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## Cross-Country Evidence on Human Capital and the Level of Economic Development: The Role of Measurement Issues in Education

*Ludger Wößmann\**

**Abstract:** The use of imperfect proxies for human capital introduces severe measurement errors in the empirical growth literature. This paper tries to improve on the measurement of human capital by allowing rates of return to education to differ between education levels and by weighing standard quantitative measures of education (years of schooling) by an indicator of the quality of education (student performance on cognitive achievement tests). With this improved measurement of education, 45 percent of the world-wide dispersion in levels of economic development (as measured by per-capita income) can be accounted for by differences in human capital. Leaving countries with imputed human-capital data, which may be further contaminated by classical measurement error, out of the sample, human-capital differences account for as much as 60 percent of the income dispersion. In the sample of OECD countries, virtually the whole income dispersion can be accounted for by differences in quality-adjusted human capital. The quality adjustment of the human-capital measure seems to be much more crucial for the development-accounting results than recent attempts to improve on the data recording of the quantity of education. The results suggest that the human-capital-augmented neoclassical growth model is a useful framework for understanding international development differences, while an effect of human capital on technical differentiation across countries cannot be substantiated.

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## 1. Introduction

A central pre-requisite for conducting cross-country empirical research is the availability of internationally comparable data. Thus, when investigating the relationship between human capital and the level of economic development across countries, it is crucial to have a reliable measure of human capital which is comparable across countries. Focusing on education as the central means to accumulate human capital, this paper deals with central issues in the derivation of a meaningful, internationally comparable measure of human capital based on the education of the labor force in the different countries.

There may be two kinds of measurement error in the measurement of human capital: First, there may be data recording errors; second, even with perfectly recorded data, the chosen measure may be an imperfect proxy for the concept of human capital. This paper uses a measure of human capital which tries to improve on measurement errors in this second sense in a development-accounting exercise which accounts for the share of international variation in development levels attributable to international differences in human capital. The central features of this improved measure of human capital are that it allows rates of return to education to differ between primary, secondary, and higher education, and that it weighs standard quantitative measures of education (years of schooling) by an indicator of the quality of education (student performance on cognitive achievement tests). In comparing development-accounting results based on this improved human-capital measure to results based on more standard human-capital measures used in the literature, it is shown that these measurement issues are crucial for an evaluation of the economic importance of cross-country differences in human capital.

Problems in the international comparison of measures of education have repeatedly been stressed in the literature. They derive mainly from the facts that there is a poor coverage of countries regarding collection of the basic education data, that the censuses and surveys on which these data are based often use varying definitions for the variables collected, and that various kinds of extrapolations and intrapolations used to derive estimates for years when no censuses or surveys were conducted introduce a fair amount of noise into the data. Thus, Behrman and Rosenzweig (1994) reveal serious comparability problems in cross-country education data. Two recent studies on the reliability of education data conclude that “measurement errors in education severely attenuate estimates of the effect of the change in schooling on GDP growth” (Krueger and Lindahl 2001, p. 1102), and that “a fair amount of detailed work remains to be done before we can say with some confidence that we have a reliable and detailed picture of worldwide educational achievement levels or their evolution over time” (de la Fuente and Doménech 2000, p. 12).

The cited studies focus on the first kind of measurement error in the measurement of human capital, namely data recording errors. By contrast, this paper

focuses on the second kind of measurement error by trying to bring the measure of human capital more in line with what one might have in mind when thinking of the concept of human capital, as it seems fair to conclude with Temple (1999, p. 139) that “[t]he literature uses somewhat dubious proxies for aggregate human capital.” Wößmann (2001a) uses human-capital theory to show that the stock of human capital is misspecified by the proxy which is most commonly used in the literature, namely average years of schooling of the working-age population, because this proxy implies an incorrect specification of the functional form of the education-human capital relationship. As discussed in Section 2, the measure of human capital applied in this paper tries to improve on this by taking account of decreasing returns to education and of international differences in the quality of education.

Section 3 discusses theoretical views on the relationship between human capital and economic development, deriving the human-capital-augmented neoclassical model of economic growth and development as a framework for the empirical analysis. Section 4 describes the data used in the empirical analysis, as well as the methodology used to estimate the share of international variations in economic development which can be accounted for by differences in human capital.

Section 5 reports the results of this development-accounting analysis. The results reveal that using the more standard human-capital measures leads to a severe understatement of the development impact of human capital. With the improved measure of human capital, 45 percent of the world-wide dispersion in levels of economic development can be accounted for by cross-country differences in human capital. Leaving countries with imputed human-capital data – which seem to contain a large amount of measurement error in the sense of poor data recording – out of the sample, the share in income dispersion accounted for by human-capital differences is as large as 60 percent. Within the sample of OECD countries, virtually the whole income dispersion can be accounted for by differences in quality-adjusted human capital. These findings corroborate Gary Becker's (1964/1993, p. 12) early contention that “few if any countries have achieved a sustained period of economic development without having invested substantial amounts in their labor force.”

Furthermore, the results suggest that the quality adjustment of the human-capital measure seems to be much more crucial for the results of development-accounting exercises than recent attempts to improve on the data recording of the quantity of education. Finally, the results underscore the usefulness of the human-capital-augmented neoclassical growth model, where the stock of human capital has *level* effects due to its accumulation as a factor input, as a framework for understanding international differences in levels of economic development. A potential effect of human capital working through technical differentiation across countries, as suggested in many models of endogenous growth in which the stock of human capital has *growth* effects because it facili-

tates technical progress, does not seem to add to an understanding of this specific research question.

## 2. The Measurement of Human Capital: Decreasing Returns to and Quality Differences in Education<sup>1</sup>

Two main critiques of the most commonly used proxy for human capital, namely average years of schooling in the labor force, are dealt with here: First, one year of schooling does not raise the human-capital stock by an equal amount regardless of whether it is a person's first or seventeenth year of schooling. Second, one year of schooling does not raise the human-capital stock by an equal amount regardless of the quality of the education system in which it has taken place.<sup>2</sup>

As for the first point, specifying human capital by average years of schooling implicitly gives the same weight to any year of schooling acquired by a person. I.e., productivity differentials among workers are assumed to be proportional to their years of schooling. This disregards the findings of a whole microeconomic literature on wage rate differentials which shows that there are decreasing returns to schooling (Psacharopoulos 1994). Therefore, a year of schooling should be weighted differently depending on how many years of schooling the person has already accumulated.

As for the second point, using years of schooling as a human-capital measure gives the same weight to a year of schooling in any schooling system at any time. I.e., a year of schooling is assumed to deliver the same increase in skills regardless of the efficiency of the education system, of the quality of teaching, of the educational infrastructure, or of the curriculum. In cross-country work, a year of schooling in, say, Papua New Guinea is assumed to create the same increase in productive human capital as a year of schooling in, say, Japan. Instead, a year of schooling should be weighted differently depending on the quality of the education system in which it has taken place. In the following two sub-sections, I propose specifications of the human-capital stock which deal with these two criticisms.

### 2.1 Rates of Return to Education Differing by Education Level

The stock of human capital embodied in the labor force is a variable expressed in money units. To transform a measure of education measured in units of time into the stock of human capital expressed in units of money, each year of

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<sup>1</sup> This section draws heavily on Wößmann (2001a).

<sup>2</sup> See also Mulligan and Sala-i-Martin (2000) for a critique of schooling years as a proxy for human capital.

schooling should be weighted by the earnings return it generates in the labor market. Human capital theory offers a straightforward specification of the functional form of this relationship between education and the stock of human capital, the human capital earnings function (Mincer 1974, cf. Chiswick 1998). Assuming that the total cost  $C$  to an individual of investing into a year of schooling lies in the earnings which he or she foregoes during that year, annual earnings  $W$  after  $t$  years of schooling are equal to annual earnings with  $t-1$  years of schooling plus the cost of the investment ( $C_t = W_{t-1}$ ) times the rate of return  $r$  on that investment:

$$(1) \quad W_t = W_{t-1} + r_t W_{t-1} .$$

For  $r = r_t$  being constant across levels of schooling, it follows that log earnings after  $s$  years of schooling are then given by (cf. Chiswick 1998):

$$(2) \quad \ln W_s = \ln W_0 + rs .$$

Thereby, the relationship in equation (1) between earnings and investments in education measured in money units is converted to the relationship in equation (2) between the natural logarithm of earnings and investments in education measured in time units. That is, the logarithm of individuals' earnings is a linear function of their years of schooling. This log-linear formulation suggests that each additional year of schooling raises earnings by  $r$  percent.

Mincer (1974) estimated the rate of return to education  $r$  for a cross-section of workers as the regression coefficient on years of schooling in an earnings function like equation (2), controlling for work experience of the individuals. A whole literature of micro labor studies has confirmed that this log-linear specification gives the best fit to the data (cf. Card 1999, Krueger and Lindahl 2001). To be able to interpret the schooling coefficient in an earnings function as the rate of return to education, however, the assumption must hold that total costs of investment in the  $t$ th year of schooling  $C_t$  are equal to foregone earnings  $W_{t-1}$ . If the opportunity cost of schooling is a full year's earnings, this would imply that there are no direct costs such as tuition, school fees, books, and other school supplies. Furthermore, the regression coefficient in the earnings function method is a biased measure of the rate of return if age-earnings profiles are not constant for different levels of education.

Therefore, rates of return estimated by the elaborate discounting method, which can account both for the total cost of schooling and for variable age-earnings profiles, are superior to estimates based on the earnings function method. The elaborate discounting method consists in calculating the discount rate  $r$  which equates the stream of costs of education to the stream of benefits from education:

$$(3) \quad \sum_{t=1}^s (C_{h,t} + W_{l,t})(1+r)^t = \sum_{t=s+1}^{A_h} (W_{h,t} - W_{l,t})(1+r)^{-t}$$

where  $C_h$  is the resource cost of schooling incurred to achieve a higher level  $h$  from a lower level  $l$ ,  $W_l$  are the foregone earnings of the student while studying,  $(W_h - W_l)$  is the earnings differential between a person with a higher level of education and a person with a lower level of education,  $s$  is years of schooling, and  $A_h$  is the highest possible working age.

By counting both private and public educational expenditures as the cost of schooling  $C$ , the elaborate discounting method is able to estimate social rates of return to education. Social - as opposed to private - rates of return are the relevant choice when dealing with questions from a society's point of view. The estimated rates of return are "narrow-social," taking account of the full cost of education to the society (including public expenditure) while disregarding any potential external benefits. Recent studies by Heckman and Klenow (1997), Acemoglu and Angrist (2000), and Ciccone and Peri (2000) show that there is little evidence in favor of such external returns to education.<sup>3</sup>

As first suggested by Bils and Klenow (2000), the micro evidence derived from the log-linear Mincer formulation can be used to specify the aggregate human-capital stock in macro studies as

$$(4) \quad H^M = e^{\phi(s)}L \quad \Leftrightarrow \quad h^M = e^{\phi(s)}$$

where  $H^M$  is the stock of human capital based on the Mincer specification,  $L$  is labor as measured by the number of workers, and  $h \equiv H/L$  is the stock of human capital per worker. The function  $\phi(s)$  reflects the efficiency of a unit of labor with  $s$  years of schooling relative to one with no schooling. With  $\phi(s)=0$ , the specification melts down to one with undifferentiated labor. Furthermore, the derivative of this function should equal the rate of return to education as estimated in the labor literature, so that  $\phi'(s)=r$ . In the simplest specification, this would imply

$$(5) \quad \phi(s) = rs .$$

Thereby, a human-capital measure can be constructed for every country by combining data on years of schooling with rates of return estimated in micro labor studies which weight each year of schooling by its market return.

In addition to taking account of the log-linear relationship between earnings and schooling, this specification can also be used to include decreasing returns to education. While the original work by Mincer entered schooling linearly over the whole range of schooling years, international evidence as collected by Psacharopoulos (1994) suggests that rates of returns to education are decreasing with the acquisition of additional schooling. Therefore, one year of schooling should be weighted differently depending on whether it is undertaken by a

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<sup>3</sup> Note that if there were signaling effects in the private rate of return, the social rate of return might be overstated (cf. Weiss 1995). See Temple (2001b) for a discussion of the issues involved.

student in primary school, in high school, or in college. The available evidence allows a piecewise linear specification for the primary, secondary, and higher level of schooling:

$$(6) \quad \phi(s) = \sum_a r_a s_a \quad \Rightarrow \quad H_i^M = e^{a \sum r_a s_{ai}} L_i \quad \Leftrightarrow \quad h_i^M = e^{a \sum r_a s_{ai}}$$

where  $r_a$  is the rate of return to education at level  $a$  and  $s_{ai}$  is years of schooling at level  $a$  in country  $i$ .

Barro and Lee (2001) argue that there are potential problems with the available estimates of returns to education because of biases through unmeasured characteristics like ability and because of disregard of social benefits. However, ample research in the modern labor literature has shown that the upward ability bias is offset by a downward bias of about the same order of magnitude due to measurement error in years of education (cf. Card 1999). Estimates based on siblings or twin data and instrumental variable estimates based on family background or institutional features of the school system are of about the same magnitude as rates of return to education estimated by cross-sectional regressions of earnings on schooling, suggesting that rates of return to education reflect real productivity enhancements. Furthermore, recent studies have found no evidence in favor of externalities to education (see above).

## 2.2 Taking Account of the Quality of Education

While several studies have by now taken on the Mincer specification to deal with the first criticism, the second criticism of qualitative differences in a year of schooling has as yet not led to a generally accepted refinement in human-capital measurement. However, it is not just the *quantity* of education, i.e. the average years of schooling  $s$  embodied in the labor force, which differs across countries, but also the *quality* of each year of schooling, i.e. the cognitive skills learned during each of these years. One year of schooling is not the same everywhere because one unit of  $s$  may reflect different amounts of acquired knowledge in different countries. Estimated development effects of human capital based on merely quantitative measures may be strongly misleading if qualitative differences do not vary with years of education. However, the assumption that international differences in the quality of education should simply vary with years of education seems heroic, given that evidence abounds that there are serious problems in the efficiency of educational production (cf. Hanushek 2002, Gundlach et al. 2001) and given that countries differ in the institutional structures of their education systems which influence this efficiency (cf. Wößmann 2002a,b). Therefore, differences in the quality of education should be introduced into the human-capital measure in addition to differences in the mere quantity of education to account for how much students have learned in each year.



Data on the quality of education can be derived from direct measures of the cognitive skills of individuals obtained from tests of cognitive achievement. There are two international organizations which have conducted a series of standardized international tests in varying sets of countries to assess student achievement in the fields of mathematics and natural sciences. The International Assessment of Educational Progress (IAEP), which builds on the procedures developed for the main national testing instrument in the United States, administered two international studies in 1988 and 1991, both encompassing mathematics and science tests. The International Association for the Evaluation of Educational Achievement (IEA), an agency specializing in comparative education research since its establishment in 1959, conducted cross-country mathematics studies in 1964 and 1981, cross-country science studies in 1971 and 1984, and the Third International Mathematics and Science Study (TIMSS) in 1995. Most studies include separate tests for students in different age groups (primary, middle, and final school years) and in several subfields of the subjects.

Hanushek and Kimko (2000) combine all of the available information on mathematics and science scores up to 1991 to construct a single measure of educational quality for each country. All together, they use 26 separate test score series (from different age groups, subfields, and years), administered at six points in time between 1965 and 1991, and encompassing a total of 39 countries which have participated in an international achievement test at least once. To splice these test results together for each country, they first transform all test scores into a “percent correct” format. To account for the different mean percent correct of the test score series, their quality index  $QL2^*$  makes use of intertemporally comparable time-series information on student performance in the United States provided by the National Assessment of Educational Progress (NAEP). These national tests establish an absolute benchmark of performance to which the US scores on international tests can be keyed. Thus, the results of the different test series are combined by allowing the mean of each international test series to drift in accordance with the US NAEP score drift and the US performance on each international comparison. The constructed quality measure is a weighted average of all available transformed test scores for each country, where the weights are the normalized inverse of the country-specific standard error of each test, presuming that a high standard error conveys less accurate information. By combining tests from the relevant time range when current workers were students, the measure tries to approximate the cognitive skills embodied in the current labor force.<sup>4</sup>

To incorporate the thus measured cross-country differences in educational quality into measures of the stock of human capital, I normalize Hanushek and

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<sup>4</sup> Hanushek and Kimko (2000) show that such quality measures of education matters more in growth regressions than quantity measures, a finding also confirmed by Barro (2001).

Kimko's (2000) educational quality index for each country relative to the measure for the United States (cf. also Gundlach et al. 2002). This measure of relative quality can then be viewed as a quality weight by which each year of schooling in a country can be weighted, where the weight for the United States is unity. To obtain a quality-adjusted human-capital specification, the quality and quantity measures of education are combined with rates of return to education at the different education levels in a Mincer-type specification of the human capital function:

$$(7) \quad h_i^Q = e^{a \sum r_a Q_i s_{ai}}$$

where  $r_a$  is the world-average rate of return to education at level  $a$  and  $Q_i$  is Hanushek and Kimko's (2000) educational quality index for country  $i$  relative to the US value.

One virtue of this quality adjustment of the human-capital specification is that one may think of the quality of human capital to rise continually and without an upper bound. By contrast, the growth in pure quantity specifications of human capital is bounded because educational attainment is asymptotically a constant. Such a specification is hard to reconcile with most models of economic growth, where the stock of physical capital also has no natural upper bound. A further virtue of this specification is that it yields one single human capital variable. Since human capital is embodied in the labor force, it is more natural to think of it as one combined factor of production, rather than as several independent factors. By combining information on the labor force, quantity of education, rates of return to these educational investments, and quality of this education, the final quality-adjusted human-capital specification is more readily interpreted in growth and development applications.

### 3. Two Theoretical Views on Human Capital and Economic Development

Having thus specified the stock of human capital of a country, the contribution of cross-country differences in human capital to cross-country differences in the levels of economic development can be estimated. Research on economic growth in general deals with three related but conceptually distinct central issues: world growth, country growth, and dispersion in income levels (Klenow and Rodriguez-Clare 1997a). Research on the first issue tries to explain the continuous growth of income per capita in the world economy, research on the second issue deals with cross-country differences in growth rates, and research on the third issue tries to answer why some countries are significantly richer than others at a given point in time. In this paper, I deal with the third issue - explaining levels rather than explaining growth -, which is called "development

accounting” by King and Levine (1994) because it looks for sources of differences in economic development across the countries in the world. The focus on dispersion in levels of development is chosen because they are arguably the ultimate reason why research is interested in economic growth in the first place. Differences in development levels capture differences in long-run economic performance which are directly relevant to welfare, while recent studies show that differences in growth rates are largely transitory (cf. Hall and Jones 1999).

Human capital takes a central role in most theories of economic growth and development. Both the augmented neoclassical growth model and most endogenous growth models stress the importance of human capital for development in one way or another. However, the different models can be summarized into two distinct groups of theoretical views on the relationship between human capital and economic development (cf. Aghion and Howitt 1998, Benhabib and Spiegel 1994). In the first view, the accumulation of human capital as a factor of production drives economic growth, so that differences in levels of human capital are related to differences in output *levels* across countries (the “neoclassical view”). In the second view, a greater human-capital stock affects economic growth mainly by facilitating innovation and adoption of new technologies, so that differences in levels of human capital cause differences in output *growth* across countries (the “technical-progress view”).

### 3.1 The “Neoclassical View”

The first view - that growth rates of human capital should be connected to growth rates of income - can be easily depicted on the basis of the human-capital-augmented neoclassical growth model, where human capital enters as a factor of production.<sup>5</sup> In his neoclassical growth model, Solow (1956) uses a macroeconomic Cobb-Douglas production function with labor as an homogeneous factor and with physical capital as the only factor of production which can be accumulated. Mankiw et al. (1992) augment this model by introducing human capital as an additional factor of production which can be accumulated, acknowledging that labor is not an homogeneous factor. The level of output  $Y$  produced in a country  $i$  is then given by

$$(8) \quad Y_i = K_i^\alpha (h_i L_i)^{1-\alpha} A_i^{1-\alpha}$$

where  $K_i$  is the stock of physical capital in country  $i$ ,  $\alpha$  is the production elasticity of physical capital, and  $A_i$  is the level of total factor productivity in country  $i$ . Steady-state output per worker  $y_i \equiv Y_i/L_i$  is then given as

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<sup>5</sup> Endogenous growth models in the spirit of Lucas (1988), which also view human capital as an input factor in the production function, share the same result.

$$(9) \quad y_i = k_i^\alpha h_i^{1-\alpha} A_i^{1-\alpha} \quad \Leftrightarrow \quad y_i = \left( \frac{k_i}{y_i} \right)^{\frac{\alpha}{1-\alpha}} h_i A_i$$

where  $k_i \equiv K_i/L_i$  is the ratio of physical capital to labor. Thus, the steady-state *level* of output is a function of the *level* of human capital.

Long-run growth in this model is unaffected by the accumulation of human capital inputs because the marginal product of each input is diminishing. However, accumulation of human capital leads to output growth along a transitional growth path from one steady-state to the next. Equation (9) implies that the growth rate of output  $\gamma_{y_i} \equiv \Delta y_i / y_i$  is given as

$$(10) \quad \gamma_{y_i} = \alpha \gamma_{k_i} + (1-\alpha) \gamma_{h_i} + (1-\alpha) \gamma_{A_i} .$$

Thus, in the “neoclassical view,” differences in growth rates across countries are related to differences in the rates at which human capital is accumulated.

### 3.2 The “Technical-Progress View” in a Cross-Country Development Perspective

The second view - of effects of human capital levels on economic growth - is the central part of many endogenous growth models, and it goes at least as far back as Nelson and Phelps (1966). In this “technical-progress view,” the growth of total factor productivity depends on the stock of human capital. This may be either due to effects of human capital on the domestic production of technological innovation (Romer 1990) or due to effects of human capital on the adoption and implementation of new technology from abroad (Nelson and Phelps 1966). In either case, the growth of total factor productivity  $A$  in country  $i$  is a positive function of the country's average level of human capital  $h$ :

$$(11) \quad \gamma_{A_i} = \psi(h_i), \psi'(h_i) > 0 .$$

This relationship implies that output *growth* is a function not only of the growth of human capital but also of the *level* of human capital.

This second class of models emphasizes the endogenous nature of growth and technical progress. In that sense, the main contribution of these endogenous growth models is to give an explanation of economic growth over time, usually by suggesting microfoundations for technological advances. As noted above, this issue is conceptually distinct from the development-accounting question raised in this paper. Specifically, technological differences across countries should be transitory since technological knowledge is fairly free to move across countries as long as a country is open to the adoption of technological advances from abroad. As is directly evident from the Nelson and Phelps (1966) model of technological catch-up, the effect of the human-capital stock on the growth of total factor productivity is a short-run effect of catching

up to the technological leader. In the long run, total factor productivity in any country grows again at the growth rate of the world technological frontier, which in that model is exogenous. And while the innovation models endogenize the growth rate of the world technological frontier, this will not have an effect of the long-run income distribution across countries as long as catching-up through technological diffusion is taking place.

One of the central ideas of the innovation models is actually that technological knowledge is a non-rival and non-excludable good. Therefore, by the very nature of technological knowledge, all countries should in principle have access to the same technologies, and even at a relatively modest cost (Olson 1996). The only way in which the knowledge available for productive use may differ across countries is through the knowledge embodied in people, i.e. through the available stock of human capital. Topel (1999) suggests that in that sense, the differences between the two views may be more semantic than real because human capital, when defined broadly, may encompass the creation of knowledge in a person and the ability of human beings to apply new knowledge. The non-rivalry and non-excludability of technological knowledge implies that the “technical-progress view,” while providing a possible explanation of worldwide advances in knowledge, should not be a major factor in cross-country differences in development levels.

In contrast, the “neoclassical view” takes worldwide technical progress as given and provides an explanation of economic development which may very well differ across countries, namely the accumulated stocks of factor inputs.<sup>6</sup> I thus use the neoclassical growth specification of equation (9) as a framework for the following empirical analysis. In Section 5.3, I return to the question whether the “technical-progress view” can add to an understanding of international differences in levels of development.

## 4. Methodology and Data

### 4.1 Methodology

Since the empirical interest is in the contribution of differences in human-capital stocks to cross-country differences in levels of economic development, I use the “covariance measure” proposed by Klenow and Rodríguez-Clare (1997b) to decompose the cross-country variance in output per worker (the measure of the level of economic development) into the relative contributions of differences in human-capital stocks, in physical-capital stocks, and in levels of total factor productivity. From equation (9), one can derive

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<sup>6</sup> Since neoclassical and endogenous growth models are thus able to answer distinct research questions, they should be viewed as complements (cf. Mankiw 1995).

$$(12) \quad \begin{aligned} \text{var}(\ln(y)) &= \text{cov}(\ln(y), \ln(y)) \\ &= \text{cov}(\ln(y), \ln(h)) + \text{cov}\left(\ln(y), \ln\left(\left(\frac{k}{y}\right)^{\frac{\alpha}{1-\alpha}}\right)\right) + \text{cov}(\ln(y), \ln(A)) \end{aligned}$$

This decomposition allows the measurement of the relative contributions of the three factors as percentages:

$$(13) \quad \frac{\text{cov}(\ln(y), \ln(h))}{\text{var}(\ln(y))} + \frac{\text{cov}\left(\ln(y), \ln\left(\left(\frac{k}{y}\right)^{\frac{\alpha}{1-\alpha}}\right)\right)}{\text{var}(\ln(y))} + \frac{\text{cov}(\ln(y), \ln(A))}{\text{var}(\ln(y))} = 1$$

The three terms on the left-hand side equal the coefficients from regressing  $\ln(y)$  on the logs of each of the three factors separately. Applying this method gives the respective average fraction of output dispersion across countries that can be statistically attributed to international differences in human-capital stocks and in physical capital-output ratios, leaving the rest to be explained by residual total factor productivity. Precisely, the three terms can be interpreted as the percentage of one percent which the respective input in a given country can be expected to be above the mean across countries, conditional on output per worker in that country being one percent above the mean across countries.

As a robustness test for the results of the covariance measure, the “five-country measure,” which is based on a calculation in Hall and Jones (1999), focuses on the highest and lowest part of the sample distribution. It shows, also in percentage terms, how much of the difference in output per worker between the five most developed and the five least developed countries (in terms of output per worker) is due to differences in the three input components:

$$(14) \quad \frac{\ln\left(\frac{\prod_{i=1}^5 h_i}{\prod_{j=n-4}^n h_j}\right)}{\ln\left(\frac{\prod_{i=1}^5 y_i}{\prod_{j=n-4}^n y_j}\right)} + \frac{\ln\left(\frac{\prod_{i=1}^5 (k_i/y_i)^{\frac{\alpha}{1-\alpha}}}{\prod_{j=n-4}^n (k_j/y_j)^{\frac{\alpha}{1-\alpha}}}\right)}{\ln\left(\frac{\prod_{i=1}^5 y_i}{\prod_{j=n-4}^n y_j}\right)} + \frac{\ln\left(\frac{\prod_{i=1}^5 A_i}{\prod_{j=n-4}^n A_j}\right)}{\ln\left(\frac{\prod_{i=1}^5 y_i}{\prod_{j=n-4}^n y_j}\right)} = 1$$

where  $n$  is the sample size and countries  $i, \dots, j, \dots, n$  are ranked according to output per worker.

To calibrate the macroeconomic production function, I assume a production elasticity of physical capital of  $\alpha = 1/3$ , which is the standard figure used for parameterization in the literature. It broadly resembles the share of physical capital in factor income as reported in national income accounts of developed countries (Maddison 1987), and it also seems to apply for developing countries once the labor income of the self-employed and other proprietors is properly accounted for (Gollin 1998).

## 4.2 Data

Data on output per worker  $y$  and on the ratio of physical capital to labor  $k$  are taken from Summers and Heston's (1991) Penn World Table, Version 5.6a (1994). Output per worker  $y$  is measured in 1990 or the next available year. The 1990 value of the stock of physical capital  $K$  is constructed by the perpetual inventory method based on annual investment rates and an assumed depreciation rate of 6 percent. The initial value for  $K$  is estimated by  $I_t / (g_{t+10} + \delta)$ , where  $I_t$  is the first year for which investment data are available,  $g_{t+10}$  is the average growth rate of investment in the subsequent decade, and  $\delta$  is the depreciation rate (cf. Hall and Jones 1999). The figures for labor  $L$  in 1990 are derived by multiplying per-capita output with population and dividing by output per worker.

In calculating the human-capital measures, I use average years of schooling  $s$  in the total population aged 15 and over in 1990 from Barro and Lee (2001), separately at the primary, secondary, and higher level. Years of schooling in the population aged 15 and over are taken because this age group corresponds better to the labor force for most developing countries than the population aged 25 and over.

The rates of return to education  $r_a$  are world-average social rates of return at the primary, secondary, and higher level of education estimated by the elaborate discounting method. As reported by Psacharopoulos (1994, Table 2), the world-average social rate of return to education is 20.0 percent at the primary level, 13.5 percent at the secondary level, and 10.7 percent at the higher level.

As the quality measure  $Q$  for the quality-adjusted human-capital specification  $h^Q$ , I use Hanushek and Kimko's (2000) index of educational quality  $QL2^*$ , relative to the US value. To obtain a full set of human capital estimates, some values for  $s$  and  $Q$  have been imputed. The imputation takes the mean of the respective regional average and the respective income-group average for any country with a missing value on one of these variables, using the World Bank's (1992) classification of countries by major regions and income groups.<sup>7</sup>

Instead of using equation (6) as the function  $\phi(s)$  which links the stock of human capital to average years of schooling in equation (4), Hall and Jones (1999) and Gundlach et al. (2002) use

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<sup>7</sup> The regions used are Asia, Latin America, Sub-Saharan Africa, North Africa, Middle East, Eastern Europe, and OECD. The income groups are low, lower-middle, upper-middle, and high income.

(15)

$$\phi^{HJ}(s) = \begin{cases} r^{Pri} s & \text{if } s \leq D_{pri} \\ r^{Pri} D_{pri} + r^{Sec} (s - D_{pri}) & \text{if } D_{pri} < s \leq D_{pri} + D_{sec} \\ r^{Pri} D_{pri} + r^{Sec} D_{sec} + r^{High} (s - D_{pri} - D_{sec}) & \text{if } s > D_{pri} + D_{sec} \end{cases}$$

$$\Rightarrow h^{HJ} = e^{\phi^{HJ}(s)}.$$

Hall and Jones (1999) additionally assume that  $D_{pri} = D_{sec} = 4$  for each country. This equation yields a biased allocation of level-specific rates of return to respective schooling years. For example, all the schooling years in a country whose average years of schooling are less than 4 will be weighted by the rate of return to primary education, although presumably some of the years which make up the total stock will have been in secondary or higher education. By just looking at the average and not splitting down the acquired years of education into those acquired at the primary, secondary, and higher levels, this method allocates the wrong rates of return to a substantial part of the acquired schooling years. Furthermore, Hall and Jones (1999) employ private rates of return to education calculated on the basis of the earnings function method, also reported in Psacharopoulos (1994), using the ad-hoc assumption that the rate of return to primary education equals the average rate of return in Sub-Saharan Africa (13.4 percent), the rate of return to secondary education equals the world-average rate of return (10.1 percent), and the rate of return to higher education equals the average rate of return in OECD countries (6.8 percent).<sup>8</sup> To be able to compare results based on my estimates of  $h^M$  and  $h^O$  to the method used by Hall and Jones (1999), I report results based on their measure  $h^{HJ}$ , updated to 1990 with years of schooling from Barro and Lee (2001).<sup>9</sup>

## 5. Development-Accounting Results

### 5.1 Global Evidence

Table 1a presents the covariance measure for the broadest sample of countries for which the relevant data is available. The sample size of 132 countries is determined by the availability of investment data in the Penn World Tables to construct the physical-capital stock. The first row begins with the specification used by Hall and Jones (1999),  $h^{HJ}$ , where 21 percent of the international varia-

<sup>8</sup> Note that while in general, narrow-social rates of return must be lower than private rates, the reported private estimates based on the earnings function method are even lower than the narrow-social estimates based on the elaborate discounting method.

<sup>9</sup> A table presenting all the data used in this paper is available in the appendix of Wößmann (2001a).



tion in output per worker is accounted for by differences in human capital per worker. Since another 19 percent can be attributed to differences in the physical capital-output ratio, 60 percent remain as residual total factor productivity. With the human-capital specification  $h^M$ , which attributes rates of return to years of schooling through equation (6) instead of equation (15) and uses social rates of return estimated by the elaborate discounting method, 33 percent of development differences are accounted for by human-capital differences.

Table 1a: Human Capital and Economic Development: World Evidence

Covariance measure:  $\frac{\text{cov}(\ln(y), \ln(Z))}{\text{var}(\ln(y))}$  with  $Z$  given in each column

	$h^X$	$(k/y)^{\frac{\alpha}{1-\alpha}}$	$A$	Sample Size
$X=$				
$HJ$	0.21	0.19	0.60	132
$M$	0.33	0.19	0.48	132
$Q$	0.45	0.19	0.36	132

Note: For  $h^{HJ}$ ,  $h^M$ , and  $h^Q$ , see equations (6), (7), and (15).

Table 1b: Human Capital and Economic Development: World Evidence

Five-Country Measure:  $\ln\left(\frac{\prod_{i=1}^5 Z_i}{\prod_{j=n-4}^n Z_j}\right) / \ln\left(\frac{\prod_{i=1}^5 y_i}{\prod_{j=n-4}^n y_j}\right)$

with  $n$  = sample size, countries  $i, \dots, j, \dots, n$  ranked according to  $y$ , and  $Z$  given in each column

	$h^X$	$(k/y)^{\frac{\alpha}{1-\alpha}}$	$A$	Sample Size
$X=$				
$HJ$	0.24	0.19	0.57	132
$M$	0.39	0.19	0.42	132
$Q$	0.47	0.19	0.34	132

Note: For  $h^{HJ}$ ,  $h^M$ , and  $h^Q$ , see equations (6), (7), and (15).

Results based on the quality-adjusted human-capital specification  $h^Q$  are reported in the last row of Table 1a. The adjustment of the human-capital specification for differences in the quality of education boosts the share of variation in development levels attributed to human-capital differences to 45

development levels attributed to human-capital differences to 45 percent. This evidence shows that the assumption implicit in the previous specifications, that differences in educational quality can be neglected in the specification of human-capital stocks, can give rise to misleading results on the development effect of human capital in development-accounting studies.

The results based on the five-country measure, reported in Table 1b, confirm the results based on the covariance method. The share attributed to human capital is slightly higher with the five-country measure for all the specifications reported. With  $h^Q$ , the five-country measure attributes 47 percent of the variation in development levels to human-capital differences.

Table 2 shows the robustness of the calculated development impact of quality-adjusted human capital to some refinements.<sup>10</sup> Using years of education in the population aged 25 and over (instead of 15 and over) leaves the human-capital share unchanged. Recalculating the development-accounting exercise for the year 1980 yields a development share attributed to differences in  $h^Q$  of 42 percent. Since these results may be affected by the oil-price shocks in the 1970s, an additional sample excludes countries dependent on primary resources by excluding all countries whose value added in the mining sector accounts for more than 10 percent of total value added. In this sample of 115 countries, the share attributed to quality-adjusted human capital is 47 percent in 1980 and 48 percent in 1990. Thus, the results are robust against changes in the point of time at which the cross-sectional analysis is performed. The long-run relationship holds both in 1980 and in 1990, thereby being unaffected by short-run swings in the data due to business-cycle movements.

Table 2: Quality-Adjusted Human Capital and Economic Development: Robustness

Covariance measure:  $\frac{\text{cov}(\ln(y), \ln(Z))}{\text{var}(\ln(y))}$  with  $Z$  given in each column

	$h^Q$	$(k/y)^{\frac{\alpha}{1-\alpha}}$	$A$	<i>Sample Size</i>
Population 25 and over	0.45	0.19	0.36	132
1980	0.42	0.19	0.39	132
1980: Low mining share	0.47	0.22	0.31	115
1990: Low mining share	0.48	0.20	0.33	115

<sup>10</sup> Results on the human-capital share for the other specifications and results of the five-country measure are reported in Table A1 in the appendix.

## 5.2 Evidence from Countries with Relatively Reliable Data

Given that the human-capital data is imputed rather than original data in many countries, the data quality for these countries might not be of a high standard. That is, the data recording errors referred to in Section 1 might be large in these countries, calling into question the reliability of this data. Table 3 reports results for several sub-samples of countries in 1990 where countries with more dubious data quality are not included. These results reveal that the human-capital share is understated by the use of non-original data. When countries with imputed values on years of schooling  $s$ , on the quality index  $Q$ , or on either of them are excluded, the share of development variation accounted for by human capital exceeds 50 percent.<sup>11</sup> The same is true when countries are excluded which never participated in one of the benchmark studies underlying the Penn World Tables. In the sample of PWT benchmark countries without imputed  $s$  or  $Q$  data, with a sample size of 64 countries, the share attributed to quality-adjusted human capital rises to 60 percent.

Table 3: Quality-Adjusted Human Capital and Economic Development: Sub-Samples with Relatively Reliable Data

Covariance measure:  $\frac{\text{cov}(\ln(y), \ln(Z))}{\text{var}(\ln(y))}$  with  $Z$  given in each column

	$h^Q$	$(k/y)^{\frac{\alpha}{1-\alpha}}$	$A$	Sample Size
Non-imputed $s$	0.51	0.19	0.30	104
Non-imputed $Q$	0.51	0.15	0.34	88
Non-imputed $s$ and $Q$	0.52	0.15	0.33	85
PWT benchmark study (BS)	0.52	0.22	0.27	82
BS, non-imputed $s$ and $Q$	0.60	0.13	0.27	64
Non-projected $Q$	0.51	0.18	0.31	38
BS, non-imp. $s$ , non-proj. $Q$	0.61	0.13	0.26	29

Furthermore, of the 88 available values of the quality index  $Q$ , more than half had been projected in Hanushek and Kimko (2000) on the basis of observed country and education-system characteristics. When confining the sample to the 38 countries with original data on educational quality, the calculated human-capital share is 51 percent. And when combining all the restrictions

<sup>11</sup> Table A2 in the appendix presents results on the human-capital share for the other specifications, as well as results of the five-country measure.

discussed, yielding a sample of 29 countries which participated in a PWT benchmark study and which do not have any imputed or projected human-capital data, 61 percent of the international variation in the level of economic development are accounted for by differences in quality-adjusted human capital.

All this shows that the development impact of human capital seems to be severely understated by previous human-capital specifications and by misreported human-capital data. Leaving countries with imputed human-capital data – which seem to contain a large amount of measurement error in the sense of poor data recording – out of the sample, the share in income dispersion accounted for by human-capital differences indeed seems to be as large as 60 percent.

### 5.3 Human-Capital Stocks and Technical Differentiation

Still, differences in the residual  $A$  account for between 26 and 36 percent (depending on the inclusion of imputed human-capital data) of the cross-country variance in economic development. This result may be due to three different causes. First, there may be cross-country technological differences, so that the “technical-progress view” on the relation between human capital and economic development (Section 3.2) may have explanatory power. Second, cross-country differences in total factor productivity may arise from other factors, notably institutional differences across countries. Third, the residual may be caused by data recording errors, giving rise to attenuation bias in the shares attributed to the factor inputs, in which case the residual would not reflect real cross-country differences in total factor productivity.

To estimate whether the recognition of the “technical-progress view” on the relationship between human capital and growth can add to an understanding of the residual, I use a simple conclusion of this view. If a higher stock of human capital caused a country's rate of technological progress to be higher than that of other countries with lower stocks of human capital, then the level of total factor productivity in the former countries - increased by technological advances - should be superior to the total factor productivity used in the latter countries. It follows by integration from equation (11) that the level of total factor productivity  $A$  should be a positive function of the stock of human capital, and at an increasing rate:

$$(16) \quad A_i = A_{i0} e^{\psi(h_i)^{\beta}} .$$

Therefore, the stock of human capital and the level of total factor productivity of a country should be positively correlated.

Calculating the level of total factor productivity as the residual in the neo-classical framework of equation (9), where  $A_i = y_i / \left[ (k_i / y_i)^{\frac{\alpha}{1-\alpha}} h_i \right]$  reflects

what is left over of development differences after accounting for differences in factor inputs, in principle allows for a positive correlation between the level of total factor productivity and the human capital input. This contrasts with the regression methodology used in Mankiw et al. (1992), where total factor productivity is reflected in a regression residual which by construction is uncorrelated with the inputs (and by construction does not systematically differ across countries). By looking at the correlation between the residual  $A$  and the human-capital stock  $h$ , the addition of the “technical-progress view” to an understanding of the residual in the development-accounting framework can be estimated.

As can be seen in Table 4, there is indeed some correlation between the residual  $A$  and the human-capital specifications which ignore quality differences, namely  $h^{HJ}$  and  $h^M$ . However, when differences in educational quality are accounted for in the human-capital stock  $h^Q$ , there is no longer any correlation between the residual and the stock of human capital.<sup>12</sup> This evidence suggests that while the human-capital-augmented neoclassical growth model is able to explain a substantial amount of the cross-country dispersion in development levels, the effect of the stock of human capital on economic development working through technical differentiation, as stressed by “technical-progress view,” does not seem to add to an explanation of international differences in development levels.

Table 4: Correlation with the Level of Productivity  $A$   
Correlation coefficients; all variables measured in logs

	$h^X$	$(k/y)^{\frac{\alpha}{1-\alpha}}$	$y$
$X=$			
$HJ$	0.575	0.286	0.898
$M$	0.337	0.140	0.786
$Q$	-0.043	-0.018	0.587

Note: For  $h^{HJ}$ ,  $h^M$ , and  $h^Q$ , see equations (6), (7), and (15).

Since with human-capital specification  $h^Q$ , the residual is also uncorrelated with the physical-capital component, international differences in the level of technology driven by human- or physical-capital stocks do not add to an understanding of the residual. This suggests the implication that this residual in cross-country productivity differences may not reflect differences in the technology used, corroborating the argumentation that, by the very nature of technological knowledge, all countries should in principle have access to the same

<sup>12</sup> There is also no correlation when considering the non-linear form of the relationship as in equation (16): The correlation between  $\ln(A)$  and  $h^Q$  is -0.140.

technologies (Section 3.2). When neglecting potential attenuation bias in the results and assuming that the residual reflects real differences in the level of total factor productivity, these differences would then have to be caused by other cross-country differences which affect the productivity with which production factors are put to use. One causal factor which suggests itself are cross-country differences in the basic institutions which constitute the framework within which individuals produce and interact economically (cf. Hall and Jones 1999).

#### 5.4 OECD-Sample Development-Accounting Results

An indirect way to test whether international differences in residual total factor productivity in the world sample may indeed reflect institutional differences is to look at a sample of countries in which such fundamental institutional differences do not exist. One such sample arguably is the sample of OECD countries, which share common basic institutional features which allow markets to function properly. When evaluated relative to many developing countries, OECD countries all have comparatively reliable legal frameworks securing private property rights, freedom of contracting, agencies ensuring competitive markets, market-friendly policies, and internal monetary stability. They also exhibit a relatively high degree of openness to trade and capital mobility which enables them to access similar technologies. Because of these similar institutional frameworks, there should be no differences in residual total factor productivity among OECD countries, with all countries producing on a common macroeconomic production function and differences in factor inputs sufficing to explain differences in development levels among these countries.

I use the sample of all OECD countries in 1990 except Luxembourg, for which no schooling quantity data is available. With output per worker in Turkey at less than a quarter of the US value and in Portugal and Greece at less than half the US value, there is sizable variation in development levels to be explained in this sample. One advantage of the OECD sample over the world sample is that data should be recorded more accurately, so that data-quality problems should be relatively small.

As the results based on the covariance measure presented in Table 5a reveal, the share of development variation accounted for by differences in human-capital stocks is larger in the OECD sample than in the world sample. With specification  $h^{HJ}$ , the share attributed to human capital is 39 percent, with  $h^M$  70 percent, and with  $h^Q$  100 percent. That is, the covariance between the quality-adjusted human-capital specification and output per worker in the OECD sample is just as large as the variance of output per worker, so that the whole variation in development levels can be accounted for by differences in quality-adjusted human capital. This result is confirmed by the five-country measure (Table 5b).

Table 5a: Human Capital and Economic Development: OECD Sample

Covariance measure:  $\frac{\text{cov}(\ln(y), \ln(Z))}{\text{var}(\ln(y))}$  with  $Z$  given in each column

	$h^X$	$(k/y)^{\frac{\alpha}{1-\alpha}}$	$A$	Sample Size
$X=$				
$HJ$	0.39	0.15	0.47	23
$M$	0.70	0.15	0.15	23
$Q$	1.00	0.15	-0.14	23

Note: For  $h^{HJ}$ ,  $h^M$ , and  $h^Q$ , see equations (6), (7), and (15).

Table 5b: Human Capital and Economic Development: OECD Sample

Five-Country Measure:  $\ln\left(\frac{\prod_{i=1}^5 Z_i}{\prod_{j=n-4}^n Z_j}\right) / \ln\left(\frac{\prod_{i=1}^5 y_i}{\prod_{j=n-4}^n y_j}\right)$

with  $n$  = sample size, countries  $i, \dots, j, \dots, n$  ranked according to  $y$ , and  $Z$  given in each column

	$h^X$	$(k/y)^{\frac{\alpha}{1-\alpha}}$	$A$	Sample Size
$X=$				
$HJ$	0.38	0.11	0.51	23
$M$	0.72	0.11	0.17	23
$Q$	0.94	0.11	-0.05	23

Note: For  $h^{HJ}$ ,  $h^M$ , and  $h^Q$ , see equations (6), (7), and (15).

When the human-capital specification accounts for differences in educational quality, the development-accounting evidence suggests that OECD countries are broadly producing on a common level of total factor productivity.<sup>13</sup> The evidence reveals that the “neoclassical view” on the relationship between human capital and economic development yields a model which fits the data

<sup>13</sup> This result is also confirmed by the fact that there is no correlation between total factor productivity  $A$  and output per worker  $y$  in the OECD sample when human capital is specified as  $h^Q$  (the correlation coefficient is -0.09).

well. As an explanation of the differences in output per worker among OECD countries, the human-capital-augmented neoclassical growth model suffices. The “technical-progress view” on growth effects of human capital does not add to an understanding of the cross-country dispersion in development levels. The OECD results have an indication that the residual in the world evidence may be either due to poor data quality or due to differences in basic institutions governing the market processes.

### 5.5 Data Recording Errors versus Specification Errors

Recent studies by Krueger and Lindahl (2001) and de la Fuente and Doménech (2000, 2001) have argued that there are serious data recording errors in the data on average years of schooling which lead to biased estimates of growth effects. However, as argued in Wößmann (2001a), data quality may not be a major problem for cross-country level comparisons in 1990, because basically all observations at least in the OECD sample are direct census observations. To assess the importance of data-quality problems in human-capital measurement relative to the specification problems stressed in this paper, I compare development-accounting results based on the three available data sets on average years of schooling in the population aged 15 and over which have been constructed on the basis of the attainment census method (cf. Wößmann 2001a): the Barro and Lee (1996) data set, the Barro and Lee (2001) data set, and the de la Fuente and Doménech (2000) data set. Barro and Lee (2001) improve on their earlier data set by taking account of changes in the duration of schooling cycles and by a refined fill-in procedure for missing observations. De la Fuente and Doménech (2000) thoroughly revise the Barro and Lee (1996) data set for the OECD sample by using additional national data sources and deleting data inconsistencies.

When comparing the covariance-measure results based on the Barro and Lee (1996) data set in Table 6a to the results in Table 1a which are based on the revised Barro and Lee (2001) data set, it is obvious that the improvement in data quality had only a minor impact on the development-accounting results. The estimated share in output variation accounted for by differences in quality-adjusted human capital is half a percentage point higher in the case of the revised data set. The more thorough revision of the OECD data set by de la Fuente and Doménech (2000) has a larger effect on the development-accounting results, but the difference in the share attributed to quality-adjusted human capital is still only 4 percentage points (Table 6b).<sup>14</sup> The effect on development-accounting results of having improved human-capital data seems to be minor relative to specification effects of using superior rate-of-return estimates and of adjusting for educational quality. While improving on the re-

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<sup>14</sup> These results based on the covariance measure are confirmed by the five-country measure.



ording of educational data is indeed a worthy issue, the recording issue of considering *data* quality seems to be less important for the results of development-accounting studies than the specification issue of considering *human-capital* quality.

Table 6a: Alternative Schooling Quantity Data Sets: Barro and Lee (1996)

Covariance measure:  $\frac{\text{cov}(\ln(y), \ln(Z))}{\text{var}(\ln(y))}$  with  $Z$  given in each column

	$h^X$	$(k/y)^{\frac{\alpha}{1-\alpha}}$	$A$	Sample Size
$X=$				
$HJ$	0.20	0.19	0.61	132
$M$	0.33	0.19	0.48	132
$Q$	0.44	0.19	0.37	132

Note: For  $h^{HJ}$ ,  $h^M$ , and  $h^Q$ , see equations (6), (7), and (15).

Table 6b: Alternative Schooling Quantity Data Sets: De la Fuente and Doménech (2000), OECD Sample

Covariance measure:  $\frac{\text{cov}(\ln(y), \ln(Z))}{\text{var}(\ln(y))}$  with  $Z$  given in each column

	$h^X$	$(k/y)^{\frac{\alpha}{1-\alpha}}$	$A$	Sample Size
$X=$				
$HJ$	0.46	0.15	0.40	21
$M$	0.86	0.15	-0.01	21
$Q$	1.04	0.15	-0.19	21

Note: For  $h^{HJ}$ ,  $h^M$ , and  $h^Q$ , see equations (6), (7), and (15).

## 6. Conclusion

The empirical results presented in this paper reveal that two crucial aspects in the measurement of human capital are the correct inclusion of rates of return to education and the consideration of the quality of education. While data recording errors do seem to affect estimates of the development effect of human capital, decent empirical specifications of the concept of human capital appear to be even more crucial. International differences in quality-adjusted human capital can account for about half the global dispersion of development levels and for virtually all the development dispersion among OECD countries within the framework of a simple human-capital-augmented neoclassical model of economic growth and development.

As a development-accounting study, this paper has taken a mainly descriptive approach in accounting for the “proximate” causes of international differences in levels of economic development - human capital, physical capital, and residual total factor productivity. To search for “ultimate” causes of economic development, one has to go beyond development accounting and look at what lies behind productivity and the accumulation of human and physical capital. Still, the development-accounting results give a hint on where to look for these deeper causes. For example, the difference in the development-accounting results between the world and the OECD-sample results suggests that the analysis of institutions as an underlying cause of economic development seems promising (cf. Olson 1996, Hall and Jones 1999, Acemoglu et al. 2001). More specifically to the topic of human capital, as educational quality seems to be a major factor in the stock of human capital, research on the causes of differences in the quality of education seems to be a fertile part of growth research (cf. Temple 2001a). First evidence by Wößmann (2001b, 2002a) suggests that cross-country differences in human-capital quality are strongly linked to differences in institutional features of the education systems and unrelated to differences in educational spending. Both improvements in the measurement of educational quality and further research on its determinants could broaden our understanding of the relationship between human capital and economic development.

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## Appendix Tables

Table A1a: Share of Human Capital: Robustness

$$\text{Covariance Measure: } \frac{\text{cov}(\ln(y), \ln(h^X))}{\text{var}(\ln(y))}$$

	$h^{HJ}$	$h^M$	$h^Q$
Population 25 and over	0.22	0.34	0.45
1980	0.21	0.33	0.42
1980: Low mining share	0.23	0.36	0.47
1990: Low mining share	0.22	0.35	0.48

Note: For  $h^{HJ}$ ,  $h^M$ , and  $h^Q$ , see equations (6), (7), and (15).

Table A1b: Share of Human Capital: Robustness

$$\text{Five-Country Measure: } \ln \left( \frac{\prod_{i=1}^5 h_i^X}{\prod_{j=n-4}^n h_j^X} \right) \bigg/ \ln \left( \frac{\prod_{i=1}^5 y_i}{\prod_{j=n-4}^n y_j} \right)$$

with  $n$  = sample size, countries  $i, \dots, j, \dots, n$  ranked according to  $y$

	$h^{HJ}$	$h^M$	$h^Q$
Population 25 and over	0.24	0.39	0.47
1980	0.19	0.30	0.36
1980: Low mining share	0.23	0.36	0.44
1990: Low mining share	0.24	0.39	0.47

Note: For  $h^{HJ}$ ,  $h^M$ , and  $h^Q$ , see equations (6), (7), and (15).

Table A2a: Share of Human Capital: Sub-Samples with Relatively Reliable Data

$$\text{Covariance Measure: } \frac{\text{cov}(\ln(y), \ln(h^X))}{\text{var}(\ln(y))}$$

	$h^{HJ}$	$h^M$	$h^Q$
Non-imputed $s$	0.23	0.37	0.51
Non-imputed $Q$	0.20	0.34	0.51
Non-imputed $s$ and $Q$	0.20	0.33	0.52
PWT benchmark study (BS)	0.22	0.36	0.52
BS, non-imputed $s$ and $Q$	0.20	0.35	0.60
Non-projected $Q$	0.21	0.34	0.51
BS, non-imp. $s$ , non-proj. $Q$	0.19	0.34	0.61

Note: For  $h^{HJ}$ ,  $h^M$ , and  $h^Q$ , see equations (6), (7), and (15).

Table A2b: Share of Human Capital: Sub-Samples with Relatively Reliable Data

$$\text{Five-Country Measure: } \ln\left(\frac{\prod_{i=1}^5 h_i^X}{\prod_{j=n-4}^n h_j^X}\right) / \ln\left(\frac{\prod_{i=1}^5 y_i}{\prod_{j=n-4}^n y_j}\right)$$

with  $n$  = sample size, countries  $i, \dots, j, \dots, n$  ranked according to  $y$

	$h^{HJ}$	$h^M$	$h^Q$
Non-imputed $s$	0.25	0.40	0.51
Non-imputed $Q$	0.23	0.39	0.51
Non-imputed $s$ and $Q$	0.24	0.39	0.54
PWT benchmark study (BS)	0.22	0.36	0.44
BS, non-imputed $s$ and $Q$	0.19	0.35	0.47
Non-projected $Q$	0.21	0.36	0.49
BS, non-imp. $s$ , non-proj. $Q$	0.14	0.36	0.37

Note: For  $h^{HJ}$ ,  $h^M$ , and  $h^Q$ , see equations (6), (7), and (15).