	(11.28)
LY5	-0.35	-0.26	-0.29	-0.22	-0.24	-0.22
	(5.83)	(4.50)	(4.99)	(4.16)	(4.21)	(4.01)
Determinants of country-specific FEDUC coefficient:						
Intercept (common coefficient across	-0.15	-0.10	-0.11	-0.05	-0.03	0.02
	(7.62)	(3.71)	(4.11)	(2.12)	(0.59)	(0.53)
TROPICS			0.082	0.057	0.101	0.063
			(2.80)	(2.19)	(2.70)	(1.82)
OPEN6590				-0.100		-0.125
				(6.33)		(5.49)
COASTAL			-0.090	-0.083	-0.240	-0.196
			(2.78)	(2.68)	(4.84)	(4.19)
Model Statistics						
Within-country Variance Reduction	83%	94%	85%	86%	94%	94%
Between-country Variance Reduction	85%	19%	85%	89%	38%	41%
# of Parameters Estimated	6	10	10	11	12	13
Deviance	-215	-417	-276	-332	-446	-468

Figure 1: The Responsiveness of IMR to Changes in Income and Education -- Sensitivity to Relaxing the Assumption that the Rate of Technical Progress is the Same for All Countries



Note: Models 1 and 2 include only income, education and technical progress as determinants of IMR. Model 1 assumes technical progress to be constant across all countries; Model 2 relaxes this assumption. Model 8 includes an assessment of determinants of the variation across countries in technical progress.

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

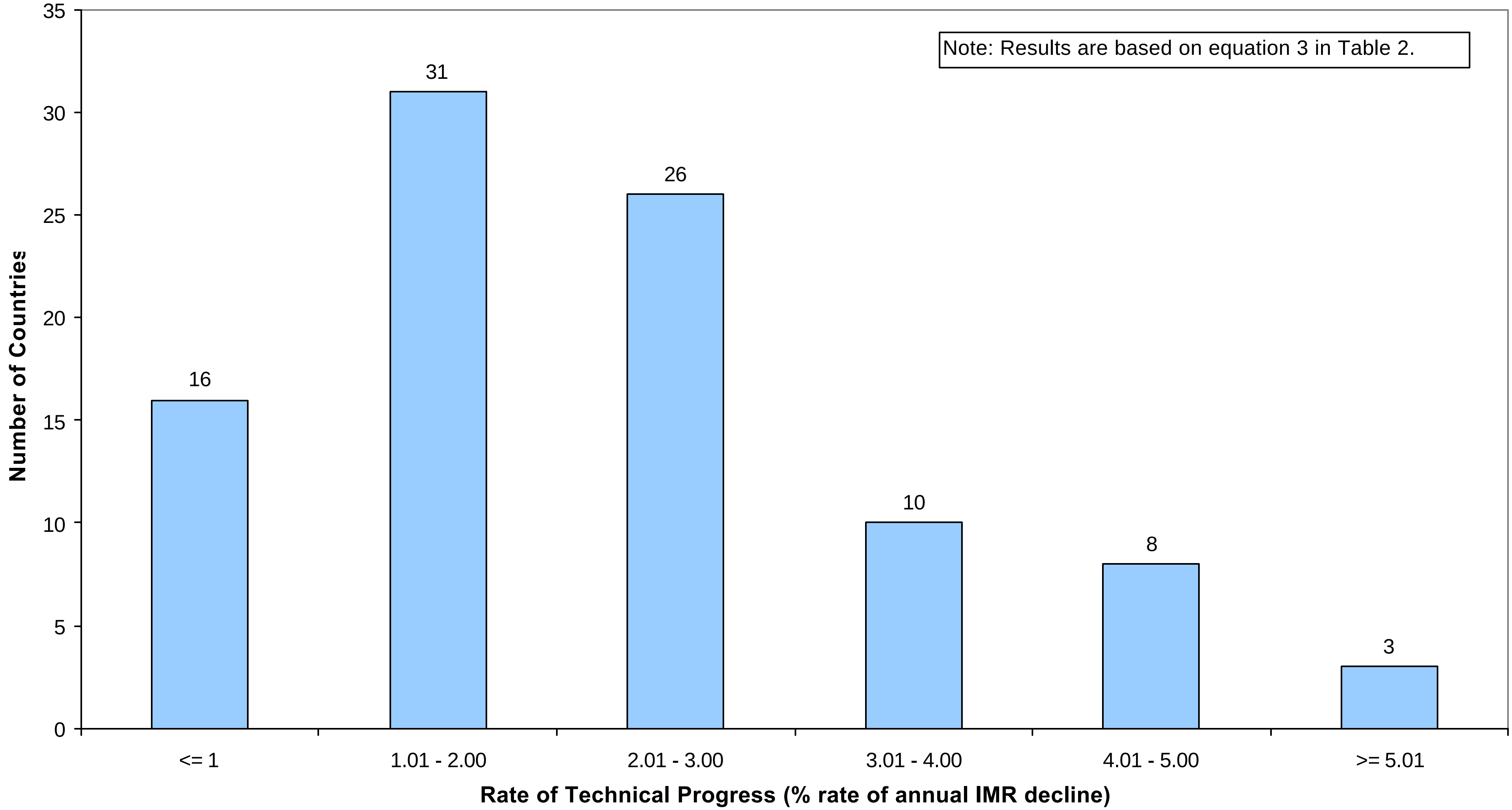
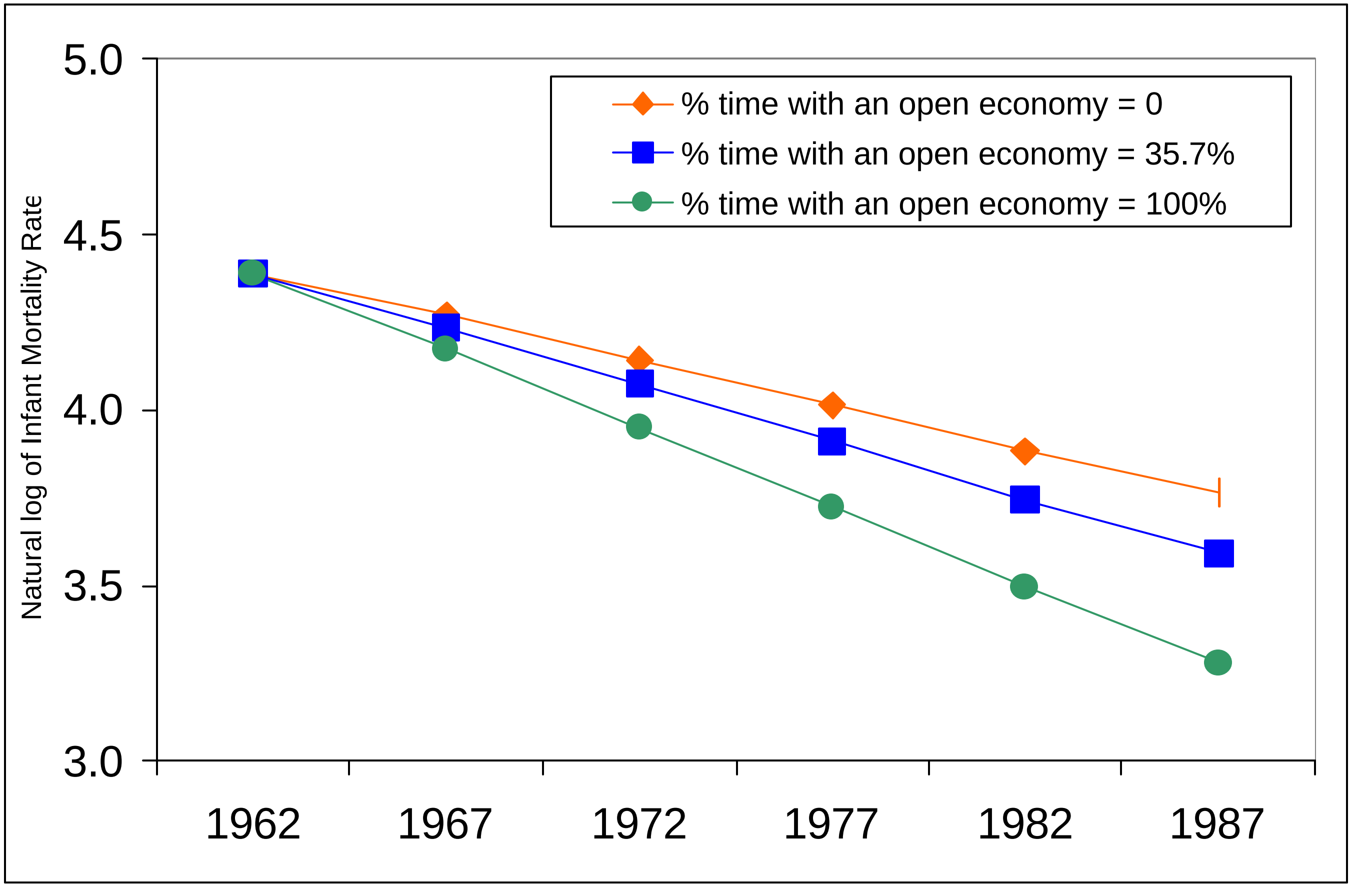


Figure 3: Variations in Policy Result in Divergence of Levels of IMR



Note: Results are based on equation 8, table 3 (other varaibles at mean values for appropriate year).

Figure 4: Sources of Decline in IMR, 1962-87

4A: Bangladesh

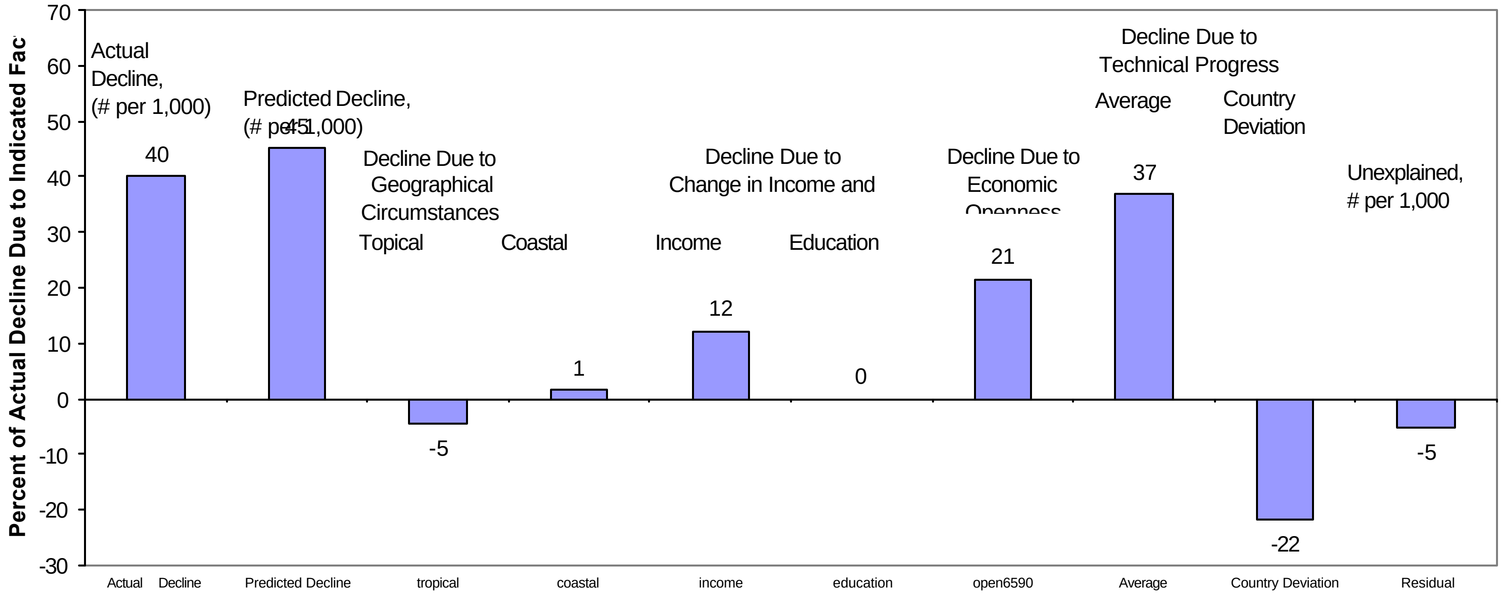


Figure 4: Sources of Decline in IMR, 1962-87

4B: India

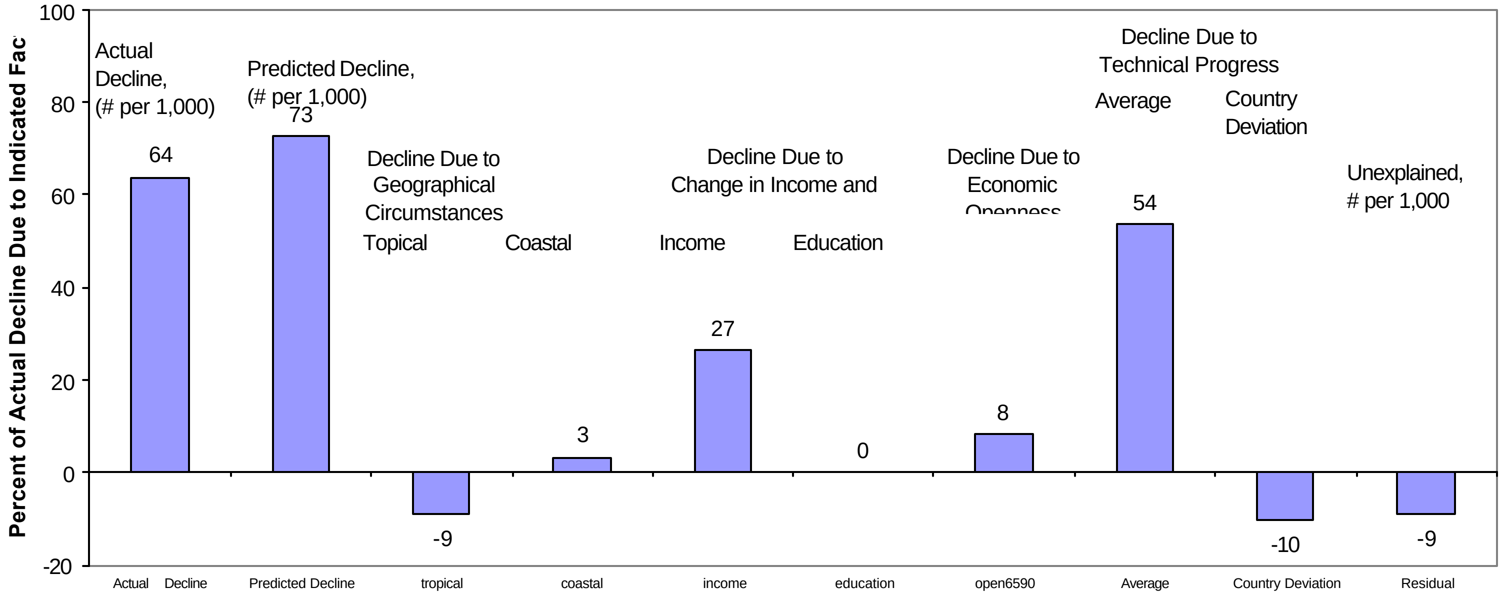


Figure 4: Sources of Decline in IMR, 1962-87

4C: Republic of Korea

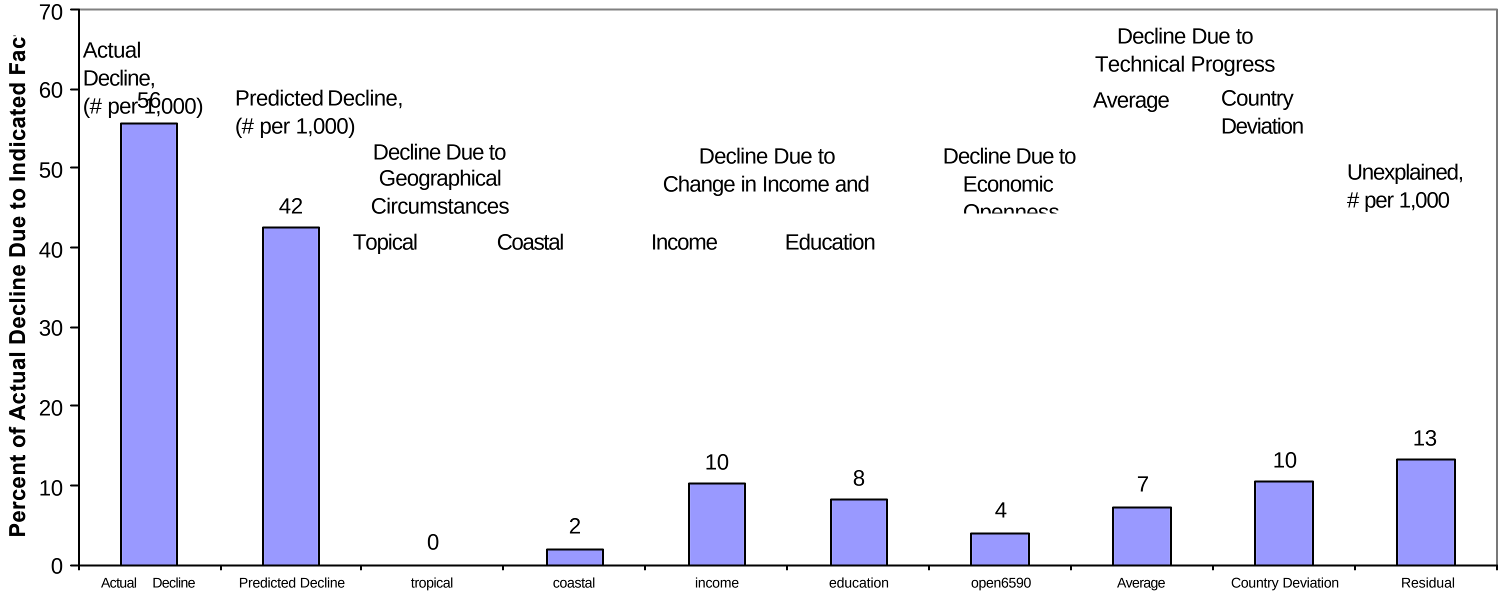


Figure 4: Reasons for Decline in IMR in the Period of 1962-87,

4D: Mozambique