www.elsevier.com/locate/worlddev

World Development Vol. 32, No. 1, pp. 1–13, 2004

Printed in Great Britain
0305-750X/$ - see front matter

doi:10.1016/j.worlddev.2003.07.002

The Effect of Health on Economic Growth: A Production Function Approach

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Summary. — We estimate a production function model of aggregate economic growth including two variables that microeconomists have identified as fundamental components of human capital: work experience and health. Our main result is that good health has a positive, sizable, and statistically significant effect on aggregate output even when we control for experience of the workforce. We argue that the life expectancy effect in growth regressions appears to be a real labor productivity effect, and is not the result of life expectancy acting as a proxy for worker experience.

Key words — economic growth, international health

1. INTRODUCTION

Although labor quality, in the form of human capital, clearly contributes significantly to economic growth, most crosscountry empirical studies identify human capital narrowly with education. This practice ignores strong reasons for considering health to be a crucial aspect of human capital, and therefore a critical ingredient of economic growth. Healthier workers are physically and mentally more energetic and robust. They are more productive and earn higher wages. They are also less likely to be absent from work because of illness (or illness in their family). Illness and disability reduce hourly wages substantially, with the effect especially strong in developing countries, where a higher proportion of the work force is engaged in manual labor than in industrial countries. A substantial body of microeconomic evidence documents many of these effects (see Strauss & Thomas, 1998). The objective of this paper is to determine whether this micro evidence can be corroborated by macro evidence of an effect of population health on economic growth. Health, in the form of life expectancy, has appeared in many crosscountry growth regressions, and investigators generally find that it has a significant positive effect on the rate of economic growth (see Bloom & Canning, 2000, 2003). (Table 1 reports a selection of the papers that include health as a determinant of economic growth and the magnitude of the effect on growth they find.) These regressions, however, do not indicate whether health directly benefits growth or whether it is merely a proxy for other missing or mismeasured factors (as suggested, for example, by Barro & Sala-I-Martin, 1995).

The main objective of this study is to include health in a well-specified aggregate production function in an attempt to test for the existence of an effect of health on labor productivity, and to measure its strength. Because human capital is multidimensional, however, we need a model of growth that includes all its major components. This helps ensure that we do not erroneously overestimate the contribution of one component by mistakenly attributing to it the contributions of those components we omit. In particular, there is a potential bias in estimates of the effect of health that rely on life expectancy data in that countries with high life expectancies tend to have older work forces with higher levels of experience. Considerable microeconomic evidence—dating back to

* The authors gratefully acknowledge financial support from the World Health Organization's Economic Advisory Service. Earlier drafts of this paper were presented at the National Bureau of Economic Research Summer Institute and at meetings of the WHO Commission on Macroeconomics and Health (Working Group One). The authors are grateful for many helpful comments received during the course of those presentations. Final revision accepted: 29 July 2003.

Table 1. *Estimates of the effect of health on economic growth*[a]

Study	Health measure (in logs)	Coefficient (standard error)	Growth effect of increasing life expectancy by 5 years	Data	Estimator	Other covariates (all papers have the log of initial income per capita or per worker)
Barro (1996)	Life expectancy	0.042 (0.014)	0.33	Three periods 1965–75, $n = 80$; 1975–85, $n = 87$; 1985–90, $n = 84$	3SLS using lagged values of some regressions as instruments, period random effects	Male secondary and higher schooling, log(GDP) × male schooling, log fertility rate, government consumption ratio, rule of law index, terms of trade change, democracy index, demo- cracy index squared, inflation rate, continental dummies
Barro and Lee (1994)	Life expectancy	0.073 (0.013)	0.58	Two periods $n = 85$ for 1965–75, $n = 95$ for 1975–85	SUR with country random effects	Male and female secondary schooling, I/GDP, G/GDP, log(1 + black market premium), revolutions
Barro and Sala-I-Martin (1995)	Life expectancy	0.058 (0.013)	0.46	Two periods $n = 87$ for 1965–75, $n = 97$ for 1975–85	SUR with country random effects	Male and female secondary and higher education, log(GDP) × human capital, public spending on education/GDP, investment/GDP, government consumption/GDP, log(1 + black market premium), political instability, growth rate in terms of trade
Bhargava, Jamison, Lau, and Murray (2001b)	Adult survival rate ASR × log(GD PC)	0.358 (0.114) −0.048 (0.016)	NA	25-year panel at 5-year intervals, 1965–90, $n = 92$	Dynamic random effects	Tropics, openness, log fertility, log (Investment/GDP)
Bloom, Canning, and Malaney (2000)	Life expectancy	0.063 (0.016)	0.50	25-year panel at 5-year intervals, 1965–90, $n = 391$	Pooled OLS	GDP per worker, tropics, land-locked, institutional quality, openness, log of years of secondary schooling, population growth, working-age population growth, log ratio of working-age to total population, population density, period dummies

Bloom and Malaney (1998)	Life expectancy	0.027 (0.107)	0.21	25-year cross-section, 1965–90, $n = 77$	OLS	Population growth, growth of economically active populations, log years of secondary schooling, natural resource abundance, openness, institutional quality, access to ports, average government savings, tropics, ratio of coastline distance to land area
Bloom *et al*. (1999)	Life expectancy	0.019 (0.012)	0.15	25-year cross-section, 1965–90, $n = 80$	2SLS	Log of ratio of total population to working-age population, tropics, log of years of secondary schooling, openness, institutional quality, population growth rate, working-age population growth rate
Bloom and Sachs (1998)	Life expectancy	0.037 (0.011)	0.29	25-year cross-section, 1965–90, $n = 65$	OLS	Log secondary schooling, openness, institutional quality, central government deficit, percentage area in tropics, log coastal population density, log inland population density, total population growth rate, working-age population growth rate, Africa dummy
Bloom and Williamson (1998)	Life expectancy	0.040 (0.010)	0.32	25-year cross-section, 1965–90, $n = 78$	OLS	Population growth rate, working-age population growth rate, log years of secondary schooling, natural resource abundance, openness, institutional quality, access to port, average government savings rate, tropics dummy, ratio of coastline to land area
Caselli, Esquivel, and Lefort (1996)	Life expectancy	−0.001 (0.032)	0.00	25-year panel at 5-year intervals, 1960–85, $n = 91$	GMM (Arellano-Bond method)	Male and female schooling, I/GDP, G/GDP, black market premium, revolutions

Table 1 (*continued*)

Study	Health measure (in logs)	Coefficient (standard error)	Growth effect of increasing life expectancy by 5 years	Data	Estimator	Other covariates (all papers have the log of initial income per capita or per worker)
Gallup and Sachs (2000)	Life expectancy	0.030 (0.009)	0.24	25-year cross-section, 1965–90, $n = 75$	OLS	Years of secondary schooling, openness, quality of public institutions, population within 100 kilometers of the coast, malaria index in 1966, change in malaria index from 1966 to 1994
Hamoudi and Sachs (1999)	Life expectancy	0.072 (0.020)	0.57	15-year cross-section, 1980–95, $n = 78$	OLS	Institutional quality, openness, net government savings, tropics land area, log coastal population density, population growth rate, working-age population growth rate, Africa dummy
Sachs and Warner (1997)	Life expectancy life expectancy squared	45.48 (17.49) −5.40 (2.24)	0.06	25-year cross-section, $n = 79$	OLS	Openness, openness $\times$ log(GDP), land-locked, government saving, tropical climate, institutional quality, natural resource exports, growth in economically active population minus population growth

ASR: adult survival rate; GDP: gross domestic product; GMM: generalized method of moments; OLS: ordinary least squares; 3SLS: three stage least squares; SUR: seemingly unrelated regression.

Source: Authors.

[a] The growth effects of a five year increase in life expectancy are calculated for a country with a life expectancy of 63, the average life expectancy in developing countries in 1990.

Mincer (1974)—indicates that experience has an impact on workers' earnings. By including the experience of the workforce directly into the model we control for this effect.

To this end we specify an aggregate production function that expresses a country's output as a function of its inputs and the efficiency with which it uses these inputs. These inputs are physical capital, labor, and human capital in the three dimensions of education, experience, and health. Our model also considers the efficiency with which these inputs are used, that is, total factor productivity (TFP) allowing both for crosscountry differences in steady-state TFP and for technological diffusion. We estimate all the parameters of this production function using panel data for 1960–90 and obtain measures of the relative contributions of each of the inputs and of TFP to economic growth. An alternative approach would be to calibrate the model using microeconomic evidence for parameter values (see, for instance, Klenow & Rodriguez-Clare, 1997; Prescott, 1998; Young, 1994, 1995). The potential advantage of estimation over calibration is that the microeconomic evidence measures the effect of improvements in an individual's human capital on own earnings, ignoring the additional effects it might have on other individuals or on society as a whole. These additional effects, that is, externalities, might arise because people's productivity depends on the productivity of their coworkers. When workers obtain more schooling, their earnings rise, but those of their coworkers may rise as well. By estimating the returns to human capital in aggregate, we let these returns differ from microeconomic estimates, which allows us to make inferences about the existence and magnitude of the externalities.

Our main result is that health has a positive and statistically significant effect on economic growth. It suggests that a one-year improvement in a population's life expectancy contributes to a 4% increase in output. We also find that our estimates of the contributions of education and work experience are close to those found in microeconomic studies. Indeed, the differences between our parameter estimates and the averages found in microeconomic studies are usually statistically insignificant. Thus we find no evidence of the existence of externalities to human capital in the form of schooling and experience (or such externalities are too small for us to detect). While large crosscountry differences in life expectancy and average years of schooling explain a substantial proportion of the income gaps we observe between countries, crosscountry differences in average work experience are small, implying that work experience plays a relatively minor role in explaining income gaps.

Our model captures the direct effect of education and health on output. We do not investigate how education and health are themselves created—to do this would require a system of equations mapping out the development process. This implies however, we may miss the effect of increased education on health (Pritchett & Summers, 1996; Summers, 1992; and Younger, 2002), and of improved health on education (Balasz *et al.*, 1986; Bhargava, Jukes, & Sachs, 2001a; Kremer & Miguel, 2001; Pollitt, 1997, 2001).

2. THEORY

We assume that we can decompose economic growth into two sources: growth in the level of inputs and growth in TFP. We take our inputs to be physical capital, labor, and human capital.

We model output as a function of inputs and technology using the following aggregate production function:

$$Y = AK^{\alpha}L^{\beta}e^{\phi_1 s+\phi_2 \exp +\phi_3 \exp^2 +\phi_4^h}, \quad (1)$$

where Y is output or gross domestic product (GDP); A represents TFP; K is physical capital; L is the labor force; and human capital consists of three components, average years of schooling s, averages work experience of the work force exp, average square of work experience $\exp^2$, and health h (which we proxy with life expectancy). We express the effect of the human capital terms on output as powers of an exponential. The advantage of this functional form is that it implies that log wages depend on the level of schooling, experience, experience squared, and health status, which is compatible with the relationship usually estimated in microeconomic studies.

For simplicity we assume that the effect of health and schooling on output depends only on the average level of health and schooling in the economy and not on its distribution. A more realistic model would allow for a nonlinear effect of human capital on output at the individual level, implying that the distribution of human capital would matter at the macroeconomic level. For policy purposes, we estimate the effect of increasing health *on average;* particular health interventions that affect different sections of society in different ways may have a greater or lesser effect than this.

Taking logs of the aggregate production function, we derive an equation for the log of output in country i at time t:

$$y_{it} = a_{it} + \alpha k_{it} + \beta l_{it} + \phi_1 s_{it} + \phi_2 \exp_{it} + \phi_3 \exp^2_{it} + \phi_4 h_{it}, \quad (2)$$

where y_{it}, k_{it}, and l_{it} are the logs of Y_{it}, K_{it}, and L_{it}, respectively. Eqn. (2) is an identity, but in practice a_{it}, the level of TFP in country i at time t, is not observed and appears as an error term when the equation is estimated.

We model TFP as follows:

$$a_{it} = a^*_i + a^*_t + v_{it},$$

where

$$v_{it} = \rho v_{i,t-1} + \varepsilon_{it}, \quad (3)$$

where $0 < \rho < 1$ and ε_{it} is a random shock. Each country has a steady-state level of TFP given by a country specific level a^*_i and a worldwide technological frontier a^*_t. Its actual TFP, given by a_{it}, deviates from the steady-state level by the difference v_{it}. This deviation from steady state may be persistent, but as time passes, this country's TFP converges to its steady-state level at the rate $1 - \rho$, which we take to represent the speed of technological diffusion.

While technology may eventually diffuse, some countries may enjoy long-run advantages in TFP that are not eroded over time. To model parsimoniously how steady-state TFP may differ across countries, we assume a^*_i to be a function of geography, proxied by the percentage of country i's area that is in the tropics, and a measure of the quality of its political institutions. Tropical location has recently been viewed as a geographical disadvantage to growth because of the difficulty of diffusing agricultural technologies from temperate to tropical zones, disadvantages in food production, and infectious disease ecology (see Bloom & Sachs, 1998). The quality of political institutions, on the other hand, has been argued to affect economic growth because it provides the social stability, effective provision of public services, and enforcement of private contracts that are required for growth.

For estimation purposes, turning our production function into a growth equation is useful. Differencing Eqn. (2) gives us

$$\Delta y_{it} = \Delta a_t + \alpha \Delta k_{it} + \beta \Delta l_{it} + \phi_1 \Delta s_{it} + \phi_2 \Delta \exp_{it} + \phi_3 \Delta \exp^2_{it} + \phi_4 \Delta h_{it} + \Delta v_{it}. \quad (4)$$

Substituting out the error term Δv_{it} using Eqn. (3) and noting that the lagged productivity gap v_{it-1} is the difference between actual output and output at the average world TFP level at time $t-1$ generates

$$\begin{aligned}\Delta y_{it} = {} & \Delta a_t + \alpha \Delta k_{it} + \beta \Delta l_{it} + \phi_1 \Delta s_{it} \\ & + \phi_2 \Delta \exp_{it} + \phi_3 \Delta \exp^2_{it} + \phi_4 \Delta h_{it} \\ & + (1-\rho)(a_{i,t-1} + \alpha k_{i,t-1} + \beta l_{i,t-1} \\ & \quad + \phi_1 s_{i,t-1} + \phi_2 \exp_{i,t-1} + \phi_3 \exp^2_{i,t-1} \\ & \quad + \phi_4 h_{i,t-1} - y_{i,t}) + \varepsilon_{it}. \quad (5)\end{aligned}$$

Eqn. (5) shows that growth in output can be decomposed into four components: the growth of world TFP; the growth of inputs; a catch-up term as some of the country's TFP gap, v_{it-1}, is closed and the country converges to its steady-state level of TFP at the rate $1 - \rho$; and an idiosyncratic shock to the country's TFP, ε_{it}. The estimation of this type of relationship is discussed in more detail in Bloom, Canning, and Sevilla (2002).

There is clearly a potential problem of reverse causality in Eqn. (5), since the growth of output may affect the growth rate of inputs. To overcome this problem we use lagged levels and growth rates of inputs and output as instruments for current input growth rates. The validity of these lagged variables as instruments depends on their being uncorrelated with current shocks to TFP, represented by the error term ε_{it}. We test this using overidentifying restrictions.

An important implication of our theoretical model is that the coefficients on a lagged input level in the catchup term and the current growth rate of this input should be the same. We test this restriction as a check on our model's assumptions. Failure to satisfy these equality restrictions would point toward a more complex error structure for TFP.

3. DATA

We construct a panel of countries observed every 10 years over 1960–90. Output data (GDP) are obtained from the Penn World Tables (see Heston & Summers, 1994 for a description). We obtain total output by multiplying real per capita GDP measured in 1985 international purchasing power parity dollars (chain index) by national population.

We measure a country's labor supply by the size of its economically active population using data from the International Labour Office (1997), which also gives labor force participation rates disaggregated by gender and five-year age groups. But, our labor supply measure is unable to adjust for the fact that some fraction of the labor force is unemployed, and therefore should not be counted as providing labor inputs. Nor are we able to adjust for the hours the labor force works. Schooling is measured by the average total years of schooling of the population aged 15 years and older from Barro and Lee (2000).

Life expectancy data are from the United Nations (1998). We use these as a proxy for the health of the work force, even though they measure mortality rates rather than morbidity. Higher life expectancy is generally associated with better health status and lower morbidity (Murray & Chen, 1992; Murray & Lopez, 1997).

We construct a measure of aggregate work experience for each country by computing an experience measure for each of 22 gender and age group combinations (male and female for age groups 15–19, 20–24, ..., 60–64, 65+). Experience is simply the amount of time spent in the labor force. For each group we proxy this by average age minus average years of schooling minus the age at which schooling starts, which we uniformly assume to be six. In this calculation of experience, we use four measures of average years of schooling derived from Barro and Lee (2000) dividing the population into males and females and for those 15–24 and those 25 and over. [1]

This measure of experience is likely to be reasonable for males, but may overstate the experience of females, who more frequently spend periods out of the labor market. Average work force experience for the country as a whole is a weighted average of the group-specific experience measures, where the weights are the shares of each group in the total economically active population. Aggregate squared experience is the analogous weighted average of the squared experience of each group.

We generate a capital stock series for each country using a perpetual inventory method. We initialize the capital stock series in the first year for the Penn World Tables (version 5.6) provide investment data, setting the capital stock equal to the average investment/GDP ratio in the first five years of data, multiplied by the level of GDP in the initializing period, and divided by 0.07, our assumed depreciation rate. This is the capital stock we would expect in the initial year if the initial investment/GDP ratio is representative of previous rates. Each succeeding period's capital is given by current capital minus depreciation at 7%, plus the level of current investment. Our need for instruments means that we limit estimation to 1970–90; since investment series for our countries start either in 1950 or 1960 the assumption on initial capital stocks does not affect our estimates very much due to depreciation.

Our capital stock series has wider coverage than the Heston and Summers (1994) variable for capital stock per worker, which is only available for 62 countries from 1965 onward. Where the two overlap, the correlation coefficient between the log levels of our series and theirs is 0.97, indicating that the two series are very similar.

Our governance variable is based on the index created by Knack and Keefer (1995), which is itself an average of five indicators of the quality of public institutions, including (a) the perceived quality of the government bureaucracy, (b) the extent of corruption in government, (c) efficacy of the rule of law, (d) the risk of expropriation of private investment, and (e) the risk of repudiation of contracts by the government. Each country is scored on these five dimensions on the basis of surveys of business attitudes within the countries. The sub-indexes on the five measures are then summed to produce a single, overall index that is scaled between zero and 10. The index is based almost entirely on data for 1982.

Data on the percentage of land area in the tropics come from Gallup, Sachs, and Mellinger (1999).

Table 2 shows the correlation between our variables in 1990. Log output per worker, capital per worker, life expectancy, and average years of schooling are all highly correlated. This high degree of correlation makes it difficult to disentangle the separate effect of each input. These measures are all, however, negatively correlated with average experience and average experience squared. While higher life expectancy tends to create an older workforce and increase experience levels, this effect is more than offset in developed countries by higher levels of education that delay entry into the workforce. Average experience and average

Table 2. *Correlation in levels 1990*

Variable	Log output per worker	Log capital per worker	Life expectancy	Average years of schooling	Average experience	Average experience squared	% Tropical area
Log capital per worker	0.974	1.000					
Life expectancy	0.901	0.901	1.000				
Average years of schooling	0.850	0.853	0.834	1.000			
Average experience	−0.279	−0.281	−0.292	−0.462	1.000		
Average experience squared	−0.472	−0.470	−0.487	−0.590	0.957	1.000	
% Tropical area	−0.631	−0.609	−0.567	−0.634	0.126	0.253	1.000
Governance	0.740	0.735	0.599	0.701	−0.141	−0.301	−0.570

experience squared are very highly positively correlated, making it difficult to disentangle their effects in aggregate data. Percentage area in the tropics is negatively correlated with output per worker while our measure of good governance is positively correlated with output per worker.

4. ESTIMATION AND RESULTS

We begin by estimating Eqn. (5) under the assumption that steady-state TFP levels are the same in every country. The results are reported in Table 3. The parameters of each regression are estimated by nonlinear least squares, and all contemporaneous growth rates of inputs are instrumented with their lagged growth rates. Time dummies (not reported) are included that act as proxies for the average worldwide level and growth rate of TFP.

The results in column (1) of Table 3 include only physical capital, labor, and schooling as inputs. We find coefficients of close to 0.5 for both capital and labor. This is slightly different from the respective shares of capital and labor in national income; typically one-third and two-thirds, respectively (see Mankiw, 1994, p. 74) which are the figures we would expect if each factor earned its marginal product. The sum of these coefficients is however close to one, which is consistent with constant returns to scale. Our estimate of the coefficient on schooling translates into a social rate of return of 17.2%, [2] which is higher than the average of 9.1% found in microeconomic studies. But, while we find that this estimated rate of return to schooling is significantly different from zero, it is not well determined, and we cannot reject the hypothesis that it is the same as the microeconomic estimate of 9.1%. The catch-up coefficient is 0.196, indicating that almost 20% of the gap between a country's actual and steady-state TFP is closed over a decade, implying an annual rate of convergence of about 2%.

Adding experience variables in column (2) has the effect that none of the human capital coefficients is now significant. But, when we calculate the rate of return to schooling we get 12.8%, which is statistically different from zero, though once again we cannot reject the hypothesis that the actual rate of return is 9.1%. The coefficients on average experience and average experience squared are large in absolute size, though poorly determined. We cannot reject the possibility that these coefficients are jointly zero, or indeed, that they produce estimates of the productivity of experience that are the same as those found in the microeconomic studies.

The reason for the poorly determined coefficients on our experience measures seems to be that in our sample average experience and average of experience squared are highly correlated (the correlation coefficient is above 0.98). Average experience in our sample ranges from 18 to 28 years, and over this short range its relationship with the average of experience squared is almost completely linear. [3] The wide range of years of work experience we see in microeconomic data allows us to identify the nonlinear relationship between experience and wages, but in macroeconomic data the small variation in average experience across countries means we cannot pick up such subtle effects.

Table 3. *Production function in growth form, common long-run TFP across countries dependent variable: growth rate of GDP; nonlinear two-stage least squares estimates*

Right-hand side variables	1	2	3
Capital	0.522* (0.067)	0.424* (0.094)	0.342* (0.116)
Labor	0.493* (0.080)	0.633* (0.121)	0.708* (0.136)
Schooling	0.085* (0.039)	0.081 (0.048)	0.082 (0.049)
Experience		0.208 (0.176)	0.266 (0.203)
Experience^2		−0.0045 (0.0029)	−0.005 (0.003)
Life expectancy			0.013 (0.011)
Technological catch-up coefficient	0.196* (0.040)	0.191* (0.041)	0.214* (0.043)
N	175	175	175
R^2 adjusted	0.628	0.581	0.549
Test of equality of growth and level coefficients (χ^2 d.o.f. under null)	4.15 (3)	2.66 (5)	0.93 (6)
Estimate of the rate of return to schooling	0.172* (0.062)	0.128* (0.063)	0.116 (0.060)
Test that rate of return to schooling equals 0.091 (χ^2 d.o.f. under null)	1.66 (1)	0.34 (1)	0.18 (1)
Test of zero coefficients on experience (χ^2 d.o.f. under null)		4.39 (2)	4.00 (2)
Test of constant returns to scale (χ^2 d.o.f. under null)	0.13 (1)	1.19 (1)	1.09 (1)

d.o.f.: degrees of freedom; estimated asymptotic standard errors are reported in parentheses next to parameter estimates; estimated on a panel of 104 countries for the growth periods 1970–80 and 1980–90; year dummies are included throughout.
Source: Authors' calculations.
*Significant at the 5% level.

Adding life expectancy in column (3) gives similar results. Again, the human capital measures are jointly statistically significant, but we cannot reject the hypothesis that the coefficients are equal to those found in microeconomic studies. The coefficient on life expectancy is 0.01, suggesting that increasing life expectancy by one year improves work force productivity and raises output by about 1%, though this effect is not well determined and the coefficient is not statistically significant. Note that in column 3 the coefficients on capital and labor take on values that are close to their stylized factor shares of one-third and two-thirds.

In all three regressions in Table 3 we cannot reject the hypothesis that we have constant returns to scale, that is, that the coefficients on physical capital and labor add to one. In addition, in each regression we cannot reject the restriction that the coefficients on the levels and growth rates of inputs are equal.

While we include time dummies in all our regression we do not report them. Bloom *et al.* (2002) discuss the problem of interpreting the time dummies in these types of regression.

Overall, the picture that emerges from Table 3 is that the macroeconomic results are surprisingly close to the results found in microeconomic studies. In every case we find that we cannot reject the hypothesis that the macroeconomic estimates on the returns to schooling and experience are the same as the microeconomic evidence. In all specifications we appear to have constant returns to scale, though in some the coefficient on physical capital appears to be closer to half rather than the one-third that seems to be the stylized fact. TFP exhibits large gaps across countries, but these gaps are being closed, on average, at the rate of about 2% a year.

The results in Table 3 may, however, depend on our assumption that the steady-state level of TFP is the same in every country. We experimented with different geographical and institutional variables that may explain long-run differences in TFP and settled on the percentage of land area in the tropics and a measure of governance as the two that seem most significant in our framework. We include these variables (which are taken as fixed over time) in the levels part of Eqn. (5).

Table 4 excludes average experience squared from the estimation because of the co-linearity problem. The average experience level in our

Table 4. *Production function in growth form, country-specific long-run TFP dependent variable: growth rate of GDP; nonlinear two stage least squares estimates*

Right-hand side variables	1	2	3
Capital	0.457* (0.065)	0.479* (0.068)	0.190 (0.151)
Labor	0.583* (0.085)	0.589* (0.088)	0.824* (0.145)
Schooling	0.015 (0.038)	−0.026 (0.045)	−0.025 (0.043)
Experience		−0.074* (0.034)	−0.059 (0.036)
Life expectancy			0.040* (0.019)
Technological catch-up coefficient	0.186* (0.039)	0.194* (0.042)	0.278* (0.045)
Percentage of land area in the tropics	−0.432* (0.207)	−0.329 (0.204)	−0.332* (0.161)
Governance	0.098* (0.045)	0.104* (0.047)	0.149* (0.050)
N	147	147	147
R^2 adjusted	0.711	0.679	0.539
Test of equality of growth and level coefficients (χ^2 d.o.f. under null)	1.901 (3)	1.069 (4)	2.764 (5)
Estimate of the rate of return to schooling	0.026 (0.064)	−0.044 (0.079)	−0.030 (0.053)
Test that rate of return to schooling equals 0.091 (χ^2 d.o.f. under null)	0.663 (1)	2.920 (1)	5.215* (1)
Test of constant returns to scale (χ^2 d.o.f. under null)	1.018 (1)	1.532 (1)	0.092 (1)
Test of joint significance of governance and tropics (χ^2 d.o.f. under null)	8.826* (2)	8.130* (2)	12.885* (2)

d.o.f.: degrees of freedom; estimated asymptotic standard errors are reported in parentheses next to parameter estimates. Year dummies are included throughout.
Source: Authors' calculations.
* Significant at the 5% level.

sample is 23 years, and at this experience level the marginal impact of an extra year of experience on wages (using estimates from microeconomic data) is about 1.8%, and the expected effect on output (assuming no externalities) is therefore just (1.8β) percent implying an expected coefficient on experience in our regressions of around 0.01.

In all three columns of Table 4 the coefficient on schooling is small and not statistically significant. But, we cannot reject the possibility that the rate of return to schooling is 0.091 as given by microeconomic data. Adding average experience in columns (2) and (3) generates coefficients on experience that are negative and lower than the productivity effects found in microeconomic studies. This suggests that experience reduces aggregate output, even though in microeconomic data it increases individual wages.

Adding life expectancy in column (3) produces a result that is positive and statistically significant, and suggests that each extra year of life expectancy raises the productivity of workers and leads to an increase of 4% in output. This is only slightly stronger than the effect found in most studies of the contribution of health to economic growth. [4] Regression (3) of Table 4 suggests that the positive effect of life expectancy on output in growth regression is not coming about because of the omission of worker experience levels and that it represents a real productivity effect.

As we would expect, countries with better governance tend to have higher steady-state levels of TFP, while those in the tropics have lower TFP. An *F*-test of the joint significance of the governance and tropics variables in each of the specifications in Table 4 shows these to be significant at the 5% level, allowing us to reject the assumption underlying Table 3, that steady-state TFP is constant across countries. The speed of TFP convergence is again around 2 to 2.5% a year.

While our results generally agree with those found in microeconomic studies, our parameter estimates are not well determined. For example, in column (3) of Table 4 even the coefficient on physical capital is not statistically significant. A central problem in macroeconomic studies is a lack of degrees of freedom. In addition, aggregate data exhibit a great deal of multicollinearity; capital intensity, education level, and health status all tend to move together. Average experience and average experience squared are highly correlated, while average experience is highly negatively correlated with average schooling (extra years of education mean less average work experience) and positively correlated with life expectancy.

Determining the rates of return to inputs from macroeconomic data with any precision is likely to be difficult. This suggests that so long as the aggregate data do not suggest the presence of large externalities, calibrating macroeconomic models using estimates of private returns from microeconomic studies is useful.

5. CONCLUSION

Our model accounts for economic growth by the growth of factor inputs, technological innovation, and technological diffusion. Our main result, which is consistent with our theoretical argument and with the microeconomic evidence, is that health has a positive and statistically significant effect on economic growth. It suggests that a one-year improvement in a population's life expectancy contributes to an increase of 4% in output. This is a relatively large effect, indicating that increased expenditures on improving health might be justified purely on the grounds of their impact on labor productivity, quite apart from the direct effect of improved health on welfare. While this supports the case for investments in health as a form of human capital, we are not able to distinguish in our analysis between the effects of different types of health investments that affect different groups within the population.

We find no evidence that the macroeconomic effects of education and experience are any greater than the corresponding effects found in microeconomic studies. This suggests the absence of externalities at the aggregate level (though we do not measure the potentially important indirect effects of improved health on education and improved education on health) and that calibration studies provide reasonable pictures of the proximate sources of economic growth. In particular, our results suggest that the positive effect of health as measured by life expectancy on output is not being caused by a correlation with an omitted variable—worker experience.

Accounting for economic growth is only the first stage of an explanation. Once we have established the importance of physical and human capital we need to go behind these variables to ask what determines crosscountry differences in factor accumulation. For example, our estimates of the effect of life expectancy capture only its direct effect on labor productivity. In a fully specified model, life expectancy may influence life cycle savings (Lee, Mason, & Miller, 2000) and capital accumulation, and the expected returns to and investment in education (Bils & Klenow, 2000). Thus improvements in health may increase output not only through labor productivity, but also through the accumulation of capital. A fully specified model of economic growth would be multidimensional, showing not only how inputs and technology affect output, but also how the growth rates of inputs and their productivity are themselves determined.

NOTES

1. Insofar as educational attainment has increased over time, older age groups within those aged 25 and over would have less education and therefore more experience than reflected by our proxy.

2. When an individual stays in school for an extra year, the marginal benefit is given by $\frac{\partial Y_{it}}{\partial S_{it}} = \phi \frac{Y_{it}}{L_{it}}$. The marginal cost of this decision is that individual's forgone production. $\frac{\partial Y_{it}}{\partial L_{it}} = \beta \frac{Y_{it}}{L_{it}}$. The social rate of return is the ratio of the benefit flow to costs the benefit flow to costs $\frac{\phi}{\beta} = \frac{0.085}{0.493} = 0.172$.

3. The average of experience squared can be written as the square of average experience plus the variance of experience across individuals within the country. This implies that it is not only the lack of variation in average experience that is the problem, but also that the variance of experience across the work force is similar across countries.

4. Studies of the contribution of health to growth often fit regressions of the form, $y_{it} - y_{it-1} = \alpha_0 y_{it-1} + \alpha_1 \ln h_{it} + \alpha_2 x_{it} + \varepsilon_{it}$ where y_{it} is log of per capita output, h_{it} is life expectancy, and x_{it} represents other regressors. When output reaches the steady-state, $y_{it} - y_{it-1} = 0$ and simple computation shows that $\frac{\partial y_{it}}{\partial h_{it}} = \frac{-\alpha_1}{\alpha_0 h_{it}}$. This quantity should be directly comparable to our coefficient on life expectancy of 0.04. We can compute this quantity using representative results from Bloom and Canning (2003)

which have $\alpha_0 = -0.69$, $\alpha_1 = 2.81$, $\bar{h}_{it} = 63$ giving us $\frac{\partial y_{it}}{\partial h_{it}} = 0.0264$. Thus our present results imply somewhat larger returns to health than previous crosscountry studies.

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