Very Preliminary
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Accounting for the Effect of Health on Economic Growth

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Abstract

Variation in health, as measured by height and by adult mortality rates, explains 17% of the variance in output per worker across countries, or almost one-third of the variation in output that is left unexplained by other measures of factor accumulation. Variation in health explains almost as much of the cross-country variance in output as is explained by either education or accumulation of physical capital.

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1. Introduction

Health is both a result and a determinant of income. People who are better off are better nourished and better cared for. At the same time, healthier people are able to work harder, think more clearly, and earn a higher return in the labor market. Similarly, at the national level, countries that are richer have, on average, healthier citizens; and the health of a country's population is an important determinant of its economic success.

My goal in this paper is to examine the magnitude of one of these relations. Specifically, I ask how much of the variation in income per capita between countries can be attributed to differences in their average level of health. My goals in this paper – and how it relates to existing literature – can be most easily thought about with reference to Figures 1-3. These figures show the simultaneous determination of income, y, and health, which is denoted by the symbol v, for vitality.

Figure 1 shows the two structural functions that relate income and health: v(y) showing the effect of income on health and y(v) showing the effect of health on income. The intersection of the curves shows the simultaneous determination of health and income.

The mechanisms that lead to a positive dependence of health and income are fairly obvious. People who are richer can afford better food, shelter, and medical treatment. Countries that are richer can afford higher expenditures on public health.[1] The v(y) function in Figure 1 is drawn with a diminishing slope at higher levels of income, reflecting the fact that income's effects on health seem to be limited. It is likely that the richest countries in the world are today at a point where further increases in income will have only minor effects on health (which is not to say that the health will not improve due to shifts in the v(y) function itself.)

Regarding the y(v) function, existing literature has pointed out several channels by which better health will raise the level of income. Most directly, healthier workers are able to work harder and longer, and also to think more clearly. Improvements in health raise the incentive to acquire schooling, since investments in schooling can be amortized over a longer working life (Kalemli-Ozcan, Ryder, and Weil, 2000) Healthier students also have lower absenteeism and higher cognitive functioning, and thus receive a better education for a given level of schooling.

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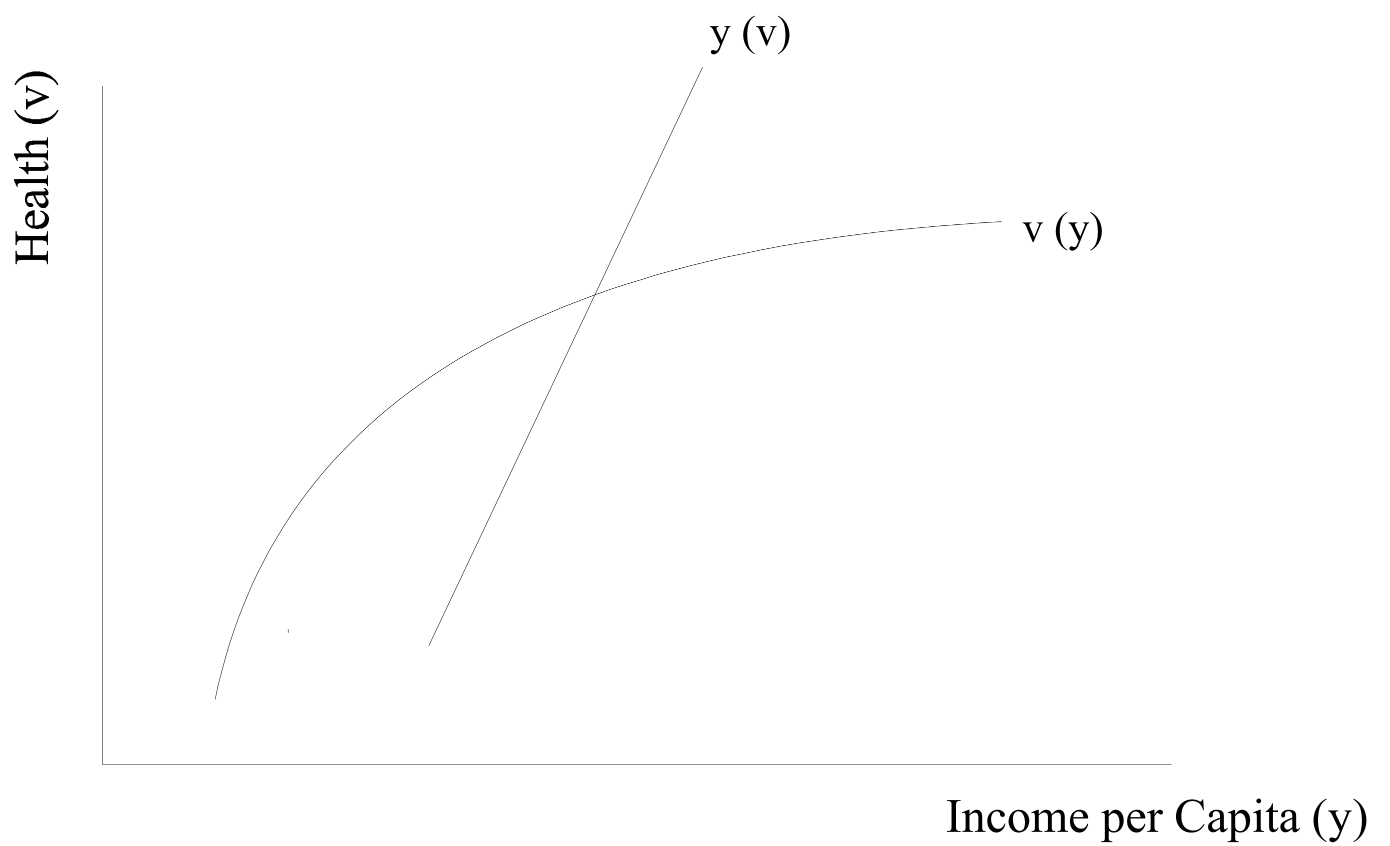
[1] Pritchett and Summers (1996), using an instrumental variables procedure, find a significant effect of income on health, as measured by infant and child mortality. The instruments that they use are terms of trade shocks, the ratio of investment to GDP, the black market premium, and the deviation of the exchange rate from PPP.

Figure 1

The Relationship Between Health and Income



Improvements in mortality may also lead people to save for retirement, thus raising the levels of investment and physical capital per worker. Lower infant and child mortality can also lower the Net Rate of Reproduction, and thus reduce population growth, leading to a higher level of capital per worker.[2]

Figure 2 shows how shifts in the v(y) and y(v) functions will lead to a change in the levels of both income and health. The figure can be thought of as showing how the determination of income and health differs between countries or over time.[3]

One of the most important aspects of the process of economic growth over the last century has been the upward shift in the v(y) function, due to improvements in health knowledge and the development of new health technologies. Just as significant as this upward shift has been a dramatic change in the *slope* of this function. As stressed originally by Preston (1980), the effect of higher income on health is much smaller today than it was prior to World War II.

A more contentious question is the degree to which the v(y) function differs between countries today. Gallup and Sachs (1998) argue that tropical areas have fundamentally worse health environments than do the temperate parts of the world. They claim, for example, that the fact that malaria has been eliminated in currently rich areas (such as Spain or the Southern US) but not in poor ones (such as sub-Saharan Africa) does not reflect differences in income, but rather the fact that malaria's grip is much stronger in Africa. Under this view, these fundamental differences in the health environment present a very strong obstacle to economic growth in the tropics. In contrast, recent work by Acemoglu, Johnson, and Robinson (2000) takes the view that differences in the fundamental health environment between countries are not large, and that high level of disease in tropical countries is more a result than a cause of their poverty. In terms of the v(y) function, the former view is that there are large inter-country differences in the v(y) function, while the latter view is that the function itself has a steep slope, but that there are not big differences across countries in the function's level.

Differences over time or between countries in the y(v) function can be attributed to any influence on income other than health. For example, improvements in productive technology, accumulation of physical capital or human capital in the form of education, or development of better institutions will all shift the y(v) function upward.

Figure 2 makes it clear that a full accounting of differences in income and health between

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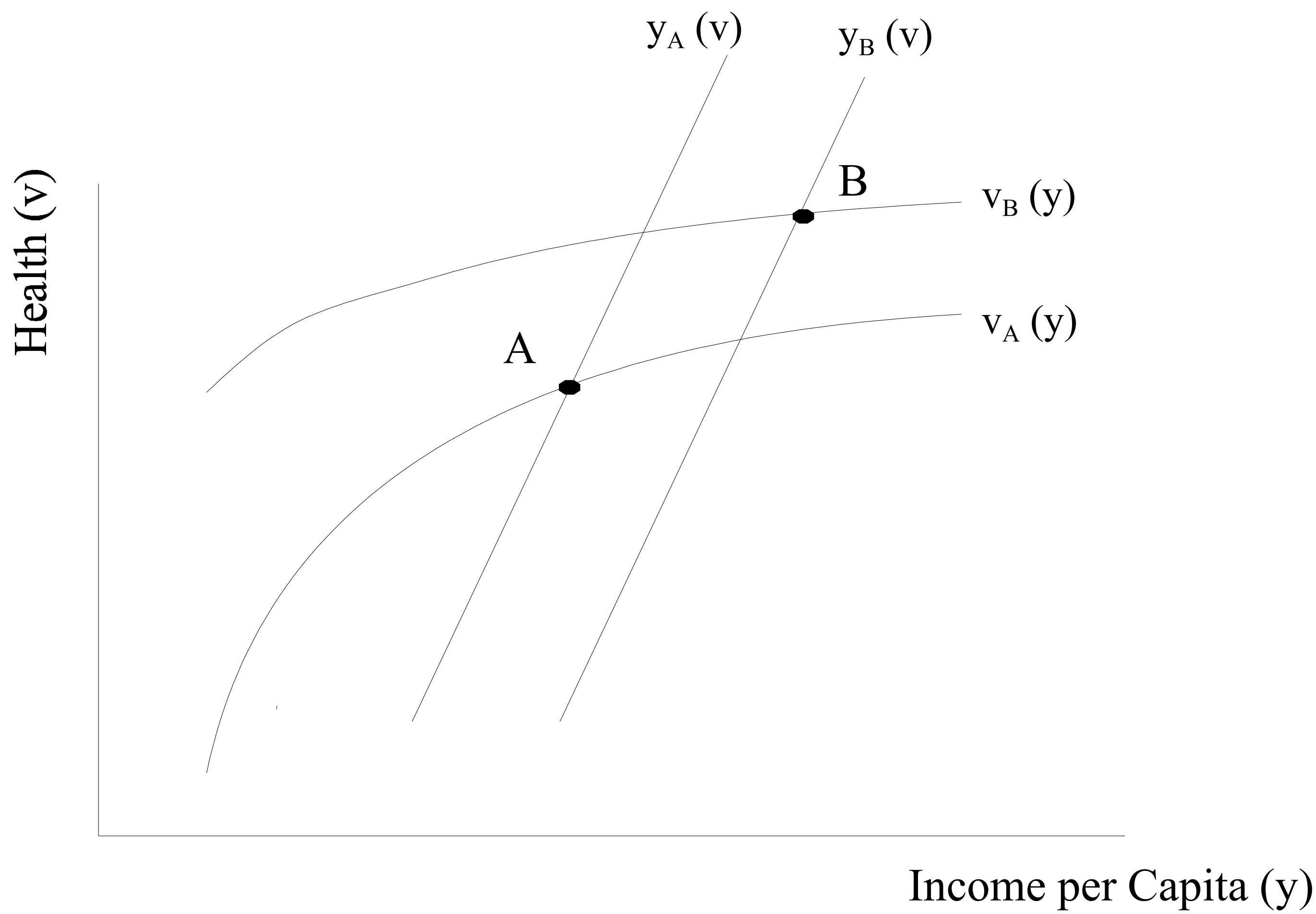
[2]See Bloom and Canning (2000) for a discussion of many of these issues.

[3]In presenting the analysis in this simple form, I am ignoring any dynamics. Since I will mostly be looking at changes over very long periods of time, or differences between countries that are arguably close to their steady states, this may not be a problem. Hall and Jones (1999) argue that differences in income levels between countries are well modeled as being a steady state phenomenon.

Figure 2

The Relationship Between Health and Income



two countries (or within a single country over time) would require a description of both the shapes of the y(v) and v(y) functions and also of the shifts that these functions had undergone.

Despite the desirability of such a complete accounting, in this paper I undertake a much more modest investigation. I wish to ask how much of the variation in income that we observe between countries can be directly explained by differences in health – that is, how much income would differ between two countries if they had the same y(v) function and their actual levels of health. As the Figure 3 makes clear, doing this calculation requires only knowing the difference in health between the two countries (or the single country at two points in time) and the slope of the structural effect of health on income. In particular, one does not have to know anything about the shape of the v(y) function, or about relative position of the two countries' y(v) functions.[4] It is also clear from Figure 3 that the "income gap due to health" that I calculate is not the same as the gap in income that would exist if the two countries had the same y(v) functions but their own v(y) functions – that is, it is not the income gap due to differences in the underlying health environment.

In fact, the calculation that I do is even more limited than this, because in practice, I will look only at the direct effect of health on income. In the discussion of the y(v) function above, one can distinguish several channels in which health differences may be an underlying cause of income differences between countries, but in which the effect of health operates via some intermediate (and measurable) variable. For example, poor health may lower the saving rate or the level of investment in education, resulting in lower levels of physical and human capital. If one looks for effects of health on income, controlling for the levels of physical and human capital, these indirect effects will not be attributed to health. Since this is exactly what I do below, the health effects that I measure will only be the direct ones.

2. Height and Health

Like human capital from education, human capital from health is not something that we can measure directly. In the case of human capital from education, we generally measure inputs, in the form of years of schooling. In the case of human capital from health, the approach taken here will be instead to look at *indicators* of health – specifically height and mortality.

Adult height is a good indicator of the health environment in which a person grew up. Factors such as malnutrition and illness, both in utero and during childhood, result in diminished adult stature. Looking across individuals, there is also a large degree of non-health related variation in height, but much of this variation is washed out when one looks at population

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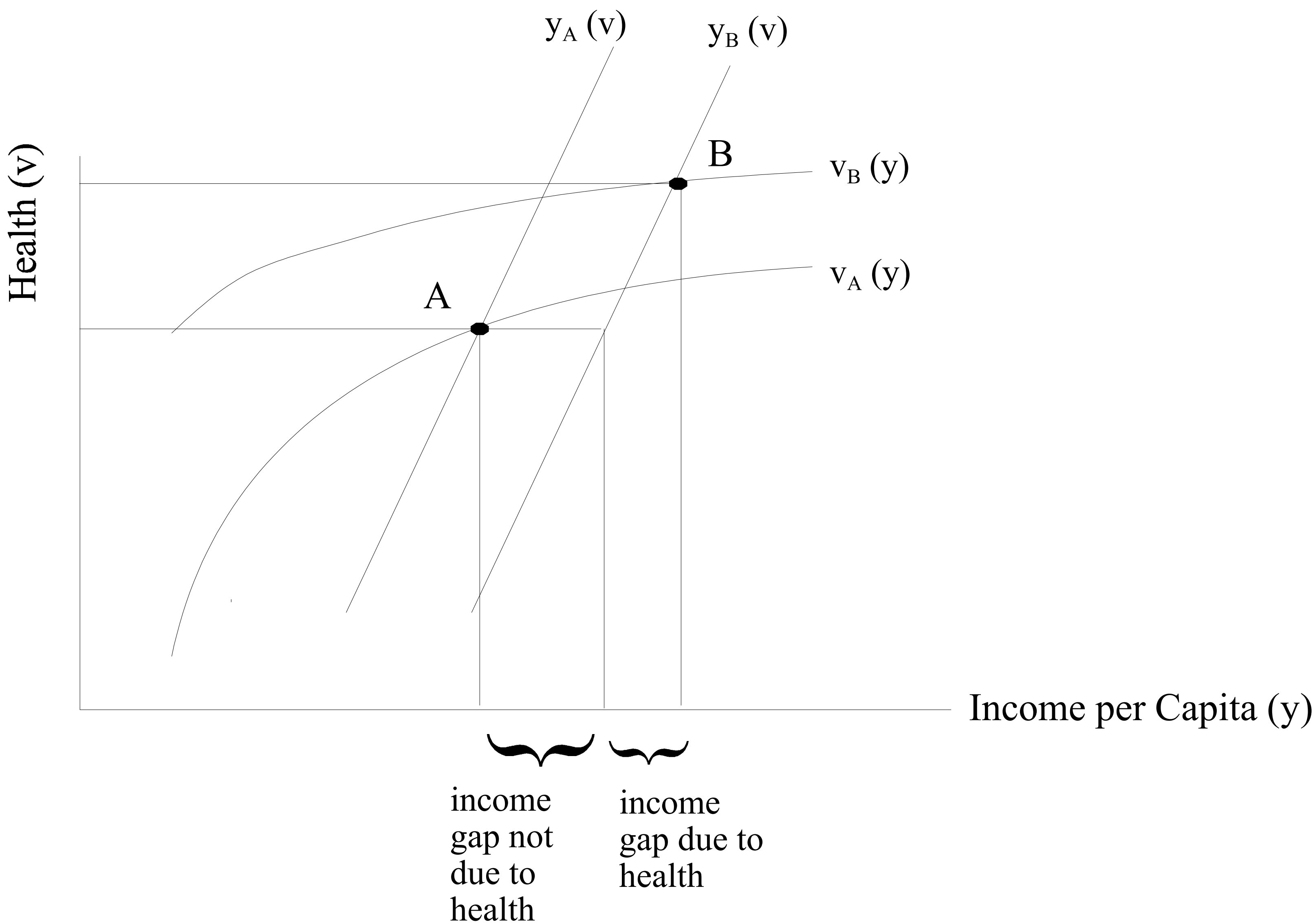
[4]Notice that I have assumed that the y(v) function has a constant slope and shifts in a parallel fashion. Were this not the case, then the results of the decomposition that I am proposing would depend on which country one started with. Below I present a simple model in which the constant slope assumption is justified.

Figure 3

Decomposing Income Differences



averages. Thus the change in average height within a single country over time provides a good indicator of the change the health environment (assuming a genetically stable population). And in settings where data such as income per capita are unavailable, height may serve as the best available measure of the standard of living.[5]

Of course, the average height of adults is not a perfect indicator of the average *health* of adults, since height is almost completely determined by the time a person is in his or her mid-twenties. Thus it is possible that health environment in which an adult lives will be very different from the one in which he grew up. If one is looking at historical data from periods of time in which the environment was changing only slowly, or looking cross-sectionally at countries which differ greatly in their health environments, then this timing effect will not be a serious problem; however, if one looks at countries with rapidly changing health environments, it is a possible concern.

Even where the health environment is changing rapidly, and so adult height is not a good indicator of the health environment in which adults live, it is still the case that adult height provides a lot of information about adult health. The reason for this is that, as recent literature has shown (Fogel, 1994), there is a "long reach" of childhood malnutrition and ill health into adulthood. Adults who are shorter because of a poor childhood environment have higher rates of many chronic illnesses in middle and old age. As I show below, the close correlation between adult height and adult mortality rates suggests that height is indeed a good indicator of health.

Having established that height is a good indicator of health, we would like to go farther and measure the magnitude of this relation. Our approach parallels the method used by Hall and Jones (1999) and Klenow and Rodriguez-Clare (1997) to covert years of education into a measure of human capital due to education.

Start with a Cobb-Douglas aggregate production function that takes as its arguments capital and a composite labor input,

$$Y = K^{\alpha}(A\,H)^{1-\alpha}$$

where A is a country-specific productivity term. The labor composite, H, is determined by

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[5]Looking at differences in average adult height between countries as an indicator of differences in the health environment is more problematic, since there may be systematic genetic variation in the height of healthy adults. Steckel (1995) argues that although genetic differences can have some impact of differences in average heights between populations, such differences are in fact largely attributable to environmental factors. He reports that the correlation between height of adult men and the log of income per capita for his sample of 15 countries is 0.82.

$H = h\ v\ L$,

where h is per-worker human capital in the form of education, v is per-worker human capital in the form of health, and L is the number of workers. (As is common in this literature, we assume away heterogeneity in considering the aggregation to national averages, but then turn around and exploit this heterogeneity to derive parameter estimates from microeconomic data.)

The wage to a unit of the labor composite, w, is simply its marginal product,

$$w = (1-\alpha)\, K^{\alpha} (A\, H)^{-\alpha}.$$

The wage earned by worker *j* will be a function of his own health and education[6]

$$w_j = w\, h_j\, v_j$$

Taking logs,

$$\ln(w_j) = \ln(w) + \ln(h_j) + \ln(v_j)$$

the usual Mincer-style analysis relates the quantity of human capital to years of education (denoted *e*),

$$\ln(h_j) = constant + \beta e_j$$

Ignoring health for a moment, one can recover the coefficient β from a regression of log wages on the number of years of education:

$$\ln(w_j) = constant + \beta e_j$$

(Notice that the β in the two previous equations is the same. The reason is the assumption that wages move one for one with human capital.)

In the case of health, we similarly assume that there is a linear relation between log health and the level of height.

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6 Notice that implicit in this formulation is the notion that a worker with more education or health supplies more units of the same basic labor input as workers who are less educated or healthy. In the case of education, this assumption seems hard to justify, since one worker with a Ph.D. is hardly a perfect substitute for four workers who have no education. In the case of health, the assumption may be marginally more satisfactory: one healthy worker who can work faster or longer may indeed be a substitute for several unhealthy workers.

$$\ln(v_j) = constant + \gamma s_j$$

As in the case of human capital from education, one could then recover the coefficient γ from a regression of log wages on height. However, there are two econometric problems that arise in estimating the relation between height and wages. The first is that there is presumably a large error term in equation that relates height to health. The source of the error term in this equation is that, while an individual's height is affected by his or her health status, health is not the only thing that determines height. Rather, looking across people, there is also a large degree of genetic heterogeneity. Thus, using height as an indicator of health introduces a large degree of measurement error, and the coefficient on height in a wage regression will be biased downward.

A second econometric problem in estimating this equation is that there is likely to be a positive correlation between a person's height and unmeasured determinants of his wage. Although adult height is determined by the time a person is his mid 20's, and thus is not directly dependent on his adult wages, many of the factors that determine a person's health are also likely to a have an effect on wages. People from high-income families will be well nourished and cared for as children, and they will also carry into the labor market advantages, such as better schooling and family connections, that are not observed by the econometrician. The omission of these factors will bias upward the coefficient on height in a wage regression.

Both of these problems can be overcome by using an instrumental variables procedure. What is needed is a variable which is correlated with height but uncorrelated with the unobserved determinants of wages. One such variable is inputs into health in childhood. These inputs will increase height, but will not increase wages except through their effect on height. By instrumenting for height with inputs into health, the estimated coefficient in the regression will reflect only the true structural effect of height, as determined by health, on wages. Schultz (1999, table 5) reports the results of studies using cross-sectional data on individuals from Brazil, Ghana, and Colombia in which hourly wages are regressed on height, with the latter instrumented by measures of the price and availability of inputs into health in childhood (specifically, the distance to local health facilities and the relative price of food in the worker's area of origin). The estimated effect of an extra centimeter of height on male wages in the different studies is 4%, 6%, and 8%, respectively.[7] In what follows below, I use the average of these figures, 6%, as an estimate of the structural effect of health-induced height on wages.

All of the regressions that Schultz reports control for years of education as well as height, and so any indirect effects of health on the level of schooling are not included in the coefficient on height. Further, in all of these regressions, the dependent variable is the log of the hourly wage. Thus the extent to which good health allows a person to work more hours, as well as to do better work during the hours employed, is not accounted for. For both of these reasons, the estimates may understate the effect of health on income.

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[7] For female wages, the results are 6%, 8%, and 7%, respectively. Schultz also reports results from Cote d'Ivoire which are not significant at the 5% level for either males or females.

3. Health and Income at the National Level

The microeconomic evidence discussed above establishes that an individual's health, as reflected in his or her height, will have an effect on wage earnings. If countries differed in their average levels of health, that would be expected to affect the level of income per capita. Indeed, it is straightforward to show that in the steady state of a Solow model, income per capita in a will simply be proportional to the level of health per capita, v. We now turn to data to ask the extent to which changes in health over time or differences in health between countries can explain income.

3.1 A Single Country Over Time

As a first test of my methodology, I examine the impact of health improvement in a single country – the United Kingdom – over a period of 200 years. An advantage of studying this case is that there is a good benchmark against which to compare my results. In a series of papers, Robert Fogel (see 1997 for a summary) carefully analyzes caloric intake and measures of calorie demand in the UK over the period 1780-1980. His analysis takes into account both the total quantity of calories consumed and the distribution of these calories across the population. He also carefully accounts for use of calories in basal metabolic maintenance (which increased over this period, as people got bigger), in order to calculate how many calories were left over for work.

Fogel's conclusion is that increased calorie consumption had two significant impacts on labor supply. First, over this 200 year period, the fraction of the population that was simply too poorly nourished to work at all fell from 20% to zero, leading to an increase in labor input by a factor of 1.25. Second, among the adults who were working, increased caloric consumption allowed for a 56% increase in labor effort.[8] Combining these effects, improved nutrition raised labor input by a factor of 1.95, or at an annual rate of 0.33% per year increase in labor input.[9]

In comparison to Fogel's detailed analysis, the calculation using my technique is quite simple. Over the period 1775-1995, average height in the UK rose by 9.1 centimeters (Fogel, 1994). Applying the coefficient of 6% per centimeter of height implies that labor input would

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[8]More specifically, Fogel finds that the number of calories *available* for work increased by 56% over this period, and then further assumes, for lack of any data, that the division of energy output between work and "discretionary activities" remained constant.

[9]Although Fogel's work concentrates on nutrition and not other aspects of health, the link between the two is quite close. For example, Fogel calculates that improvements in nutritional status, such as those indicated by stature, accounted for 90% of the mortality decline in England between 1775 and 1875, and half of the decline between 1875 and 1975.

have increased by a factor of 1.70 – slightly less than Fogel's estimate, but certainly in the same ballpark.

Expressed in terms of annual growth rates, my calculation implies that improvements in health explained growth in income per capita of 0.27% per year. Actual growth in income per capita over this period was 1.15% per year. Thus my calculation implies that health improvement directly explained 23% of the total growth in income. As we shall see below, this is fairly close to my estimate of the fraction of cross-country income variation that is directly explained by health.[10]

3.2 Measuring Health Across Countries

The analysis above suggests that looking at changes in height over time may be a reasonable way of assessing the effect on income of health changes. Ideally, one would like to be able to apply a similar analysis across countries. Two obstacles intrude, however. The first is the lack of any uniform data on adult heights across countries. The second problem is that, as discussed above, the genetic component of height almost certainly varies between countries. This could potentially be a source of serious measurement error.

Both of these problems can be surmounted by using a different indicator of health. Specifically, I use the data on adult mortality rate (AMR): the fraction of fifteen year olds who will die before age 60, using the current life table.[11] These mortality rates are available in consistent form for a large cross-section of countries. Further, it seems reasonable to assume that the relation between mortality and health shows less genetic variation across countries than does the relation between height and health. The AMR has the advantage of measuring mortality during working years, and thus seems likely to be a good measure of health during working years, which is what should be most relevant for determining the level of output per worker.

Figure 4 shows the relation between adult mortality and income per capita across countries in 1990. Table 1 shows the unweighted means and standard deviations of the AMR

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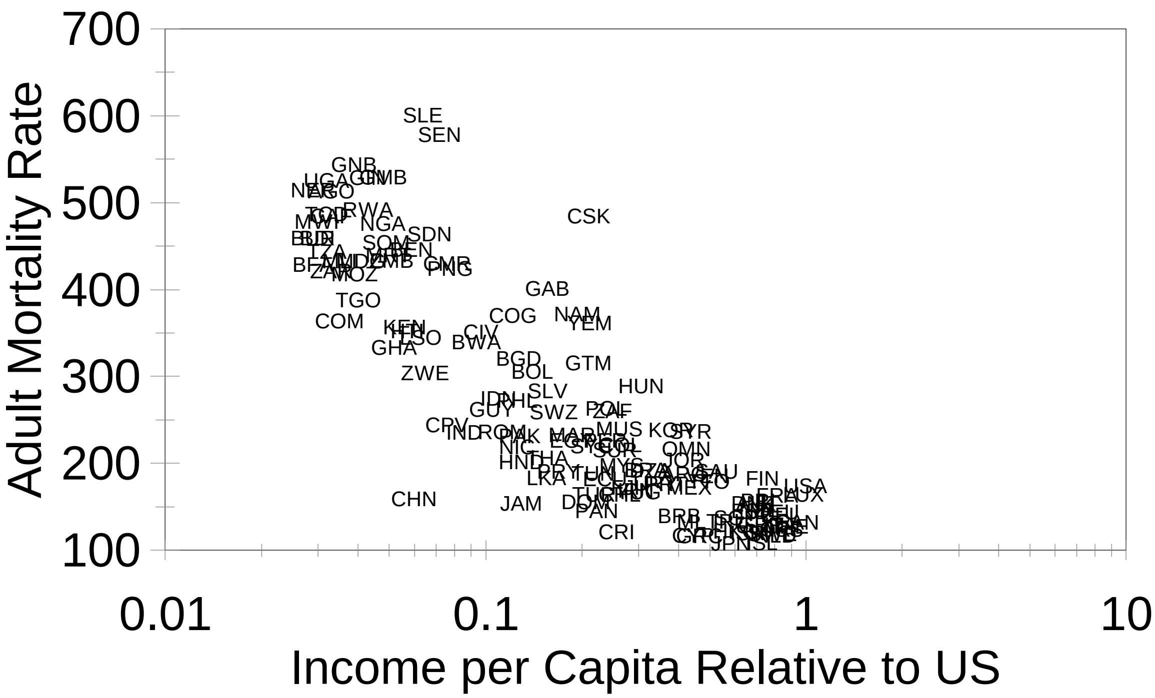
[10]Following Fogel's methodology, Sohn (2000) conducted a similar accounting exercise for South Korea over the period 1962-95, using data on total caloric consumption and income distribution. Sohn's finding is that over this period, increased caloric intake raised available labor by between 0.99 and 1.68% per year. Once again, we can use this calculation as a benchmark. Over this period, height of adult males rose by 4.8 centimeters, implying an increase in labor input of 0.85% per year.

[11]Like the more common measure, life expectancy at birth, the AMR is based on a cross-sectional life table. Thus it measures how many fifteen years olds would die before age 60 if, at each age, they experienced the mortality rates of men who are currently that age. Data are from the World Bank.

Figure 4


Adult Mortality Rate
700
600
500
400
300
200
100
0.01
0.1
1
10
Income per Capita Relative to US
SLE
SEN
CSK
GAB
TGO
COM
ZWE
HUN
CHN
JAM
CRI
FIN
USA

over the period 1960-1998 for the 111 countries in which data was available for all years. Both the mean and the standard deviation of mortality declined in the period up to 1990, reflecting a worldwide trend toward better health and the catching-up of the poorest countries toward rich country health levels (even though poor country incomes did not systematically grow faster than those in rich countries). The rise in the standard deviation of the mortality rate between 1990 and 1998 reflects the impact of AIDS, which dramatically raised mortality rates in several African countries.

Table 1: Mean and Standard Deviation of the Adult Mortality Rate

Year	Mean	Standard Deviation
1960	.377	.160
1970	.340	.151
1980	.307	.141
1990	.270	.139
1998	.260	.147

Note: The Adult Mortality Rate is the number of 15 year olds who will not live to reach age 60, using the current life table.

Using mortality as a measure of health for the purposes of gauging its effect on income differences across countries requires that we have an estimate of the quantitative impact of mortality variations on wages. To get this estimate, I look to data from a single country over time. Doing so allows us to difference out the effect of genetic variation in height.

To be more specific, consider the following model. As described above, we assume that there is a linear relation between log health and the level of stature. Looking across countries (indexed by i), we allow for a country fixed effect in this relation:

$$\ln(v_{i,t}) = \lambda_i + \gamma s_{i,t}$$

Similarly, mortality is taken to be a linear function of log average health

$$\ln(v_{i,t}) = \psi + \phi AMR_{i,t}$$

We can use the second equation to look at differences between countries at a single point in time:

$$\ln(v_{i,t}) - \ln(v_{j,t}) = \phi(AMR_{i,t} - AMR_{j,t})$$

The coefficient ϕ shows the differences in health (and thus in steady state output) that result from differences in the mortality rate. Unfortunately, we don't know ϕ directly, because we don't have a structural regression of wages on health, where health is measured by the mortality rate. To get the coefficient we need, we follow a round-about procedure. First we time-difference both equations:

$$\ln(v_{i,t}) - \ln(v_{i,t-1}) = \gamma(s_{i,t} - s_{i,t-1})$$

$$\ln(v_{i,t}) - \ln(v_{i,t-1}) = \phi(AMR_{i,t} - AMR_{i,t-1})$$

Combining these two differenced equations,

$$\frac{\phi}{\gamma} = \frac{s_{i,t} - s_{i,t-1}}{AMR_{i,t} - AMR_{i,t-1}}$$

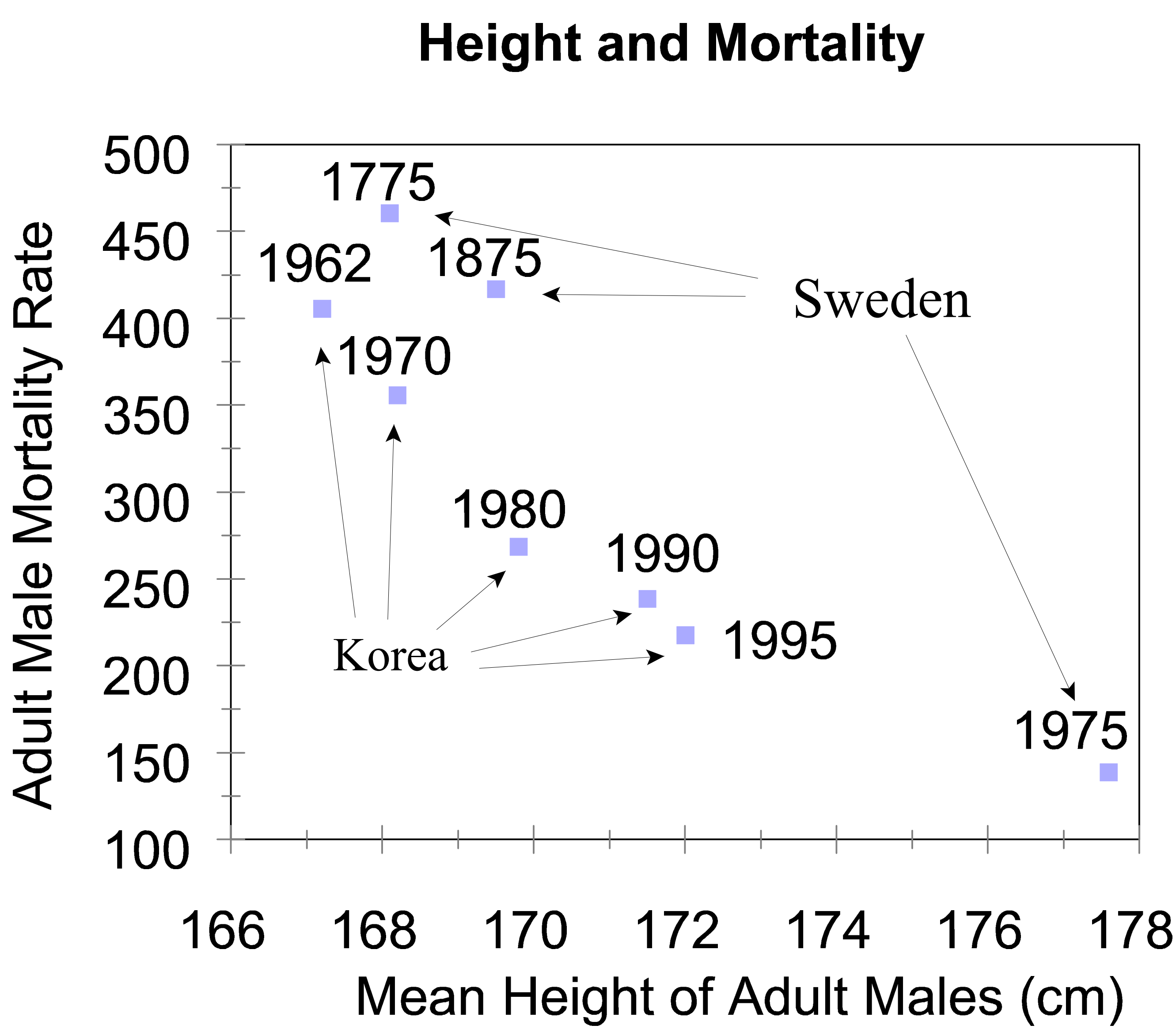
To get an estimate of ϕ/γ, then, one has to look at within-country changes in height and mortality. Figure 5 presents data for two countries: Sweden over a period of two centuries, and South Korea over a period of 33 years.[12] The data suggest that the assumption of a linear relation between changes in mortality and changes in height is not a bad approximation. Using the first and last data points for each country, the Korean data imply that value of ϕ/γ of -26 centimeters per death (in other words, the increase in height between moving from an AMR of 100% to an AMR of zero would be 26 centimeters). For Sweden the value is -30. In the calculations below I use the average of these two values.

Multiplying the estimates of ϕ/γ by Schultz's estimate of a return to height, $\gamma = .06$, we get an estimate for $\phi = 1.68$. This says that lowering the AMR by one percentage point (i.e. by 10 deaths per thousand) would raise the level of health, and thus wages, by 1.68%.

This estimate can be used to transform cross-country differences in AMR into differences in labor input, v. Figure 6 shows the relationship between income per capita and my estimate of health-induced labor input.

It is interesting to note that the difference in health-induced labor input between the richest and poorest countries – a factor of slightly more than two – is fairly similar to the difference health-induced labor input between the UK today and the UK 200 years ago, a factor

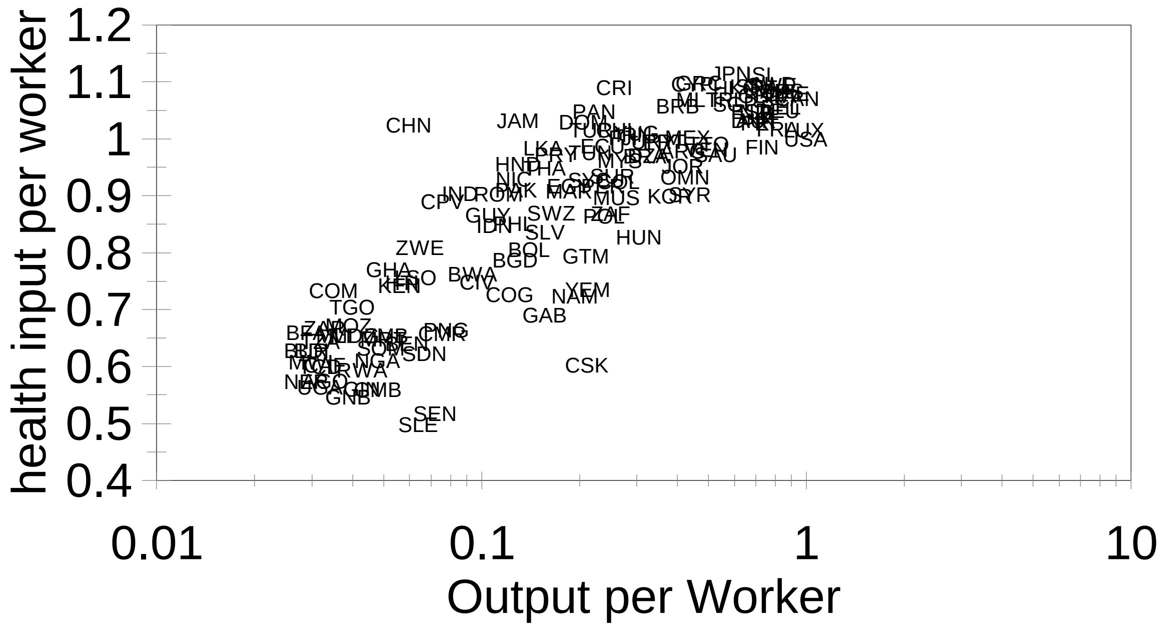
[12]Rather than look at changes within single countries, one could also run a regression of height on mortality, including country fixed effects. With only two countries' worth of data this seemed a little grandiose, but I plan to do it in the future.



Height and Mortality
Adult Male Mortality Rate
500
450
400
350
300
250
200
150
100
166
168
170
172
174
176
178
Mean Height of Adult Males (cm)
1775
1875
Sweden
1962
1970
1980
1990
1995
Korea
1975

Figure 6

Output vs Health Input



of 1.7. But while the UK today is roughly 10 times richer than it was 200 years ago, the richest countries in the sample are 30 times as wealthy as the poorest countries. This reflects the fact that the relative price of health has decreased.

4. Assessing the Contribution of Health to Income Differences

Having created a measure of how the health-induced labor input differs between countries, it is natural to ask how much of the cross-country variation in income is explained by these differences in labor input. To answer this question, I extend the "development accounting" methodology of Klenow and Rodriguez-Clare (1997) and Hall and Jones (1999) to include a measure of health.

Start with the aggregate production function introduced above:

$$Y = K^{\alpha}(AhvL)^{1-\alpha}$$

where Y is total output, K is the capital stock, L is the labor force, A is a measure of productivity, h is the average level of human capital in the form of education, and v is a measure of health.

Our interest is in asking how different factors contribute to variations in income between countries. We start by dividing both sides of the equation by the labor force, L,

$$\frac{Y}{L} = \left(\frac{K}{L}\right)^{\alpha}(Ahv)^{1-\alpha}$$

One might think that this equation would serve as a good way of assessing the contributions to differences in income between countries. A difference in Y/L between two counties could be attributed to differences in the capital/labor ratio, productivity, human capital, and health. Such an approach has a problem, however, that stems from the effect of changes in other variables on the capital/labor ratio. Consider, for example, a case where two countries differ in their levels of productivity, but have equal rates of investment and equal levels of human capital and health. Since the only determinant of output that differs between the countries is productivity, we would like our procedure to attribute all differences to this factor. However, the country that is more productive will have a higher level of capital than the country with a low value of A, since they invest the same fractions of their output. Thus using the equation above would attribute part of the difference between two countries to the K/L ratio. Exactly the same problem would arise if the countries differed in either human capital or health.

We can correct for this problem by diving both sides of the equation by $(Y/L)^{\alpha}$ and then raising them to the power 1/(1- α):

$$\frac{Y}{L} = \left(\frac{K}{Y}\right)^{\frac{\alpha}{1-\alpha}} A h v$$

Taking logs and then looking at the variance:

$$Var\left(\ln\left(\frac{Y}{L}\right)\right) = Var\left(\frac{\alpha}{1-\alpha}\ln\left(\frac{K}{Y}\right)\right) + Var(\ln(A)) + Var(\ln(h)) + Var(\ln(v)) + covariance\ \ terms$$

I apply this variance decomposition to a sample of 124 countries. The values of Y, L, K, and h are taken from Hall and Jones (1999), and apply to 1988. The value of v is constructed from 1990 data on the Adult Mortality Rate, as described above. The value of A for each country is derived from the production function.[13] Appendix Table 1 presents the full set of variance and covariance terms.

To answer the question of how much each factor contributes to the variance of output per worker, I follow Klenow and Rodriguez-Clare in simply dividing the covariance evenly between factors. Thus, for example, the fraction of the variance in output per worker due to health will be given by[14]

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[13]My sample consists of the 127 countries studied by Hall and Jones (1999), with the exception of Reunion, Taiwan, and the USSR, for which mortality data were not available. Mortality data is from 1990, except for countries where that was not available, as follows: for Egypt, Guatemala, Lesotho, Paraguay, and Somalia, I used the arithmetic average of data from 1980 and 1997. For Turkey and South Africa, I used data from 1997, while for Congo, I used data from 1998. For Botswana, data was available for 1980 and 1997 but not 1990. In this case, I used data for 1980, since I judged it more likely to match mortality in 1988 than does the data from 1997, which reflects the toll of AIDS.

I follow Hall and Jones in using a value of 1/3 for α. This choice affects the division of variance between (K/Y) and A, but does not affect the fraction of variance attributed to health.

[14]Klenow and Rodriguez-Clare justify their procedure as follows. Starting with the equation in the text, take logs and look at the covariance of ln(Y/L) with each side:

$$Var(\ln(Y/L)) =$$

$$Cov(\ln(Y/L), \frac{\alpha}{1-\alpha}\ln(K/Y)) + Cov(\ln(Y/L),\ln(A)) + Cov(\ln(Y/L),\ln(h)) + Cov(\ln(Y/L),\ln(v))$$

Dividing both sides by Var(ln(Y/L)), the four terms on the right hand side can be interpreted as

$$\frac{Var(\ln(v)) + Cov\left(\ln(v), \frac{\alpha}{1-\alpha}\ln(K/Y)\right) + Cov(\ln(v),\ln(A)) + Cov(\ln(v),\ln(h))}{Var\left(\ln\left(\frac{Y}{L}\right)\right)}$$

Table 2 presents the shares of the variation in output per worker attributable to each factor. The table implies that variation in health does indeed have a large effect on variation in output per worker. The share of the variation in output accounted for by health, 17.3%, is only slightly smaller than the shares accounted for by human capital in the form of education and by physical capital.

Table 2: Shares of Variation in Output per Worker Attributable to Each Factor	
physical capital	.185
human capital (education)	.214
health	.173
productivity	.429

The results in Table 2 also modify the conclusions reached by Hall and Jones (1999) and Klenow and Rodgriguez-Clare (1997) regarding the importance of productivity differences in explaining differences in output between countries. Since my procedure does not affect the shares of variation attributable to h and to K/Y, in comparison to the original work of Hall and Jones, any of the variance that is explained by health in my procedure would be attributed to productivity if health were not measured. Thus the share of variation in output per worker that is attributable to productivity falls from .602 to .429 with the inclusion of health. Productivity is still left as the most important determinant of income differences, but it not longer ranks as being more important than all other factors taken together.

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the fractions of the variance of output per worker that are attributable to each factor. So, for example, the fraction of variance due to health would be

$$\frac{Cov(\ln(Y/L),\ln(v))}{Var(\ln(Y/L))}.$$

Expanding this term by substituting for ln(Y/L) gives the same expression that I present in the text.

5. Conclusion

The major contribution of this paper has been to show how differences in measured mortality rates can be transformed into estimated differences in the level of health capital, and to calculate the contribution of these differences in health capital to variation in output. In a broad cross section of countries, variation in health explains roughly 17% of the variance in output per capita. This share of variance is only slightly smaller than the shares explained by human capital in the form of education and by physical capital accumulation. Accounting for health capital reduces the fraction of variance that is explained by residual productivity differences by almost one third.

Improvement in health is clearly a significant part of the story of economic growth. A not entirely unreasonable rule of thumb is that adult male height rises by about 10 centimeters between pre-industrial, agricultural economies and the time a country has industrialized (pre-agricultural populations were evidently healthier than those that followed, but there is no case of a county moving from hunting and gathering to industrialization in a single step.) Similarly, the Adult Mortality Rate falls from somewhere between 400 and 500 per thousand to around 100 per thousand. The improvement in health underlying these changes in height and mortality explains an increase in labor input of roughly a factor of 1.79 ($= 1.06^{10}$). In many developing countries, this health transition is only partially complete, and so improvements in labor quality hold the potential to provide a further boost to economic growth over the next several decades. In the most advanced countries, this health transition is mostly complete, and the fact that health will no longer be improving may be another source of slowing growth in the future (see Jones, 2000).

Appendix Table 1: Variances and Covariances		
	Value	Contribution to Var(ln(Y/L))
Var(ln(Y/L))	1.165	–
Var(ln(K/Y)$^{\alpha/(1-\alpha)}$)	0.103	0.088
Var(ln(A))	0.356	0.301
Var(ln(h))	0.084	0.072
Var(ln(v))	0.047	0.041
Cov(ln(K/Y)$^{\alpha/(1-\alpha)}$, ln(A))	0.015	0.026
Cov(ln(K/Y)$^{\alpha/(1-\alpha)}$, ln(h))	0.055	0.095
Cov(ln(K/Y)$^{\alpha/(1-\alpha)}$, ln(v))	0.042	0.073
Cov(ln(A), ln(h))	0.063	0.108
Cov(ln(A), ln(v))	0.065	0.111
Cov(ln(h), ln(v))	0.047	0.080

Note: For variance terms, the value in the second column is derived by dividing the value in the first column by Var(ln(Y/L)). For covariance terms, the value in the second column is twice the value in the first column divided by Var(ln(Y/L)).

References

Acemoglu, Daron, Simon Johnson, and James A. Robinson, "The Colonial Origins of Comparative Development: An Empirical Investigation" Mimeo, MIT, 2000.

Bloom, David E. and David Canning, "The Health and Wealth of Nations" *Science* Volume 287, Feb. 18, 2000, pp. 1207-1209.

Fogel, Robert W., "Economic Growth, Population Theory, and Physiology: The Bearing of Long-Term Processes on the Making of Economic Policy." *American Economic Review* 83:3, June, 1994, 369-395.

Fogel, Robert W., "New Findings on Secular Trends in Nutrition and Mortality: Some Implications fo Population Theory" in Mark Rosenzweig and Oded Stark, eds., *Handbook of Population and Family Economics* Volume 1A, New York: Elsevier, 1997.

Gallup, John Luke and Jeffrey D. Sachs, "The Economic Burden of Malaria," Mimeo October 1998.

Hall, Robert E. and Charles I. Jones, "Why Do Some Countries Produce So Much More Output per Worker than Others?" *Quarterly Journal of Economics* 114:1, February, 1999, 83-116.

Jones, Charles, "Sources of US Economic Growth in a World of Ideas" Mimeo, Stanford University, 2000.

Kalemli-Ozcan, Sebnem, Harl E. Ryder, and David N. Weil, "Mortality Decline, Human Capital Investment, and Economic Growth" *Journal of Development Economics*, 62:1, 2000, 1-23.

Klenow, Peter, and Andres Rodgriguez-Clare, "The Neoclassical Revival in Growth Economics: Has It Gone Too Far?" in Ben S. Bernanke and Julio Rotemberg, eds., *NBER Macroeconomics Annual 1997*, Cambridge, MA: MIT Press, 1997.

Preston, Samuel, "The Changing Relation Between Mortality and Level of Economic Development," *Population Studies* 29, 1980, 231-248.

Pritchett, Lant and Lawrence H. Summers (1996), 'Wealthier is Healthier', Journal of Human Resources, 31(4), pp.841-68.

Schultz, T. Paul, "Productive Benefits of Improving Health: Evidence from Low-Income Countries." Mimeo, Yale University, December 1999.

Sohn, Byungdoo, "How Much Has Health Improvement Contributed to the Korean Economic

Growth?" working paper, Brown University, January 2000, http://econ.pstc.brown.edu/~sohnb

Steckel, Richard, "Stature and the Standard of Living" *Journal of Economic Literature*, 1995