

The Role of Cognitive Skills in Economic Development

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The role of improved schooling, a central part of most development strategies, has become controversial because expansion of school attainment has not guaranteed improved economic conditions. This paper reviews the role of cognitive skills in promoting economic well-being, with a particular focus on the role of school quality and quantity. It concludes that there is strong evidence that the cognitive skills of the population—rather than mere school attainment—are powerfully related to individual earnings, to the distribution of income, and to economic growth. New empirical results show the importance of both minimal and high level skills, the complementarity of skills and the quality of economic institutions, and the robustness of the relationship between skills and growth. International comparisons incorporating expanded data on cognitive skills reveal much larger skill deficits in developing countries than generally derived from just school enrollment and attainment. The magnitude of change needed makes clear that closing the economic gap with developed countries will require major structural changes in schooling institutions.

1. Introduction

It takes little analysis to see that schooling levels differ dramatically between developing and developed countries. Building upon several decades of thought about human capital—and centuries of general attention to education in the more advanced countries—it is natural to believe that a productive development strategy would be to

raise the schooling levels of the population. And, indeed, this is exactly the approach of the Education for All initiative and a central element of the Millennium Development Goals (see, e.g., UNESCO 2005 and David E. Bloom 2006).

But there are also some nagging uncertainties that exist with this strategy. First, developed and developing countries differ in a myriad of ways other than schooling

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levels. Second, a number of countries—both on their own and with the assistance of others—have expanded schooling opportunities without seeing any dramatic catch-up with developed countries in terms of economic well-being. Third, countries that do not function well in general might not be more able to mount effective education programs than they are to pursue other societal goals. Fourth, even when schooling policy is made a focal point, many of the approaches undertaken do not seem very effective and do not lead to the anticipated student outcomes. In sum, is it obvious that education is the driving force or merely one of several factors that are correlated with more fundamental development forces?

The objective of this study is to review what research says about the role of education in promoting economic well-being. We pay particular attention to the robustness of the relationship between education and economic outcomes across tests of alternative specifications and hypotheses about the underlying determinants of outcomes.

The discussion also has one distinctive element. We have come to conclude that cognitive skills—particularly in assessing policies related to developing countries—are THE key issue. It is both conventional and convenient in policy discussions to concentrate on such things as years of school attainment or enrollment rates in schools. These things are readily observed and measured. They appear in administrative data and they are published on a consistent basis in virtually all countries of the world. And, they are very misleading in the policy debates.

Cognitive skills are related, among other things, to both the quantity and quality of schooling. But schooling that does not improve cognitive skills, measured here by comparable international tests of mathematics, science, and reading, has limited impact on aggregate economic outcomes and on economic development.

We will show in graphic terms the differences in cognitive skills that exist, even after allowing for differences in school attainment. Most people would, in casual conversation, acknowledge that a year of schooling in a school in a Brazilian Amazon village was not the same as a year of schooling in a school in Belgium. They would also agree that families, peers, and others contribute to education. Yet, the vast majority of research on the economic impact of schools—largely due to expedience—ignores both of these issues. The data suggest that the casual conversation based on disparities in school attainment may actually understate the magnitude of differences in true education and skills across countries. We think of education as the broad mix of inputs and processes that lead to individual knowledge. Yet, because schooling and education are conflated in common usage, we will generally refer specifically to cognitive skills, the part of education for which we have good measures.

We provide strong evidence that ignoring differences in cognitive skills significantly distorts the picture about the relationship between education and economic outcomes. This distortion occurs at three levels. It misses important differences between education and skills on the one hand and individual earnings on the other. It misses an important underlying factor determining the interpersonal distribution of incomes across societies. And, it very significantly misses the important element of education in economic growth.

The plan of this study is straightforward. Based on a simple conceptual framework, we document the importance of cognitive skills in determining individual earnings and, by implication, important aspects of the income distribution. We then turn to the relationship of education and economic growth. Research into the economics of growth has itself been a growth area, but much of the research focuses just on school

attainment with no consideration of cognitive skill differences that might arise from variations in school quality or other sources of learning. We show, in part with new evidence, that the previous estimation is highly biased by concentration on just quantity of schooling.

The simple answer in the discussion of economic implications of education is that cognitive skills have a strong impact on individual earnings. More than that, however, cognitive skills have a strong and robust influence on economic growth. Models that include direct measures of cognitive skills can account for about three times the variation in economic growth than models that include only years of schooling; including the cognitive skills measures makes the coefficient on years of schooling go to zero; and the estimates of such more inclusive models are far more robust to variations in the overall model specification. In both the earnings and the growth areas, we can reject the most frequently mentioned alternative explanations of the relationships.

To be sure, while there is a policy link to schools, none of this says that schools *per se* are the answer. Even though it is common to treat education and schooling synonymously, it is important to distinguish between knowledge and skills on the one hand and schooling. This distinction has important substantive underpinnings. Cognitive skills may be developed in formal schooling, but—as extensively documented—they may also come from the family, the peers, the culture, and so forth. Moreover, other factors obviously have an important impact on earnings and growth. For example, overall economic institutions—a well-defined system of property rights, the openness of the economy, the security of the nation—can be viewed almost as preconditions to economic development. And, without them, education and skills may not have the desired impact on economic outcomes.

Yet, while recognizing the impact of these overall institutions, we find that cognitive skills play an important role. Furthermore, there is ample evidence that a high-quality school system can lead to improved cognitive skills. And from a public policy perspective, interventions in the schools are generally viewed as both more acceptable and more likely to succeed than, say, direct interventions in the family.

Given the evidence on the importance of cognitive skills for economic outcomes, we turn to what can be said about their production in developing countries. Although information on enrollment and attainment has been fairly widely available, cognitive skills information has not. We use newly developed data on international assessments of cognitive skills (also employed in the analysis of growth) to show that the education deficits in developing countries are larger than previously appreciated.

Finally, in terms of framing the analysis here, we motivate much of the discussion by a consideration of world development goals and the impacts of educational quality on economic outcomes in the developing world. Yet the bulk of the evidence on outcomes has clear and direct implications for developed countries. In simplest terms, available evidence suggests that the economic situation in, for example, the United States and Germany is governed by the same basic educational forces as that in developing countries of South America. Thus, this should not be thought of so much as a treatise on policies toward Sub-Saharan Africa but as an analysis of the fundamental role of cognitive skills on the operations of international economies.

2. *Conceptual Framework*

We begin with a very simple earnings model: individual earnings (y) are a function of the labor market skills of the individual

(H), where these skills are frequently referred to simply as the worker's human capital. For simplicity in equation (1), we assume that this is a one-dimensional index, although this is not important for our purposes:

$$(1) \quad y = \gamma H + \varepsilon.$$

The stochastic term, ε , represents idiosyncratic earnings differences and is orthogonal to H .

This abstract model has been refined in a wide variety of ways, most importantly by considering the underlying behavior of individuals in terms of their investments in developing skills (Yoram Ben-Porath 1967, 1970; James J. Heckman 1976; Flavio Cunha et al. 2006). This basic model of earnings determination is central to most empirical investigations of wages and individual productivity. Before pursuing this existing research, however, it is useful to understand where the skills might come from. These skills are affected by a range of factors including family inputs (F), the quantity and quality of inputs provided by schools (which we incorporate as the function, $Q(S)$, where S is school attainment), individual ability (A), and other relevant factors (X) which include labor market experience, health, and so forth. Along with a stochastic term assumed uncorrelated with the other determinants of H , we can write this simply as

$$(2) \quad H = \lambda F + \phi Q(S) + \delta A + \alpha X + \nu.$$

Human capital is nonetheless a latent variable. To be useful and verifiable, it is necessary to specify the measurement of H . The vast majority of existing theoretical and empirical work on earnings determination solves this by taking the quantity of schooling of the individual (S) as a direct measure of H and then dealing in one way or another with the complications of not completely measur-

ing H or its determinants in equation (2).¹ We return to such estimation below but first discuss an alternative approach built on direct measures of cognitive skills.

Consider test score measures of cognitive skills—that is, standardized assessments of mathematics, science, and reading achievement. If these measures, denoted C , completely capture variations in H , equation (1) could be directly estimated with C , and the key parameter (γ) could be estimated in an unbiased manner. Further, if school quantity, S , is added to the estimation equation, it would have no independent influence (in expectation). But nobody believes that existing test data are complete measures of H . Instead, the achievement test measures, C , are best thought of as error prone measures of H :

$$(3) \quad C = H + \mu.$$

With classical measurement errors, one would expect the estimate of γ to be biased toward zero and, if S and C are positively correlated as would be expected, the coefficient on S in the same estimated equation would be biased upward even if S has no independent effect over and above its relationship with C . This simple model would imply that the coefficient on C would be a lower bound on the impact of human capital on incomes.

The more common development, however, begins with using school attainment as a measure of human capital and proceeds

¹ Translating the abstract idea of skills into quantity of schooling was indeed the genius of Jacob Mincer, who pioneered both the consideration of the character of human capital investment and the empirical determination of wages that built on this (Mincer 1970, 1974). This work spawned an extensive literature about the determination of earnings and the appropriate approach to the estimation. From the Mincer development and its extensions, S is substituted for H in equation (1) and its coefficient is frequently interpreted as the rate of return on investment of one year of schooling when y is measured as the log of earnings (see below).

to interpret this under a variety of circumstances. Propelled by readily available data on school attainment within and across countries, economists have devoted enormous energy to estimating the returns to additional years of schooling, and this work has been summarized and interpreted in a number of different places.² The focal point has generally been how to get an unbiased estimate of γ (or a simple transformation of γ) under various considerations of other factors that might influence earnings and skills. For example, the ubiquitous Mincer earnings model takes the form

$$(4) \quad y = b_0 + b_1S + b_2Z + b_3Z^2 + b_4W + e,$$

where Z is labor market experience, W is a vector of other measured factors affecting incomes, and y is labor market earnings, typically measured in logarithms. In this, according to equation (2), the estimated return to a year of schooling (b_1) is biased through the correlation of S with F , A , and any omitted elements of X ; examples of such correlation would be predicted in standard optimizing models of the choice of years of schooling (e.g., Card 1999, Paul Glewwe 2002). Recognizing this, significant attention has concentrated on ability bias arising from correlation of school attainment with A and from other selection effects having to do with families and ability (see Card 1999). Indeed, various estimates of earnings models have added test score measures to the Mincer model in equation (4) explicitly to control for ability differences.

There are nonetheless two complications in the interpretation of such models. The first is that schooling is but one of the factors influencing cognitive skills and human capital formation. The second is that most formulations of the Mincer model assume that school quality is either constant or can be captured by addition of direct measures of school quality in equation (4).

The importance of nonschool influences on cognitive skills, particularly from the family, has been well documented within the literature on education production functions, which provides the backdrop for the formulation in equation (2).³ If the vector of other factors, W , in the earnings model includes the relevant other influences on human capital from equation (2), the estimate of b_1 would be simply $\phi\gamma$ (as long as school quality is constant).⁴ Unfortunately, having rich information about other determinants of skills outside of school attainment is seldom if ever available, because this requires data about factors contemporaneous with schooling and long before observed labor market data are available. While a number of ingenious approaches have been used, including for example exploiting the common experiences of twins, it is seldom plausible to conclude that the other factors in equation (2) have been adequately controlled, leading to the interpretation of b_1 as the combined influence of school and correlated

³ See, for example, the discussion in Eric A. Hanushek (1979).

⁴ While equation (2) highlights measurement error and its sources, the historical treatment has concentrated almost exclusively on simple misreporting of years of schooling, as opposed to potential omitted variables bias from neglecting (correlated) components of the true skill differences contained in H . See, for example, Orley Ashenfelter and Alan B. Krueger (1994). In our context, simple survey errors in S are a relatively small part of the measurement errors and omissions in specifying human capital.

² See early discussions in Mincer (1970) and Zvi Griliches (1977) and more recent reviews in David Card (1999) and Heckman, Lochner, and Todd (2006). In an international context, see George Psacharopoulos (1994), Psacharopoulos and Harry Anthony Patrinos (2004), and Colm Harmon, Hessel Oosterbeek, and Ian Walker (2003).

but omitted other influences.⁵ As such, b_1 is a reduced form coefficient that will give biased estimates of the potential impact from a policy designed to change school attainment alone.

The second major issue revolves around variations in school quality, indicated by $Q(S)$ in equation (2). Perhaps the simplest formulation of this is

$$(5) \quad Q(S) = qS,$$

where time in school, S , is modified by a quality index, q . As long as the variation in q is small, this is not a serious additional impediment to estimation. In an international context this assumption is clearly unreasonable, as will be described below. But, even in terms of individual countries (where earnings estimation is virtually always done), there is also substantial evidence that school quality varies significantly.⁶

If estimated in logarithmic form, the specification in equation (5) suggests dealing with school quality by adding direct

measures of quality, so that the coefficient on S might be interpreted as the return to a year of average quality school.⁷ A variety of authors have pursued this approach of adding quality measures generally related to inputs such as spending per pupil or pupil-teacher ratios. Unfortunately, prior work investigating the determinants of skills following equation (2) does not support measuring school quality in this manner.⁸

Additional complications of estimation and interpretation arise if human capital includes important elements of noncognitive skills. Noncognitive skills, while seldom precisely defined, include a variety of interpersonal dimensions including communications ability, team work skills, acceptance of social norms, and the like. Along such a line, Samuel Bowles and Herbert Gintis and more recently Heckman and his coauthors have argued that noncognitive skills are very important for earnings differences.⁹ Their formulation essentially begins with the notion that

$$(6) \quad H = C + N + \mu$$

⁵ In terms of equation (2), studies using schooling and income differences of twins (see Card 1999) assume that school quality differences are relatively unimportant or unsystematic so that quantity of schooling, S , is the central object. Then, if ability, family circumstances, and other factors affecting skills are relatively constant across twins, differences in schooling can be related to differences in earnings to obtain an unbiased estimate of γ . Of course, the key question remaining is why S differs across otherwise identical twins who presumably face identical investment payoffs. Other instrumental variable approaches have also been introduced to deal with the endogeneity of schooling, but they frequently will suffer if human capital evolves from nonschool factors as in equation (2).

⁶ Moreover, changes in school quality over time within individual countries may be important. Typically, Mincer earnings models compare the earnings associated with school attainment across individuals of different ages, who necessarily obtained their schooling at different times, and implicitly assume that a year of schooling is the same, regardless of when received. As a simple example, people educated under wartime conditions may receive significantly different educational outcomes per year of

schooling than those not educated in such circumstances (Hanushek and Lei Zhang 2008).

⁷ In reality, not much attention has been given to functional form, and much of the estimation is done in linear or semilinear form. An exception is Card and Krueger (1992) who develop a multiplicative specification, but their formulation has also been criticized (Heckman, Anne Layne-Farrar, and Todd 1996).

⁸ In terms of school inputs in earnings functions, see Julian R. Betts (1996). More generally in terms of equation (2), see Hanushek (2003) and Ludger Woessmann (2007). An alternative approach related to this paper is the inclusion of test score measures C directly in equation (4) with the notion of interpreting C as a direct measure of school quality that purges any school quality variations from the coefficient on years of schooling. In the spirit of equation (2), this would not be easily interpretable if cognitive skills, C , in fact capture the relevant variations in human capital, H .

⁹ See, for example, the early work along these lines that includes Bowles and Gintis (1976) and Bowles, Gintis, and Melissa Osborne (2001). These is extended in a variety of ways in Cunha et al. (2006) and Heckman, Jora Stixrud, and Sergio Urzua (2006).

and then duplicates the general form of equation (2) to describe the underlying determinants of C and N .¹⁰ This suggests the following modification of equation (4), which is a reduced form equation that combines influences of both cognitive and noncognitive factors through the channels of C and S :

$$(7) \quad y = b'_0 + b'_1S + b'_2Z + b'_3Z^2 + b'_4X \\ + b'_5C + e'.$$

In this formulation, estimation of equation (7) with the inclusion of C yields an implication that the coefficient on S (i.e., b'_1) would reflect the impact of human capital differences that are not captured by C .¹¹ Yet, for the same reasons discussed previously, b'_1 would not be simply $\phi\gamma$. It is still biased by other omitted determinants of N , such as the family.

It is important to note, nonetheless, that finding a direct effect of schooling on earnings to be zero ($b'_1 = 0$) after conditioning on cognitive skills is not the same as saying that school attainment does not matter. It merely says that the impact of school comes entirely through the impact on cognitive skills, so that schooling that does not raise cognitive skills is not productive. In general, the impact of school attainment is

$$(8) \quad \partial y / \partial S = b'_1 + b'_5 (\partial C / \partial S).$$

A more complete approach might be to include direct measures of noncognitive skills, N , into the estimation in equation (7). While some attempts have been made to do

this, measures of N are typically not available, and there is little agreement on even what dimensions might be important.¹² If, however, various noncognitive dimensions are important, the estimate of b'_5 is the reduced form effect of cognitive skills and correlated noncognitive skills.

Focusing on measures of cognitive skills has a number of advantages. First, they capture variations in the knowledge and ability that schools strive to produce with their curricula and thus relate the putative outputs of schooling to labor market success. Second, by emphasizing total outcomes of education, they incorporate skills from any source—families, schools, ability, and so forth as seen in equation (2). Third, by allowing for differences in performance among students with differing quality of schooling (but possibly the same quantity of schooling), they open the investigation of the importance of different policies designed to affect the quality aspects of schools. In that regard, this approach permits aligning investigations of the labor market with the extensive work that has also delved into aspects of educational production functions (see Hanushek 2002). Finally, recent policy attention to accountability in schools—along with the acceptance of parents that cognitive skills are important outcomes of schools—reinforce giving more attention to test-based measures of cognitive skills.

At the same time, the test score measures of cognitive skills, as indicated, also have disadvantages. As described, the tests that are given are undoubtedly narrower than either what is taught in schools or what elements are

¹⁰ The focus of this work, Cunha et al. (2006), is somewhat different from the discussion here. They are attempting to obtain a better description of lifetime investment behavior and of the returns to varying kinds of human capital investment.

¹¹ Heckman and Edward Vytalacil (2001) go further to argue that it is not possible to separate school attainment and achievement because they are so highly correlated. The importance of this depends,

however, on the specific data samples and questions being investigated.

¹² Reviews of these analyses along with new estimation is found in Bowles, Gintis, and Osborne (2001), Cunha et al. (2006), and Heckman, Stixrud, and Urzua (2006). They use survey measures to capture such behaviors as motivation, persistence, time preference, and self control, but the choice of these appears to be heavily dependent upon the specific survey data.

important in the labor market, including non-cognitive skills. This narrowness is clearest when considering individual tests of particular domains of knowledge, such as primary school reading. Most of the available tests are given at the school level, frequently at the end of lower secondary education, so that they do not directly capture variation in higher education (although they may do so indirectly through their predictive power for obtaining further education). Additionally, even as tests of specific subject matter at the secondary school level, the issue of measurement error in the tests cannot be ignored. The tests may suffer from a variety of problems related to the sampling of knowledge in the particular domain, the reliability of questions, and even the impact of test taking conditions on scores. Again, as described above, these concerns generally imply that the estimated effects of cognitive skills will be a lower bound on the impact of improved skills.

This discussion was designed to sketch out the range of possible issues in estimating human capital earnings functions, but the importance of the various issues is an empirical question. The possibility of biased estimates through correlated omitted variables is particularly important in some contexts, such as the endogeneity of school attainment, but is also relevant elsewhere. Acknowledging the range of possible issues does not capture the importance of them in specific empirical analyses. In the subsequent interpretations of various estimation schemes, we will focus on the importance of the various issues raised in the conceptual model and emphasize evidence that deals with particular threats to identification.

This discussion of individual economic outcomes has relevance for modeling the growth of nations. Even though developed in different ways, many relevant aspects of growth models can be put in the context of equations (1) and (2) where the outcome of interest is aggregate income or growth in

income instead of individual earnings, y . Much modeling of economic growth highlights labor force skills or the human capital of the country (along with other things as described below).

Again, the vast majority of growth modeling has simply taken measures of school attainment to characterize skills. Here, however, differences in educational outcomes (either total or per year of schooling) become central because the analysis assumes that, say, ten years of schooling means the same in terms of skills regardless of the country. Intuitively, the error in measuring skills by school attainment becomes large when comparing countries. More importantly, the error will be very systematic, based on the country and, quite likely, different aspects of the country.

The relevant omitted variables and measurement errors are just those depicted in equation (2). The aggregate skills of individuals in a country will vary with family inputs, school quality, ability differences, and other country specific factors.¹³ This motivates our work here. International test scores provide consistent measures of aggregate differences in cognitive skills across countries. As such, they do not attribute all differences in cognitive skills to the schools in different countries, although many policy discussions will hinge on the importance of schools in producing differences in cognitive skills.

The following sections investigate the existing evidence about how educational outcomes relate to economic outcomes. Throughout we emphasize the impacts of variations in measured cognitive skills on economic outcomes. First, we demonstrate that these educational

¹³ Krueger and Mikael Lindahl (2001) are motivated by differences in the aggregate and individual estimates of γ , and they focus on measurement error in school attainment. That analysis is directly analogous to the work on measurement error in modeling individual earnings, and it does not consider the more significant issues about other sources of differences in skills (equation (2)).

outcomes produce the most consistent and reliable information about education and development. Second, these outcomes can then be related directly to the relevant policy options facing nations. The standardly used measures of school attainment, on the other hand, provide much less reliable measures of skill differences, particularly in the cross-country growth context.

3. *Individual Returns to Education and Economic Inequality*

3.1 *Impacts of School Attainment on Individual Incomes*

Most attention to the value of schooling focuses on the economic returns to differing levels of school attainment for individuals as depicted in equation (4). This work, following the innovative analyses of human capital by Mincer (1970, 1974), considers how investing in differing amounts of schooling affects individual earnings. Over the past thirty years, literally hundreds of such studies have been conducted around the world, reviewed and interpreted by a variety of studies such as Psacharopoulos (1994), Card (1999), Harmon, Oosterbeek, and Walker (2003), Psacharopoulos and Patrinos (2004), and Heckman, Lochner, and Todd (2006).

These basic estimations of rates of return have uniformly shown that more schooling is associated with higher individual earnings. The rate of return to schooling across countries is centered at about 10 percent with variations in expected ways based largely on scarcity: returns appear higher for low income countries, for lower levels of schooling, and, frequently, for women (Psacharopoulos and Patrinos 2004).

Much of the academic debate has focused on whether these simple estimates provide credible measures of the causal effect of schooling. In particular, if more able people tend also to obtain additional schooling, the

estimated schooling effect could include both the impacts of schooling and the fact that those continuing in school could earn more in the absence of schooling. For the most part, employing alternative estimation approaches dealing with the problems of endogeneity of schooling do not lead to large changes in the estimates, and many times they suggest that the returns are actually larger with the alternative estimation schemes than with the simpler modeling strategies (e.g., Philip Oreopoulos 2006). Harmon, Oosterbeek, and Walker (2003) systematically review the various issues and analytical approaches dealing with them along with providing a set of consistent estimates of returns (largely for OECD countries) and conclude that, while the estimation approaches can have an impact on the precise value of the rate of return, it is clear that there is a strong causal impact of school attainment on earnings.

The basic estimates of Mincer earnings models are typically interpreted as the private returns to schooling. As is well known, the social returns could differ from the private returns—and could be either above or below the private returns. The most common argument is that the social returns will exceed the private returns because of the positive effects of education on crime, health, fertility, improved citizen participation, and (as we discuss below) on growth and productivity of the economy as a whole. Recent studies indeed find evidence of externalities of education in such areas as reduced crime (Lochner and Enrico Moretti 2004), improved health of children (Janet Currie and Moretti 2003), and improved civic participation (Thomas S. Dee 2004, Kevin Milligan, Moretti, and Oreopoulos 2004). The evidence on direct production spillovers of education among workers is more mixed, with Moretti (2004) and the studies cited therein finding favorable evidence and Daron Acemoglu and Joshua D. Angrist (2001) and Antonio Ciccone and

Giovanni Peri (2006) finding no evidence for this kind of spillovers.

In the Mincer earnings work, a specific version of social rates of return is frequently calculated. The typical calculations do not take account of possible positive externalities, but they instead take account of the fact that the social cost of subsidized education exceeds the private costs—thus lowering the social rate of return relative to the private rate of return (see Psacharopoulos and Patrinos 2004). In addition, the social return could be below the private return also if schooling was more of a selection device than of a means of boosting knowledge and skills of individuals. The empirical analysis of these issues has been very difficult because the labor market outcomes of the screening/selection model and the productivity/human capital model are very similar if not identical. Fabian Lange and Robert Topel (2006) review the theory and empirical work and conclude that there is little evidence that the social rate of return to schooling is below the private rate of return. Thus, although there are many uncertainties about precisely how social returns might differ from private returns, there is overall little reason to believe that the social returns are less than the private returns, and there are a variety of reasons to believe that they could be noticeably higher.

3.2 *Impacts of Cognitive Skills on Individual Incomes—Developed Countries*

The concentration on school attainment in the academic literature, however, contrasts with much of the policy discussion that, even in the poorest areas, involves elements of “quality” of schooling. Most countries are involved in policy debates about the improvement of their schools. These debates, often phrased in terms of such things as teacher salaries or class sizes, rest on a presumption that there is a high rate of return to schools in general and to quality in particular.

But it is not appropriate simply to presume that any spending on schools is a productive investment. It is instead necessary to ascertain two things: how various investments translate into skills and how those skills relate to economic returns. This and the following sections provide a summary of what is known about the individual returns specifically to cognitive skills in both developed and developing countries.

As discussed in section 2, one of the challenges to understanding the impact of human capital has been simply knowing how to measure human capital. Here we focus on how well cognitive achievement measures—students’ performance on standardized tests—proxy for the relevant labor market skills when assessed against individuals’ performance in the labor market and the economy’s ability to grow.

Until fairly recently, little comprehensive data have been available to show any relationship between differences in cognitive skills and any related economic outcomes. The many analyses of school attainment and Mincer earnings functions rely upon readily available data from censuses and surveys, which find it easy to collect information on earnings, school attainment, age, and other demographic information. On the other hand, it is difficult to obtain data on cognitive skills along with earnings and the other determinants of wages. Although cognitive test and school resource data are increasingly available at the time of schooling, these are seldom linked to subsequent labor market information. Such analyses generally require tracking individuals over time, a much more difficult data collection scheme. Such longitudinal data are, however, now becoming available.

A variety of researchers are now able to document that the earnings advantages to higher achievement on standardized tests are quite substantial. These results are derived from different specific approaches, but the basic underlying analysis involves estimating

a standard “Mincer” earnings function and adding a measure of individual cognitive skills such as equation (7). The clearest analyses are found in several references for the United States (analyzed in Hanushek 2002; see John Hillman Bishop 1989, 1991, June O’Neill 1990, Jeff Grogger and Eric Eide 1995, McKinley L. Blackburn and David Neumark 1993, 1995, Richard J. Murnane, John B. Willett, and Frank Levy 1995, Derek A. Neal and William R. Johnson 1996, Casey B. Mulligan 1999, Murnane et al. 2000, Joseph G. Altonji and Charles R. Pierret 2001, Murnane et al. 2001, and Edward P. Lazear 2003). While these analyses emphasize different aspects of individual earnings, they typically find that measured achievement has a clear impact on earnings after allowing for differences in the quantity of schooling, the experiences of workers, and other factors that might also influence earnings. In other words, higher quality as measured by tests similar to those currently being used in accountability systems around the world is closely related to individual productivity and earnings.

Three recent U.S. studies provide direct and quite consistent estimates of the impact of test performance on earnings (Mulligan 1999, Murnane et al. 2000, Lazear 2003). These studies employ different nationally representative data sets that follow students after they leave school and enter the labor force. When scores are standardized, they suggest that one standard deviation increase in mathematics performance at the end of high schools translates into 12 percent higher annual earnings.¹⁴

¹⁴ Because the units of measurement differ across tests, it is convenient to convert test scores into measures of the distribution of achievement across the population. A one-half standard deviation change would move somebody from the middle of the distribution (the fiftieth percentile) to the sixty-ninth percentile; a one standard deviation change would move this person to the eighty-fourth percentile. Because tests tend to follow a normal distribution, the percentile movements are largest at the center of the distribution. A separate review of the normalized impact

Murnane et al. (2000) provide evidence from the High School and Beyond and the National Longitudinal Survey of the High School Class of 1972. Their estimates suggest some variation with males obtaining a 15 percent increase and females a 10 percent increase per standard deviation of test performance. Lazear (2003), relying on a somewhat younger sample from NELS88, provides a single estimate of 12 percent. These estimates are also very close to those in Mulligan (1999), who finds 11 percent for the normalized AFQT score in the NLSY data.¹⁵ Note that these returns can be thought of as how much earnings would increase with higher skills each and every year throughout the persons’ working career. Thus, the present value of the returns to cognitive skills is large if these estimates can be interpreted as the structural impact, i.e., γ in equation (1).

These estimates are obtained fairly early in the work career (mid-twenties to early thirties), and analyses of the impact of cognitive skills across the entire work life are more limited. Altonji and Pierret (2001) find that the impact of achievement on earnings grows with experience because the employer has a chance to observe the performance of workers. The pattern of how returns change with age from their analysis is shown in figure 1, where the power of school attainment differences to predict differences in earnings is replaced by cognitive skills as workers are in the labor force longer. The evidence is consistent with employers relying on readily available information on school attainment when they do

of measured cognitive skills on earnings by Bowles, Gintis, and Osborne (2001) finds that the mean estimate is only 0.07, leading them to conclude that the small gains are dwarfed by noncognitive factors. We return to this below.

¹⁵ By way of comparison, we noted that estimates of the value of an additional year of school attainment are typically about 10 percent. Of course, any investment decisions must recognize that school attainment and test performance are generally produced together and that costs of changing each must be taken into account.

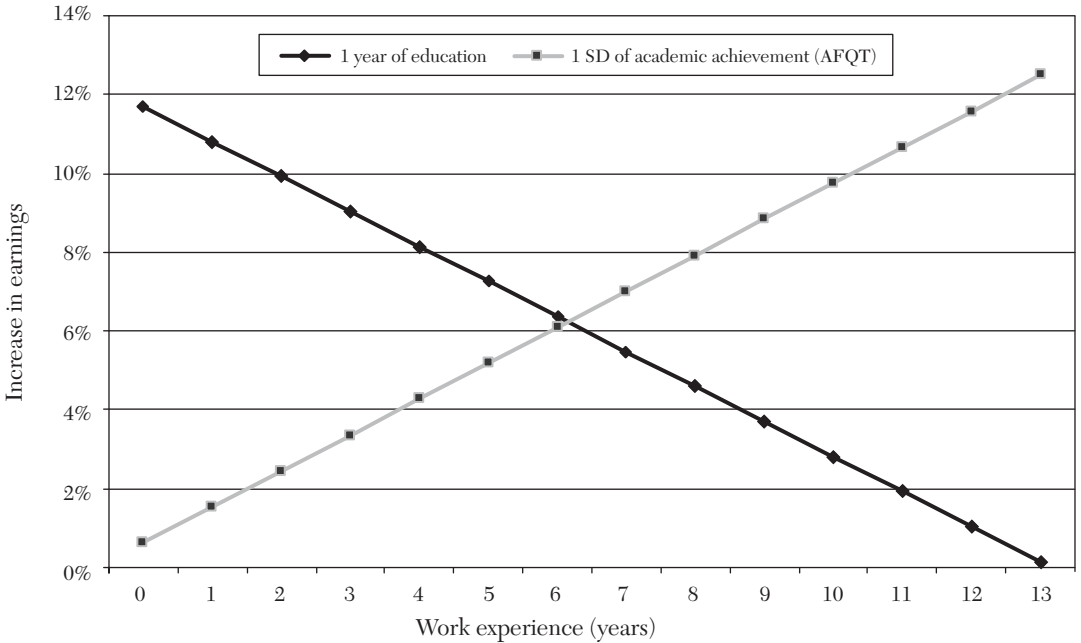


Figure 1. Returns to Observed Educational Quantity and Unobserved Academic Achievement over the Work Life

Notes: Based on data from National Longitudinal Survey of Youth (NLSY) and Armed Forces Qualification Test (AFQT). SD = standard deviation.

Source: Based on Altonji and Pierret (2001).

not have other information and switching to observations of skills and performance as that information becomes available through job performance. On the other hand, Hanushek and Zhang (2008) do not find that this pattern holds for a wider set of countries (although it continues to hold for the United States in their data). Thus, there is some uncertainty currently about whether cognitive skills have differential effects on economic outcomes over the work-experience profile.

Altonji and Pierret (2001) observe only a limited age range, so that the changing returns which they find may well be thought of as leveling off after some amount of labor market experience. Still, Hanushek and Zhang (2008) find that the importance

of cognitive skills is not restricted just to younger workers but holds across the experience spectrum.

There are reasons to believe that these estimates provide a lower bound on the impact of higher achievement. First, the labor market experiences that are observed begin in the mid-1980s and extend into the mid-1990s, but other evidence suggests that the value of skills and of schooling has grown throughout and past that period. Second, extrapolating from recent patterns, future general improvements in productivity are likely to lead to larger returns to skill. The considered analyses typically compare workers of different ages at one point in time to obtain an estimate of how earnings will change for any

individual. If, however, productivity improvements occur in the economy, these will tend to raise the earnings of individuals over time. If recent patterns of skill bias in productivity improvement continue, the impact of improvements in student skills are likely to rise over the work life instead of being constant as portrayed here (cf. Lawrence F. Katz and Kevin M. Murphy 1992). On the other hand, such skill-biased change has not always been the case, and technology could push returns in the opposite direction. Third, cognitive skills measured by test scores are prone to considerable measurement error as described earlier. Even if the tests were measuring exactly the relevant skill concept, we know that there are substantial errors in each test.¹⁶ These errors will in general lead to downward biases in the estimated coefficients.

A limited number of additional studies are available for developed countries outside of the United States. Steven McIntosh and Anna Vignoles (2001) study wages in the United Kingdom and find strong returns to both numeracy and literacy. Because they look at discrete levels of skills, it is difficult to compare the quantitative magnitudes directly to the U.S. work. Ross Finnie and Ronald Meng (2002) and David A. Green and W. Craig Riddell (2003) investigate returns to cognitive skills in Canada. Both suggest that literacy has a significant return, but Finnie and Meng (2002) find an insignificant return to numeracy. This latter finding stands at odds with most other analyses that have emphasized numeracy or math skills.

Another part of the return to cognitive skills comes through continuation in school. There is substantial U.S. evidence that stu-

dents who do better in school, either through grades or scores on standardized achievement tests, tend to go farther in school (see, for example, Dennis J. Dugan 1976, Charles F. Manski and David A. Wise 1983). Notably, Murnane et al. (2000) separate the direct returns to measured skill from the indirect returns of more schooling and suggest that perhaps one-third to one-half of the full return to higher achievement comes from further schooling. Similarly, Steven G. Rivkin (1995) finds that variations in test scores capture a considerable proportion of the systematic variation in high school completion and in college continuation, so that test score differences can fully explain black-white differences in schooling. Bishop (1991) and Hanushek, Rivkin, and Lori L. Taylor (1996), in considering the factors that influence school attainment, find that individual achievement scores are highly correlated with continued school attendance. Neal and Johnson (1996) in part use the impact of achievement differences of blacks and whites on school attainment to explain racial differences in incomes. Their point estimates of the impact of cognitive skills (AFQT) on earnings and school attendance appear to be roughly comparable to that found in Murnane et al. (2000). Jere R. Behrman et al. (1998) find strong achievement effects on both continuation into college and quality of college; moreover, the effects are larger when proper account is taken of the various determinants of achievement. Hanushek and Richard R. Pace (1995) find that college completion is significantly related to higher test scores at the end of high school. Note also that the effect of improvements in achievement on school attainment incorporates

¹⁶ In most testing situations, both the reliability of the specific test and the validity of the test are considered. Reliability relates to how well the test measures the specific material—and would include elements of specific question development and choice along with individual variations

that would occur if an individual took the same test at different points in time. Validity refers to the correspondence between the desired concept (skills related to productivity or earnings differences) and the specific choice of test domains (such as mathematical concepts at some specific level).

concerns about drop out rates. Specifically, higher student achievement keeps students in school longer, which will lead among other things to higher graduation rates at all levels of schooling.¹⁷

Tamara Knighton and Patrick Bussière (2006) find that higher scores at age fifteen lead to significantly higher rates of postsecondary schooling of Canadian nineteen-year-olds. This finding is particularly interesting for the international comparisons that we consider below, because the analysis follows up on precisely the international testing that is used in our analysis of economic growth (see section 5 below). The OECD tested random samples of fifteen-year-old students across participating countries under the Programme for International Student Assessment (PISA) in 2000, and students taking these tests in Canada were then followed and surveyed in 2002 and 2004.

The argument on the other side is that none of the studies of the impact of cognitive skills on either earnings or school attainment have provided any convincing analysis of the causal impact of scores. By this interpretation, the estimated impact of cognitive skills should be considered simply as the reduced form coefficient. Unlike the efforts to identify the rate of return to school attainment through a variety of means, this estimation has stopped without providing any substantial evidence that the observed variation in cognitive skills is truly exogenous. The concern is that other influences on earnings—say, noncognitive skills or direct influences of families on earnings—are omitted from the estimation, leading to standard omitted variables bias.

Still, even in the absence of convincing identification strategies for cognitive skills, we believe that these reduced form estimates provide an indication of the potential earnings impacts of policies that lead to improved student achievement. The consistency of the estimated impacts across different model specifications, different time periods, and different samples provides support for the underlying importance of cognitive skills. At the same time, the estimation of individual earnings models with cognitive skills almost always indicates that school attainment has an independent impact.¹⁸ By the development in section 2, this finding would imply either that the impact of schooling through the noncognitive channel or the measurement errors in cognitive skills was important. To the extent that school attainment captures these other dimensions, support for the strength of cognitive skills is increased. More generally, the identification of causal impacts of cognitive skills is an important topic for fruitful future research.

3.3 *Impacts of Cognitive Skills on Individual Incomes—Developing Countries*

Questions remain about whether the clear impacts of cognitive skills in the United States generalize to other countries, particularly developing countries. The existing literature on returns to cognitive skills in developing countries is restricted to a relatively limited number of mostly African countries: Ghana, Kenya, Morocco, South Africa, and Tanzania, as well as Pakistan. Moreover, a number of studies actually employ the

¹⁷ This work has not, however, investigated how achievement affects the ultimate outcomes of additional schooling. For example, if over time lower-achieving students tend increasingly to attend further schooling, these schools may be forced to offer more remedial courses, and the variation of what students know and can do at the end of school may expand commensurately.

¹⁸ A few previous analyses have shown that the impact of school attainment is zero or reduced substantially after inclusion of cognitive skills (e.g., W. Lee Hansen, Burton A. Weisbrod, and William J. Scanlon 1970), but the review by Bowles, Gintis, and Osborne (2001) indicates that this is uncommon.

same basic data, albeit with different analytical approaches, but come up with somewhat different results.¹⁹ Table 1 provides a simple summary of the quantitative estimates available for developing countries.

The summary of the evidence in table 1 permits a tentative conclusion that the returns to cognitive skills may be even larger in developing countries than in developed countries. This of course would be consistent with the range of estimates for returns to quantity of schooling (e.g., Psacharopoulos 1994 and Psacharopoulos and Patrinos 2004), which are frequently interpreted as indicating diminishing marginal returns to schooling. (These estimated effects reflect the increase in log earnings associated with a one standard deviation increase in measured tests; for small changes in test scores, this estimate is approximately the proportionate increase in earnings.)

There are some reasons for caution in interpreting the precise magnitude of estimates. First, the estimates appear to be quite sensitive to the estimation methodology itself. Both within individual studies and across studies using the same basic data, the results are quite sensitive to the techniques employed in uncovering the fundamental parameter for cognitive skills.²⁰ Second, the evidence on variations within developing countries is not entirely clear. For example, Jolliffe (1998) finds little impact of skills on farm income, while Behrman, David R. Ross, and Richard Sabot (2008) suggest an equivalence across sectors at least on theoretical grounds.

Nonetheless, the overall summary is that the available estimates of the impact of cognitive skills on outcomes suggest strong economic returns within developing countries. The substantial magnitude of the typical estimates indicates that educational quality concerns are very real for developing countries and that this aspect of schools simply cannot be ignored.

Evidence also suggests that cognitive skills are directly related to school attainment. In Brazil, a country plagued by high rates of grade repetition and ultimate school dropouts, Ralph W. Harbison and Hanushek (1992) show that higher cognitive skills in primary school lead to lower repetition rates. Further, Hanushek, Victor Lavy, and Kohtaro Hitomi (2008) find that lower quality schools, measured by lower value-added to cognitive achievement, lead to higher dropout rates in Egyptian primary schools. Thus, as found for developed countries, the full economic impact of higher educational quality comes in part through greater school attainment.

This complementarity of school quality and attainment also means that actions that actually improve quality of schools will yield a bonus in terms of meeting goals for attainment. Conversely, simply attempting to expand access and attainment, say through starting a large number of low quality schools, will be self-defeating to the extent that there is a direct reaction to the low quality that affects the actual attainment results.

3.4 *Evidence from the International Adult Literacy Survey*

The preceding analyses in developed countries rely largely on panel data that follow individuals from school into the labor market. The alternative approach as found in the International Adult Literacy Survey (IALS) is to test a sample of adults and then to relate

¹⁹ Unlike in much of the work in developed countries, these studies collected both earnings information and cognitive skills data at the same time and did not rely on longitudinal data collections.

²⁰ The sensitivity to estimation approach is not always the case; see, for example, Dean Jolliffe (1998). A critique and interpretation of the alternative approaches within a number of these studies can be found in Glewwe (2002).

TABLE 1
SUMMARY OF ESTIMATED RETURNS TO A STANDARD DEVIATION INCREASE IN COGNITIVE SKILLS

Country	Study	Estimated Effect ^a	Notes
Ghana	Glewwe (1996)	0.21**–0.3** (government) 0.14–0.17 (private)	Alternative estimation approaches yield some differences; math effects shown generally more important than reading effects, and all hold even with Raven's test for ability.
Ghana	Jolliffe (1998)	0.05–0.07*	Household income related to average math score with relatively small variation by estimation approach; effect is only observed with off-farm income, and on-farm income is not significantly related to cognitive skills.
Ghana	Vijverberg (1999)	?	Income estimates for math and reading with nonfarm self-employment; highly variable estimates (including both positive and negative effects) but effects not generally statistically significant.
Kenya	Boissiere, Knight, and Sabot (1985); Knight and Sabot (1990)	0.19**–0.22**	Total sample estimates: small variation by primary and secondary school leavers.
Morocco	Angrist and Lavy (1997)	?	Cannot convert to standardized scores because use indexes of performance; French writing skills appear most important for earnings, but results depend on estimation approach.
Pakistan	Alderman, Behrman, Ross, and Sabot (1996)	0.12–0.28*	Variation by alternative approaches and by controls for ability and health; larger and more significant without ability and health controls.
Pakistan	Behrman, Ross, and Sabot (2008)	0.25	Estimates of structural model with combined scores for cognitive skill; significant effects of combined math and reading scores which are instrumented by school inputs
South Africa	Moll (1998)	0.34**–0.48**	Depending on estimation method, varying impact of computation; comprehension (not shown) generally insignificant.
Tanzania	Boissiere, Knight, and Sabot (1985); Knight and Sabot (1990)	0.07–0.13*	Total sample estimates: smaller for primary than secondary school leavers.

Notes: * Significant at 0.05 level;

** Significant at 0.01 level.

^a Estimates indicate proportional increase in wages from a one standard deviation increase in measured test scores.

these measures to labor market experiences.²¹ An advantage of this data collection approach is that it provides information about the labor market experiences across a broader range of age and labor market experience.²²

Consistent data on basic skills of literacy and numeracy for a representative sample of the population aged fifteen to sixty-five were collected for a sample of countries between 1994 and 1998. The analysis here combines the different IALS scores on skills into a single measure of literacy and numeracy (referred to simply as literacy scores). These data permit direct comparisons of the relative importance of school attainment and cognitive skills across countries, although the bias toward developed economies remains. Hanushek and Zhang (2008) estimate returns to school attainment and to literacy scores for the thirteen countries where continuous measures of individual earnings are available. Their samples include full-time workers between twenty-six and sixty-five years of age. The dependent variable is the logarithm of annual earnings from employment, and control variables are gender, potential experience and its square, and an indicator for living in rural area.

Figures 2 and 3 provide the relevant summary information on the returns to cognitive skills, estimated in a model that jointly includes school attainment and literacy scores, and on the returns to school attainment.²³

²¹ This design was subsequently repeated in 2003 with the Adult Literacy and Lifeskills Survey (ALL), but only six countries participated and the data were unavailable for this study. The work in developing countries is also more likely to rely upon a single cross section of workers who are tested contemporaneously.

²² This approach does also present some complications, because the individuals of different ages have both different adult learning experiences and different times of attending school of possibly different quality. Hanushek and Zhang (2008) consider these alternatives, but they do not change the qualitative results about the impact of cognitive skills that are presented here.

²³ An element of the analysis in Hanushek and Zhang (2008) is adjusting the years of schooling obtained in dif-

ferent time periods to be equivalent in quality terms. This procedure involves equating the marginal impact of a year of schooling on literacy scores across time (after allowing for other influences on literacy scores). All references to school attainment here refer to their quality-adjusted school attainment.

As in the prior analyses, both school attainment and cognitive skills are seen to enter into the determination of individual incomes. With the exception of Poland, literacy scores have a consistent positive impact on earnings (figure 2). The (unweighted) average of the impact of literacy scores is 0.093, only slightly less than found previously for the U.S. studies. The United States is noticeably higher than other countries and the previous U.S. studies, perhaps reflecting that these earnings are obtained across the entire work life.²⁴ The average excluding the United States is still 0.08. Again, the similarity to the prior estimates of the return to cognitive skills, coming from very different sampling schemes in different economic markets, lends more support to the significance of cognitive skills as a consistent measure of human capital.

The estimated impact of school attainment across the thirteen countries is 0.059 after adjusting the Mincer returns for the literacy scores and down from 0.071 when cognitive skills are not considered. As noted in section 2, however, these estimates are difficult to interpret because of the potential role of omitted variables in determining unmeasured cognitive and noncognitive skills.

More interestingly, Hanushek and Zhang (2008) can estimate a Mincer earnings functions along the lines of equation (4) where the measured literacy scores are excluded but the model is augmented by measures of families,

²⁴ The previous discussion of the analysis by Altonji and Pierret (2001) can reconcile the difference in quantitative magnitudes of the impact of cognitive skills on U.S. earnings. Hanushek and Zhang (2008) find that the impact of literacy scores rises from that for the youngest workers, consistent with Altonji and Pierret. They do not, however, find support for this statistical discrimination hypothesis in the remaining twelve countries.

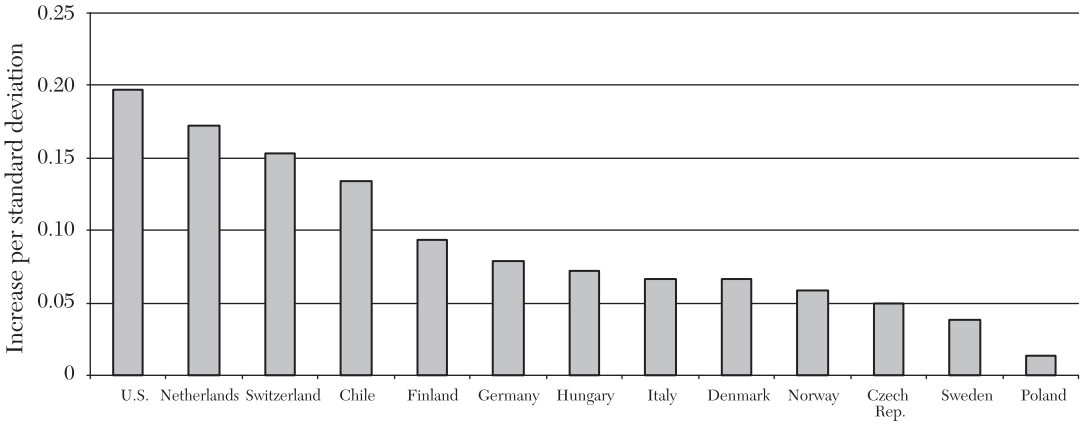


Figure 2. Returns to Cognitive Skills, International Adult Literacy Survey

Source: Hanushek and Zhang (2008).

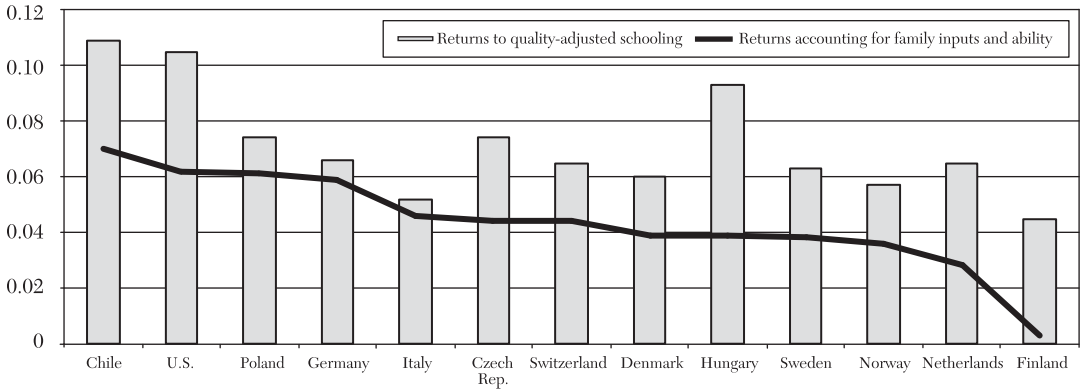


Figure 3. Impact of Controlling for Nonschool Inputs on the Estimated Returns to School Attainment, International Adult Literacy Survey

Source: Hanushek and Zhang (2008).

school quality, and ability. This permits direct estimation of the impact of school attainment on wages (conditional on the adequate modeling of the factors in equation (2)). As seen from figure 3, this adjustment to the estimated returns to schooling is more significant than just incorporating literacy scores in the model. From this figure, it is apparent that the average returns fall significantly (from 0.071 to 0.044) while the variation across countries is also lessened considerably. These adjustments are also more significant than is typical in the literature concerned with the estimation the returns to schooling (Card 1999).

The literacy tests in IALS are designed to measure quite basic skills only, and yet the differences are strongly associated with higher earnings.²⁵ These results, from a broad age spectrum across a number of countries, reinforce the importance of cognitive skills.

The sample of countries for the IALS unfortunately contains just one developing country—Chile. Nonetheless, it is suggestive that the returns both to quantity of schooling and cognitive skills exceed those found across the countries with the exception of the United States. In the three transition economies (Czech Republic, Hungary, and Poland), the returns to school attainment are also near the top of the sample, but the returns to cognitive skills are noticeably lower—perhaps reflecting institutional aspects of their labor markets.

3.5 *Causality*

For policy purposes, we are interested in a rather simple question: Would changing

an individual's cognitive skills yield earnings changes similar to those estimated in the various models? The experiment we have in mind is randomly introducing a different level of cognitive skills across a group of individuals and then observing subsequent labor market outcomes. In the case of estimation of the returns to school attainment, extensive but highly focused research has delved into these causality questions (Card 1999). As sketched in section 2, however, more general issues such as systematic variations in school quality or other sources of educational outcomes and skills have not been important in these analyses. These latter issues are the motivation for our work and the reason for our concentration on cognitive skills as a direct measure of human capital.

With cognitive skills, no similar literature on causality questions exists, but the potential problems are considerably different. Most of the cognitive skills tests used in the developed country studies, with the exception of the IALS-type sampling, are given at a date before the labor market experiences—eliminating the reverse causation possibility that higher income leads individuals to do things that raise their test scores.²⁶ Nevertheless, as was developed in section 2, this fact alone does not solve all of the interpretative issues. Two other factors threaten the interpretation of the estimated effects of cognitive skills: measurement error in tests and other correlated but omitted influences on earnings.

As is well known, test scores inherently have errors in measuring the underlying cognitive domains that are being tested. A

²⁵ It should be noted, however, that results from different tests, even when described as measuring different parts of the distribution of cognitive skills, tend to be highly correlated—particularly at the country level. Hanushek and Zhang (2008) correlate the literacy test results from IALS (identified as measuring basic skills) with the higher order math test results from the Third International Mathematics and Science Study (TIMSS) for comparable age groups in 1995 and find a

simple correlation of 0.73. This consistency suggests that the available assessments of cognitive skills may capture a wider range of knowledge and skills than would be suggested by the descriptions of the individual tests.

²⁶ The IALS sampling raises the concern that tests change with age, because of continual learning or simple age depreciation of skills and knowledge. An investigation of this by Hanushek and Zhang (2008) suggests that these are not large concerns in the estimation of the earnings functions.

portion of this is simply that individuals will obtain somewhat different scores if tested again with the same test instrument or with a different instrument designed to measure the same concepts. This type of error is a characteristic of the measurement technology and, in these specific applications, is likely to lead to a standard downward bias in the estimated impact of cognitive skills. A second issue is the specificity of the individual tests employed across the underlying research; that is, most work relies on specific subject matter tests at a given level of difficulty. Again, this is likely to be present quite generally in the various empirical applications. Its impact on the estimates is less clear, because it will depend on the structure of specific tests. On the other hand, because general cognitive skills tests for one subject tend to be very highly correlated with the scores in other subjects for individuals, this problem may not be overly important. Finally, because individual skills may change between the time of testing and the period of observed earnings, additional error may enter, but its implications are unclear in the abstract.

More important concerns come from other omitted factors that might independently influence earnings but be correlated with cognitive skills. One candidate, explored early by Bowles and Gintis (1976) and Bowles, Gintis, and Osborne (2001) and extended recently by Heckman, Stixrud, and Urzua (2006), is noncognitive skills (see also Cunha et al. 2006). The Heckman, Stixrud, and Urzua (2006) analysis explores the impact of various measures of noncognitive skills (indices of perceived self-worth and of one's control over own life) within standard earnings determination models and finds that both cognitive and noncognitive skills influence labor market outcomes. It is less clear, however, how omission of these factors might bias the estimates of the impacts of cognitive skills considered here.

The implicit inclusion of the correlated portion of the different skills does not lead *per se* to large problems as a proxy for overall labor market skills. It is a more significant problem if we subsequently consider, say, school policies that might operate on just cognitive skills and not also on the noncognitive skills.

As is generally the case, the analyses considered here cannot rule out a variety of factors that might bias the estimates and jeopardize the interpretation. Nonetheless, we return to one simple finding: Under a wide range of different labor market conditions, modeling approaches, and samples of individuals, cognitive skills are directly related to individual earnings and, moreover, there is a consistency even in the point estimates.

If we take these estimates as indicating a causal relationship, the most important issue for policy purposes is the source of any test score differences. It is natural to believe that schools have an influence on tests, but clearly other factors also enter. The extensive investigations of the determinants of achievement differences indicate that parents, peers, neighborhoods, and other factors enter along with school factors in determining achievement (see Hanushek 2002). Thus, most importantly, it is inappropriate to interpret test scores as simply reflecting school quality or school policy. In particular, if we can find approaches that increase skills reliably—whether school based or not, the available evidence strongly indicates that individual earnings and productivity will also increase.

The other side of this issue is also important, however. Using just quantity of schooling in the earnings analyses assumes that formal schooling is the only source of skill development. But, if a variety of other inputs such as families or peers is also important in the formation of human capital, simple years of schooling is subject to this additional source of omitted variables bias.

3.6 *Income Distribution*

One implication of the impact of cognitive skills on individual earnings is that the distribution of those skills in the economy will have a direct effect on the distribution of income. Cognitive skills by themselves do not of course determine the full distribution, because other factors such as labor market institutions, taxes, and the like enter. But the importance of skills is becoming increasingly evident.

Very suggestive evidence on the impact of skills on the income distribution comes from Stephen Nickell (2004). Nickell, using the IALS data, considers how differences in the distribution of incomes across countries are affected by the distribution of skills and by institutional factors including unionization and minimum wages. While union coverage is statistically significant, he concludes that “the bulk of the variation in earnings dispersion is generated by skill dispersion” (p. C11).²⁷

The impact of the skill distribution across countries is shown dramatically in figure 4, which is derived from a comparison of the dispersion of wages and the dispersion of prose literacy scores (each measured as the ratio of the ninetieth to the tenth percentile). The tight pattern around the regression line reflects a simple correlation of 0.85 (which is not affected by including the other institutional factors).

Other studies have also concluded that skills have an increasing impact on the distribution of income (e.g., Chinhui Juhn, Murphy, and Brooks Pierce 1993). In the United States, the distribution of incomes within schooling groups has been rising (Levy and Murnane 1992), i.e., holding constant schooling attainment, the income distribution has become more dispersed in reflection of growing rewards to individual skills.

Again, these studies do not attempt to describe the causal structure, and it would be inappropriate to attribute the variance in earnings simply to differences in the quantity or quality of schooling. Nonetheless, to the extent that these contribute to variations in cognitive skills, it is fair to conclude that policies aimed at improving school quality (and educational outcomes) will affect the income distribution.

4. *Quantity of Schooling and Economic Growth*

Given the microeconomic evidence of the productivity-enhancing effects of education and skills, it is natural to extend the view to the macroeconomic perspective of long-run economic growth of countries. Our approach to the education–growth relationship is the same as that to the education–earnings relationship. We pursue a simple model that aggregate human capital is relevant to growth. Our analysis is designed to compare and contrast simple school attainment measures, which have been the near universal measure of human capital, with direct international assessments of cognitive skills. This section introduces the broad literature based on school attainment; the next section provides the contrast with the use of cognitive skills measures.

From a theoretical viewpoint, there are at least three mechanisms through which education may affect economic growth. First, just as in the micro perspective, education increases the human capital inherent in the labor force, which increases labor productivity and thus transitional growth towards a higher equilibrium level of output (as in augmented neoclassical growth theories, cf. N. Gregory Mankiw, David Romer, and David N. Weil 1992). Second, education may increase the innovative capacity of the economy, and the new knowledge on new technologies, products and processes promotes growth (as in theories of endogenous

²⁷ Jose De Gregorio and Jong-Wha Lee (2002) find a (somewhat weaker) positive association between inequality in years of schooling and income inequality.

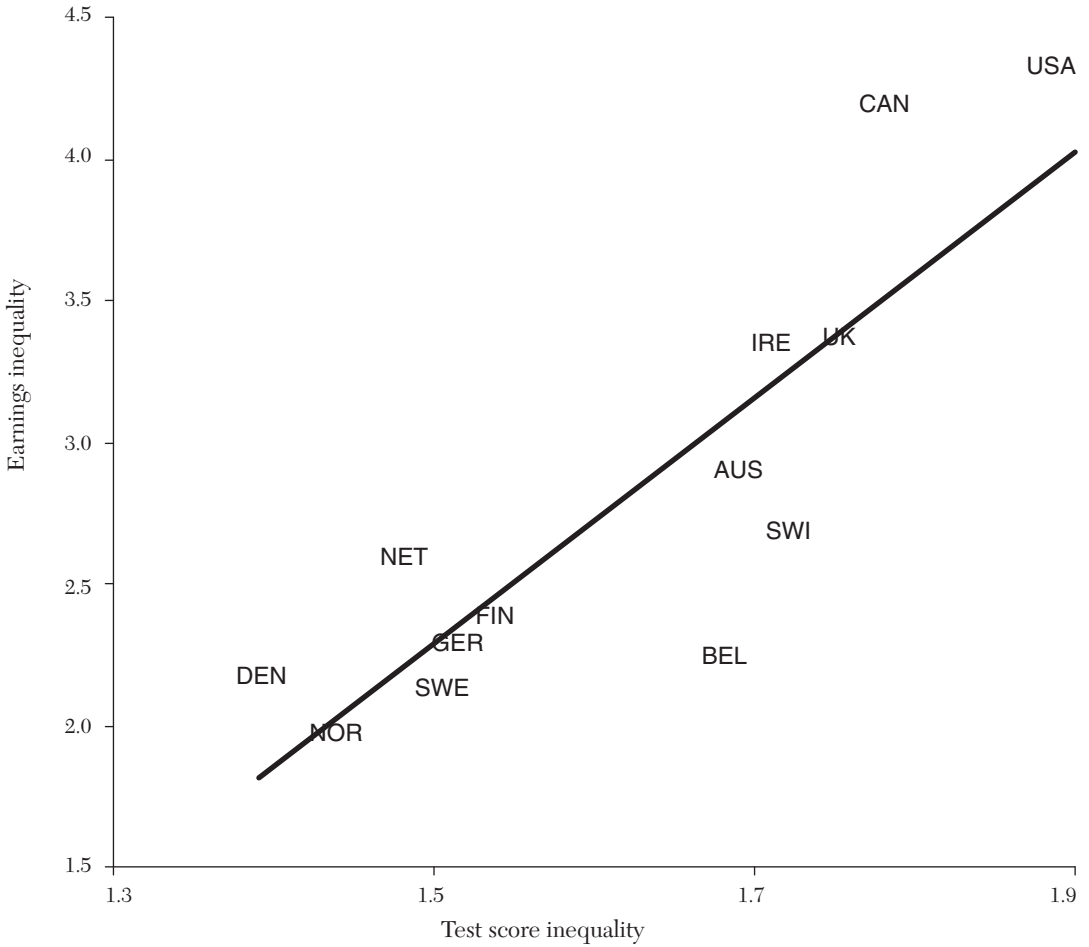


Figure 4. Inequality of Test Scores and Earnings

Notes: Measure of inequality is the ratio of ninth decile to the first decile in both cases; test performance refers to prose literacy in the International Adult Literacy Survey.

Source: Based on Nickell (2004).

growth, cf., e.g., Robert E. Lucas 1988, Paul M. Romer 1990a, Philippe Aghion and Peter Howitt 1998). Third, education may facilitate the diffusion and transmission of knowledge needed to understand and process new information and to implement successfully new technologies devised by others, which again promotes economic growth (cf., e.g., Richard R. Nelson and

Edmund Phelps 1966, Jess Benhabib and Mark M. Spiegel 2005).

4.1 *Results of Initial Cross-Country Growth Regressions*

Just as in the literature on microeconomic returns to education, the majority of the macroeconomic literature on economic growth that tries to test these predictions

employs the quantitative measure of years of schooling, now averaged across the labor force.²⁸ Early studies used adult literacy rates (e.g., Costas Azariadis and Allan Drazen 1990, Romer 1990b) or school enrollment ratios (e.g., Robert J. Barro 1991, Mankiw, Romer, and Weil 1992, Ross Levine and David Renelt 1992) as proxies for the human capital of an economy. (See Woessmann 2003 for a survey of measurement and specification issues from early growth accounting to current cross-country growth regressions.) These were followed by attempts to measure average years of schooling based on perpetual inventory methods (cf. Frederic F. Louat, Dean T. Jamison, and Lawrence J. Lau 1991, Vikram Nehru, Eric Swanson, and Ashutosh Dubey 1995). An important innovation by Barro and Lee (1993, 2001) was the development of internationally comparable data on average years of schooling for a large sample of countries and years, based on a combination of census or survey data on educational attainment wherever possible and using literacy and enrollment data to fill gaps in the census data.

But, as discussed, using average years of schooling as the education measure implicitly assumes that a year of schooling delivers the same increase in knowledge and skills regardless of the education system. For example, a year of schooling in Papua New Guinea is assumed to create the same increase in productive human capital as a year of schooling in Japan. Additionally, this measure assumes that formal schooling is the primary (sole) source of education and, again, that variations in nonschool factors have a negligible effect on education outcomes.²⁹ This neglect

of cross-country differences in the quality of education and in the strength of family, health, and other influences is probably the major drawback of such a quantitative measure of schooling, and we come back to this issue in great detail below.

The standard method to estimate the effect of education on economic growth is to estimate cross-country growth regressions where countries' average annual growth in gross domestic product (GDP) per capita over several decades is expressed as a function of measures of schooling and a set of other variables deemed to be important for economic growth. Following the seminal contributions by Barro (1991, 1997) and Mankiw, Romer, and Weil (1992),³⁰ a vast early literature of cross-country growth regressions has tended to find a significant positive association between quantitative measures of schooling and economic growth (for extensive reviews of the literature, see, e.g., Topel 1999, Temple 2001, Krueger and Lindahl 2001, Barbara Sianesi and John Van Reenen 2003). To give an idea of the robustness of this association, in the recent extensive robustness analysis by Xavier Sala-i-Martin, Gernot Doppelhofer, and Ronald I. Miller (2004) of sixty-seven explanatory variables in growth regressions on a sample of eighty-eight countries, primary schooling turns out to be the most robust influence factor (after an East Asian dummy) on growth in GDP per capita in 1960–96.

A closely related literature weights years of schooling by parameters from microeconomic Mincer earnings equations (see section 3.1 above) to construct a measure of the stock of human capital, which is then used in growth

²⁸ More precisely, the most commonly used measure is average years of schooling in the working-age population, usually defined as the population aged fifteen years and over, instead of the actual labor force.

²⁹ If the omitted variables are uncorrelated with school attainment—an unlikely event—no bias would be introduced.

³⁰ Jonathan Temple and Woessmann (2006) show that the significantly positive effect of education that Mankiw, Romer, and Weil (1992) find does not depend on their often criticized use of an education flow measure based on enrollment rates, but can be replicated when using years of schooling as a measure of the level of human capital in their model.

accounting and development accounting exercises. These use a given macroeconomic production function together with parameter estimates from other research to calculate the share of cross-country differences in growth or levels of income which can be accounted for by cross-country differences in education (see Peter J. Klenow and Andres Rodriguez-Clare 1997 and Robert E. Hall and Charles I. Jones 1999 for examples).

Because this literature has been extensively reviewed elsewhere (see references above), we focus just on a few of the most important issues that emerge in the literature with respect to the influence of human capital.

4.2 *More Recent Evidence on the Effects of Levels of and Growth in Years of Schooling*

To frame the discussion of cognitive skills that follows, we produce our own estimates of common models that incorporate school attainment. These estimates use improved school attainment data and extend the observation period for economic growth through 2000.

We use an extended version of the education data by Daniel Cohen and Marcelo Soto (2007), representing the average years of schooling of the population aged fifteen to sixty-four.³¹ As discussed below, one line of investigation has been the impact of mis-measurement of the quantity of education on growth; the Cohen and Soto (2007) data improve upon the original quantity data by Barro and Lee (1993, 2001). Data on

real GDP per capita in 1960–2000 comes from the latest update (version 6.1) of the Penn World Tables by Alan Heston, Robert Summers, and Bettina Aten (2002).³² Figure 5 plots the average annual rate of growth in GDP per capita over the forty-year period against years of schooling at the beginning of the period for a sample of ninety-two countries. Both growth and education are expressed conditional on the initial level of output, to account for the significant conditional convergence effect.³³

The regression results depicted by figure 5 imply that each year of schooling is statistically significantly associated with a long-run growth rate that is 0.58 percentage points higher. The association is somewhat lower (at 0.32) but still significant when regional dummies are added to the regression. The positive association is substantially larger in the sample of non-OECD countries (at 0.56) than in the sample of OECD countries (at 0.26). Alternatively, results based on the samples of countries below the median of initial output and above the median are in line with the pattern of larger returns to education in developing countries.

However, after controlling for the institutional differences reflected in the openness of each country and in the security of property rights, the association with school attainment

³² Jan Hanousek, Dana Hajkova, and Randall K. Filer (2004) argue that growth rates are better calculated using the IMF International Finance Statistics. Our results in this paper are not significantly affected by using these alternative growth measures.

³³ Added-variable plots show the association between two variables after the influences of other control variables are taken out. Thus, both of the two variables are first regressed on the other controls (in this case, initial-GDP). Only the residual of these regressions, which is the part of the variation in the two variables which cannot be accounted for by the controls, is used in the graph. In so doing, the graph makes sure that the depicted association between the two variables is not driven by the control variables. The procedure is numerically equivalent to including the other controls in a multivariate regression of the dependent variable (growth) on the independent variable under consideration in the graph.

³¹ Eliot A. Jamison, Jamison, and Hanushek (2007) supplement the Cohen and Soto attainment series with imputed data based on the Barro and Lee series in order to expand the number of countries available for the growth analysis. This approach adds eight countries to the growth analysis. For details of the extension along with the basic data on educational attainment, see Jamison, Jamison, and Hanushek (2006).

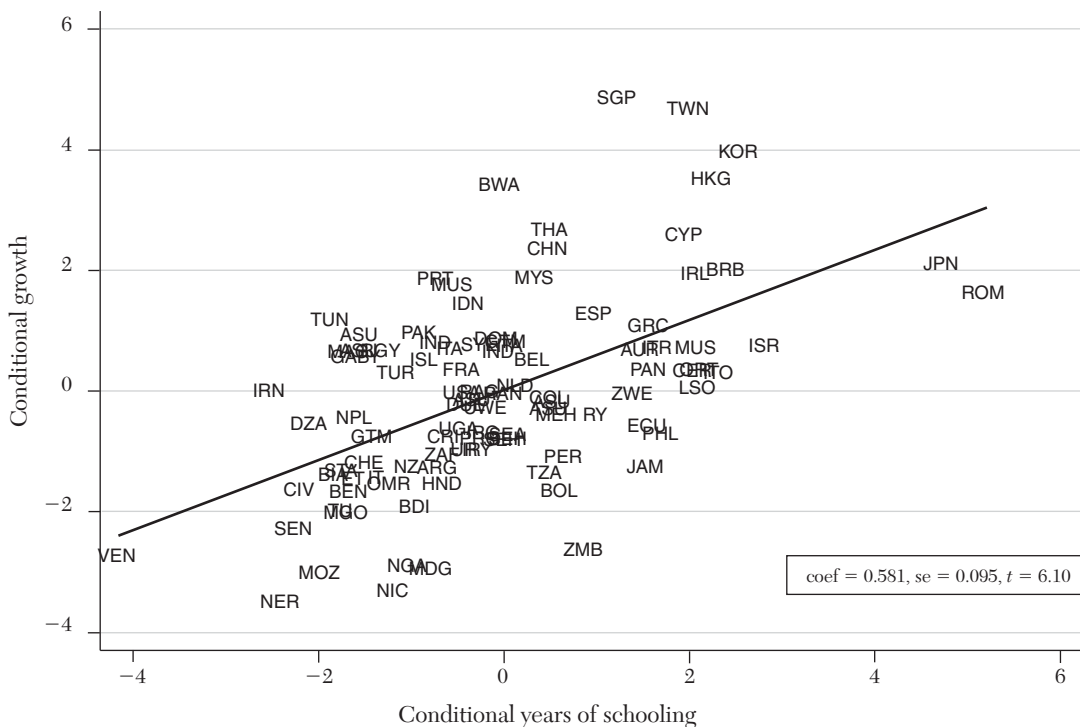


Figure 5. Added-variable Plot of Growth and Years of Schooling without Test Score Controls

Notes: Added-variable plot of a regression of the average annual rate of growth (in percent) of real GDP per capita in 1960–2000 on average years of schooling in 1960 and the initial level of real GDP per capita in 1960. Own calculations.

becomes substantially smaller and turns insignificant. It is close to zero when the total fertility rate is controlled for. Thus, while there is a clear positive association between years of schooling and growth in the latest available data, it is also somewhat sensitive to model specification.

A considerable controversy has emerged in the literature about whether it is the *level* of years of schooling (as would be predicted by several models of endogenous growth) or the *change* in years of schooling (as would be predicted in basic neoclassical frameworks) which is the more important driver of economic growth. The early evidence, such as in

Benhabib and Spiegel (1994) and discussed in Barro and Sala-i-Martin (2004), found a positive effect of educational levels, but not of changes in education. However, Temple (1999) shows that in the latter case, an existing positive association was hidden by a few unrepresentative outlying observations. Considerable evidence has also emerged that there was substantial measurement error in the education data (cf. Krueger and Lindahl 2001), and it is well known that measurement error affects results based on changes in variables even more than results based on their levels. Subsequent evidence suggests that both levels of and changes in years of

schooling may show a positive association with growth (cf. Norman Gemmell 1996, Topel 1999, Krueger and Lindahl 2001).

More recently, two studies have tried to overcome some problems of mismeasurement in the early Barro–Lee data on years of schooling: Angel de la Fuente and Rafael Doménech (2001, 2006) for the sample of OECD countries and Cohen and Soto (2007) for a broader sample of countries (and the data that we use here). Both studies find robust evidence of a positive association between changes in education and economic growth. Even more recently, Ciccone and Elias Papaioannou (2005) find strong support for both the human capital level and the human capital accumulation effects using cross-country industry-level data that allow them to control for country-specific and industry-specific effects.

When we add the change in years of schooling over 1960–2000 to the specification depicted in figure 5 and similar specifications, it never turns significant with the sole exception of the sample of twenty-three OECD countries, and there it is sensitive to the inclusion of Korea. (Because of the possibly substantial amount of mismeasurement in the education data, though, the results on the first-differenced data on changes in education may well suffer).

Thus, while recent research tends to find a positive effect of schooling quantity on economic growth, it seems beyond the scope of current data to draw strong conclusions about the relative importance of different mechanisms by which schooling quantity may affect economic growth. However, several recent studies suggest that education is important both as an investment in human capital and in facilitating research and development and the diffusion of technologies. With respect to the relative importance of the latter two mechanisms, Jerome Vandenbussche, Aghion, and Costas Meghir (2006) suggest that innovation is more important than imi-

tation for countries close to the technological frontier. As a consequence, the composition of human capital between basic and higher education may be important, with initial levels of education being more important for imitation and higher education being more important for innovation. Vandenbussche, Aghion, and Meghir (2006) provide evidence from a panel of OECD countries in line with this argument, which—when applied to developing countries—might suggest that a focus on basic skills seems warranted for developing countries. We will come back to the issue of the relative importance of basic versus advanced skills in more detail in section 5.5 below.

Two more skeptical studies raise noteworthy caveats, and we will return to each of them below. First, Mark Bilal and Klenow (2000) raise the issue of causality, suggesting that reverse causation running from higher economic growth to additional education may be at least as important as the causal effect of education on growth in the cross-country association. We address the issue in cross-country regressions in section 5.2 below. Second, one of the conclusions that Lant Pritchett (2001, 2006) draws from the fragility of the evidence linking changes in education to economic growth is that it is important for economic growth to get other things right as well, in particular the institutional framework of the economy. We address this issue in section 5.6 below.

5. *Cognitive Skills and Economic Growth*

5.1 *A Review of the Basic Results*

The most important caveat with the literature on education and growth reviewed in the preceding section, though, is that it sticks to years of schooling as its measure of human capital at the neglect of qualitative differences in ensuing knowledge. As discussed, this neglect probably misses the core of what education is all about. And

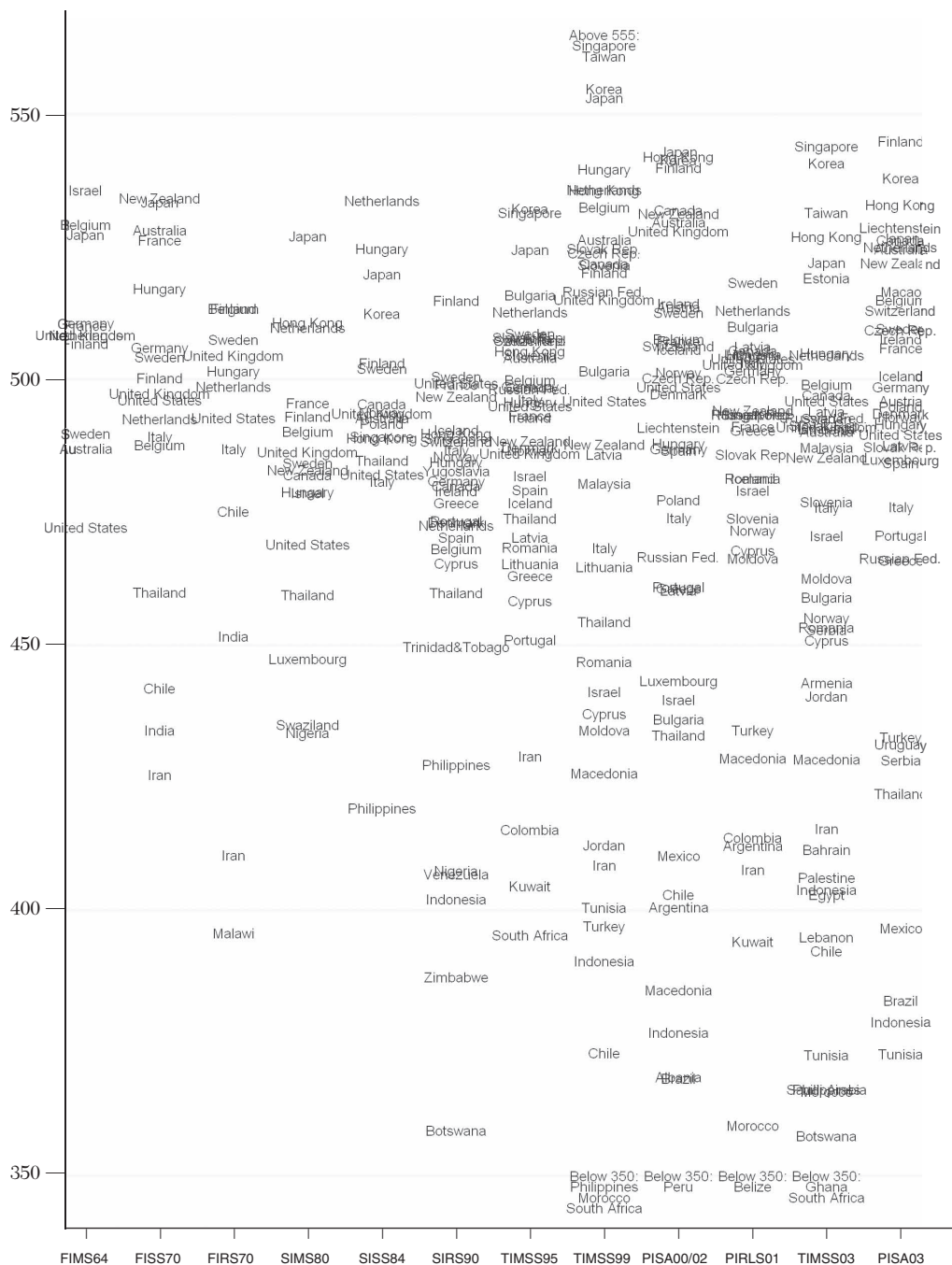
this neglect is clearly more severe in cross-country comparisons than in analyses within countries (such as the prior work on earnings determination). Rather than just counting students' average years of schooling, it seems crucial to focus on how much students have learned while in school when estimating the effect of education on economic growth.

From the mid-1960s to today, international agencies have conducted many international tests of students' performance in cognitive skills such as mathematics and science. The different tests contain both "academic" questions related to the school curricula as well as "life skill" questions requiring practical applications to real-world phenomena. Employing a rescaling method that makes performance at different international tests comparable, we can use performance on these standardized tests as a measure of cognitive skills. (See the appendix to this paper for details on testing and rescaling of the data.) Figure 6 presents average student performance on twelve testing occasions, combining results from a total of thirty-six separate test observations at different age levels and in different subjects, on the transformed scale which maps performance on each test to the scale of the recent PISA international test. This scale has a mean of 500 and a standard deviation of 100 among the OECD countries in PISA. To facilitate comparisons, the within-country standard deviation of PISA test scores ranges between 80 and 108 in mathematics in the OECD countries; the U.S. value is 98. As is obvious from the figure, the developing countries that ever participated in one of the tests perform dramatically lower than any country in the group of OECD countries. The variation in cognitive skills that exists among OECD countries is already substantial, but the magnitude of the difference to developing countries in the average amount of learning that has taken place after a given number of years of schooling dwarfs any within-OECD difference.

The precise scaling on the transformed metric is of course subject to considerable noise, in particular for the early tests and for countries performing far below the international mean. The tests are usually not developed to provide reliable estimates of performance in the tails of the achievement distribution, which would be relevant for very poorly performing countries. However, the rough pattern of overall performance should not be severely affected by the rescaling. For example, the average performance level of Peruvian students on PISA 2002 where no rescaling is involved is 292 in math, 333 in science and 327 in reading.

Over the past ten years, empirical growth research demonstrates that consideration of cognitive skills alters the assessment of the role of education and knowledge in the process of economic development dramatically. When using the data from the international student achievement tests through 1991 to build a measure of labor force quality, Hanushek and Dennis D. Kimko (2000)—first released as Hanushek and Dongwook Kim (1995)—find a statistically and economically significant positive effect of the cognitive skills on economic growth in 1960–90 that dwarfs the association between quantity of education and growth. Thus, even more than in the case of education and individual earnings, ignoring differences in cognitive skills very significantly misses the true importance of education for economic growth. Their estimates suggest that one country-level standard deviation higher test performance would yield around one percentage point higher annual growth rates. (The country-level standard deviation is equivalent to forty-seven test-score points in PISA 2000 mathematics, the scale used in figure 6.)

Their estimate stems from a statistical model that relates annual growth rates of real GDP per capita to the measure of cognitive skills, years of schooling, the initial level



Source: Hanushek and Woessmann (forthcoming), based on the different tests; see appendix for details.

of income, and a wide variety of other control variables (including in different specifications the population growth rates, political measures, openness of the economies, and the like). Hanushek and Kimko (2000) find that adding the international achievement test measures to a base specification including only initial income and educational quantity boosts the variance in GDP per capita among the thirty-one countries in their sample that can be explained by the model from 33 to 73 percent. The effect of years of schooling is greatly reduced by including cognitive skills, leaving it mostly insignificant. At the same time, adding the other factors leaves the effects of cognitive skills basically unchanged.

Several studies have since found very similar results. Another early contribution, by Doo Won Lee and Tong Hun Lee (1995), found an effect size similar to Hanushek and Kimko (2000) using data from the 1970–71 First International Science Study on the participating seventeen countries, also leaving quantitative measures of education with no significant effect on growth. Using a more encompassing set of international tests, Barro (2001) also finds that, while both the quantity of schooling and test scores matter for economic growth, measured cognitive skills are much more important. Employing the measure of cognitive skills developed by Hanushek and Kimko (2000) in a development accounting framework, Woessmann (2002, 2003) finds that the share of cross-country variation in levels of economic development attributable to international differences in human capital rises dramatically when cognitive skills are taken into account. Building on E. Gundlach, D. Rudman, and Woessmann (2002), this work analyzes output per worker in 132 countries in 1990. The variation that can be attributed to international differences in human capital rises from 21 percent to 45 percent once the interna-

tional achievement measures are taken into account, and to over 60 percent in samples with reasonable data quality.

Extensions of the measure of Hanushek and Kimko (2000) and its imputation in Woessmann (2003) are also used in the cross-country growth regressions by Barry P. Bosworth and Susan M. Collins (2003) and in the cross-country industry-level analysis by Ciccone and Papaioannou (2005). Both also find that measured cognitive skills strongly dominate any effect of educational quantity on growth.³⁴ Serge Coulombe, Jean-François Tremblay, and Sylvie Marchand (2004) and Coulombe and Tremblay (2006) use test-score data from the International Adult Literacy Survey (see section 3.4 above) in a panel of fourteen OECD countries, confirming the result that the test-score measure outperforms quantitative measures of education.

Jamison, Jamison, and Hanushek (2007) further extend the Hanushek and Kimko (2000) analysis by using the mathematics component of the transformed and extended tests shown in figure 6, replicating and strengthening the previous results by using test data from a larger number of countries, controlling for a larger number of potentially confounding variables, and extending the time period of the analysis. Using the panel structure of their growth data, they suggest that cognitive skills seem to improve income levels mainly through speeding up technological progress, rather than shifting the level of the production function or increasing the impact of an additional year of schooling.

In sum, the existing evidence suggests that what students know as depicted in tests of

³⁴ Bosworth and Collins (2003) cannot distinguish the effect of cognitive skills from the effect of quality of government institutions. The analysis in section 5.6 below shows, however, that they can be separated when we use our new measure of cognitive skills that also extends the country sample by several additional data points on international tests scores.

cognitive skills is substantially more important for economic growth than the mere quantity of schooling.

5.2 *Issues of Endogeneity*

Growth modeling is naturally subject to a common concern: Do the identified factors represent truly causal influences or mere associations that will not affect growth if altered by policy? The basic concerns were set out in section 2.

Causality is difficult to establish conclusively within the aggregate growth context, but it is possible to rule out the most important alternative hypotheses about the nature of the cognitive skills–growth relationship. Many concerns about the nature of the relationship of cognitive skills and growth are addressed in detail by Hanushek and Kimko (2000). They conclude that causation concerns are very different in the case of cognitive skills than with quantity of schooling and are much less likely to be a significant issue in interpreting the results. Because these arguments are also important for assessing our results below, we begin by describing the Hanushek and Kimko investigations. In simplest terms, by showing that the estimation is robust to major alternative specifications while also not being the result of other hypothesized mechanisms, they provide strong additional support for the validity of their central interpretation.

One common concern in analyses such as theirs (and ours here) is that schooling might not be the actual cause of growth but, in fact, may just reflect other attributes of the economy that are beneficial to growth. For example, the East Asian countries consistently score very highly on the international tests (see figure 6), and they also had extraordinarily high growth over the 1960–90 period. It may be that other aspects of these East Asian economies have driven their growth and that the statistical analysis of labor force quality simply is picking out these countries.

But in fact, even if the East Asian countries are excluded from the analysis, a strong—albeit slightly smaller—relationship is still observed between growth and test performance. This consistency of results across alternative samples suggests the basic importance of cognitive skills. Our current work, reported below, replicates this test of excluding the East Asian countries in the context of extended growth analyses and reaches similar conclusions.

Another concern is that other factors that affect growth, such as efficient market organizations, are also associated with efficient and productive schools—so that, again, the test measures might really be a proxy for other attributes of the country. To investigate this, Hanushek and Kimko concentrate on immigrants to the United States who received their education in their home countries. They find that immigrants who were schooled in countries that have higher scores on the international math and science examinations earn more in the United States. On the other hand immigrants receiving part or all of their schooling in the United States do not see any earnings advantage linked to the cognitive skills of their home country. This analysis makes allowance for any differences in school attainment, labor market experience, or being native English-language speakers. In other words, skill differences as measured by the international tests are clearly rewarded in the U.S. labor market, reinforcing the validity of the tests as a measure of individual skills and productivity (and also discounting the notion that the economic performance of these immigrants simply reflects the culture and family practices of the immigrants).

Finally, the observed relationships could simply reflect reverse causality, that is, that countries that are growing rapidly have the added resources necessary to improve their schools and that better student performance is the result of growth, not the cause of

growth. As a simple test of this, Hanushek and Kimko investigated whether the international math and science test scores were systematically related to the resources devoted to the schools in the years prior to the tests. They were not. If anything, their results suggested relatively better performance in those countries spending less on their schools. More recent work corroborates the result of no resources-skills relationship across countries (see Hanushek and Woessmann 2007).

One final issue warrants consideration: The United States has never done well on these international assessments, yet its growth rate has been very high for a long period of time. The reconciliation is that quality of the labor force is just one aspect of the economy that enters into the determination of growth. A variety of factors clearly contribute, and these factors work to overcome any deficits in quality. These other factors may also be necessary for growth. In other words, simply providing more or higher-quality schooling may yield little in the way of economic growth in the absence of other elements, such as the appropriate market, legal, and governmental institutions to support a functioning modern economy. Past experiences investing in less developed countries that lack these institutional features suggest that schooling is not necessarily itself a sufficient engine of growth (e.g., William Easterly 2001, Pritchett 2001).

We take up these issues about quality of societal institutions in detail below, because the evidence suggests that they are very important and could potentially distort the analysis of the impacts of human capital. Here, however, we briefly consider the U.S. situation, both because it sets the stage for more recent analyses and because it helps to provide some balance to the overall picture of growth.

Three other factors immediately come to mind as being important in U.S. growth and as potentially masking to detrimental effects of low school quality. First, almost certainly

the most important factor sustaining the growth of the U.S. economy is the openness and fluidity of its markets. The United States maintains generally freer labor and product markets than most countries in the world. The government generally has less regulation on firms, and trade unions are less extensive than those in many other countries. Even broader, the United States has generally less intrusion of government in the operation of the economy, including lower tax rates and minimal government production through nationalized industries. These factors encourage investment, permit the rapid development of new products and activities by firms, and allow U.S. workers to adjust to new opportunities. While identifying the precise importance of these factors is difficult, a variety of analyses suggest that such market differences could be very important explanations for differences in growth rates (see, for example, Anne O. Krueger 1974, World Bank 1993, Stephen L. Parente and Edward C. Prescott 1994, 1999).

Second, over the twentieth century, the expansion of the education system in the United States outpaced that around the world. The United States pushed to open secondary schools to all citizens (Claudia Goldin and Katz 2008). With this came also a move to expand higher education with the development of land grant universities, the G.I. bill, and direct grants and loans to students. More schooling with less learning each year still yielded more human capital than found in other nations that have less schooling but more learning in each of those years. (This advantage has, however, clearly ended as many OECD countries have expanded schools to exceed the quantity of schooling found in the United States; see Organisation for Economic Co-operation and Development 2003.)

Third, the analysis of growth rates across countries emphasizes quality of the primary and secondary schools of the United

States. It does not include any measures of the quality of U.S. colleges. By most evaluations, U.S. colleges and universities rank at the very top in the world.³⁵ A number of models of economic growth in fact emphasize the importance of scientists and engineers as a key ingredient to growth. By these views, the technically trained college students who contribute to invention and to development of new products provide a special element to the growth equation. Here, again, the United States appears to have the best programs.

5.3 *Some New Evidence*

To provide the most up-to-date picture, we extend the existing evidence in several ways. The new evidence adds additional international student achievement tests not previously available and uses the most recent data on economic growth which allow an analysis for an even longer time period (1960–2000). Furthermore, the new data extend the sample of countries with available test-score and growth information from thirty-one countries in Hanushek and Kimko (2000) to fifty countries (see the appendix to this paper for details on the data). In the subsequent sections, we will also use these data to analyze effects of the distribution of cognitive skills at the bottom and at the top on economic growth, as well as interactions between cognitive skills and the institutional infrastructure of an economy.

Our measure of cognitive skills is a simple average of the mathematics and science scores over all the international tests depicted

in figure 6.³⁶ We interpret this as a proxy for the average educational performance of the whole labor force. This measure encompasses overall cognitive skills, not just those developed in schools. Thus, whether skills are developed at home, in schools, or elsewhere, they are included in the growth analyses. As in the analyses underlying figure 5, the source of the income data is version 6.1 of the Penn World Tables (cf. Heston, Summers, and Aten 2002), and the data on years of schooling is an extended version of the Cohen and Soto (2007) data.

The basic result is reported in column 2 of table 2 and depicted graphically in figure 7 (see section 4.2 above for a brief technical description of added-variable plots). After controlling for the initial level of GDP per capita and for years of schooling, the test-score measure features a statistically significant effect on the growth in real GDP per capita in 1960–2000. According to this specification, test scores that are larger by one standard deviation (measured at the student level across all OECD countries in PISA) are associated with an average annual growth rate in GDP per capita that is two percentage points higher over the whole forty-year period. Below we discuss the quantitative size of these estimates.

When cognitive skills are added to a model that just includes initial income and years of schooling (column 1 of table 2), the share of variation in economic growth explained by the model (the adjusted R^2) jumps from 0.25 to 0.73. As in figure 5, quantity of schooling is statistically significantly related to economic

³⁵ Ranking colleges and universities is clearly difficult, but the available attempts confirm the position of U.S. research universities. In the 2007 academic rankings of the world's research universities by the Institute of Higher Education, Shanghai Jiao Tong University, the United States had seventeen of the top twenty universities and fifty-four of the top ninety-nine (see <http://ed.sjtu.edu.cn/rank/2007/ARWU2007TOP500list.htm> accessed January 12, 2008). In a 2007 professional ranking by the Ecole des mines de Paris based on graduates who were CEOs

at Global Fortune 500 countries, U.S. institutions had ten of the top twenty-two places and twenty-four of the top fifty-nine places (see <http://www.ensmp.fr/Actualites/PR/EMP-ranking.html> accessed January 12, 2008).

³⁶ Another recent set of international tests has focused on reading. We are concerned about the reliability of these measures and have not focused on them in our analysis. Nonetheless, consideration of them in addition to or instead of the math and science tests does not change our basic results.

TABLE 2
EDUCATION AS DETERMINANT OF GROWTH OF INCOME PER CAPITA, 1960–2000

	Dependent variable: average annual growth rate in GDP per capita, 1960–2000			
	(1)	(2)	(3) ^a	(4)
GDP per capita 1960	–0.379 (4.24)	–0.302 (5.54)	–0.277 (4.43)	–0.351 (6.01)
Years of schooling 1960	0.369 (3.23)	0.026 (0.34)	0.052 (0.64)	0.004 (0.05)
Test score (mean)		1.980 (9.12)	1.548 (4.96)	1.265 (4.06)
Openness				0.508 (1.39)
Protection against expropriation				0.388 (2.29)
Constant	2.785 (7.41)	–4.737 (5.54)	–3.701 (3.32)	–4.695 (5.09)
N	50	50	50	47
R ² (adj.)	0.252	0.728	0.741	0.784

Notes: *t*-statistics in parentheses.

^a Regression includes five regional dummies.

growth in a specification that does not include the measure of cognitive skills, but the association between years of schooling and growth turns insignificant and its marginal effect is reduced to close to zero once cognitive skills are included in the model (see figure 8).³⁷ In other words, school attainment has no independent effect over and above its impact on cognitive skills. The result remains the same when the measure of years of schooling refers to the average between 1960 and 2000, rather than the initial 1960 value. In the different specifications, there is evidence for conditional convergence in the sense that countries with higher initial income tend to grow more slowly over the subsequent period.

The same pattern of results is preserved when we ignore any variation between world regions—East Asia, South Asia, Latin

America, Middle East and North Africa, Sub-Saharan Africa, and the industrial countries—by including five regional dummies (column 3 of table 2). That is, even when considering just the variation that exists within each region, cognitive skills are significantly related to economic growth. Eliminating the between-region variance reduces the test-score coefficient from 1.98 to 1.55, but it remains strongly significant.

One of the most important fundamental determinants of economic growth discussed in the recent literature is the institutional framework of the economy (see section 5.6 below for details). The most common and powerful measures of the institutional framework used in empirical work are the openness of the economy to international trade and the security of

³⁷ The coefficient estimate on years of schooling in the fifty-country sample of column 1 of table 2 is somewhat smaller than the one reported for the ninety-two-country

sample reported in figure 5, corresponding to the fact discussed above that the estimate tends to be smaller in high-income countries.



Notes: Added-variable plot of a regression of the average annual rate of growth (in percent) of real GDP per capita in 1960–2000 on the initial level of real GDP per capita in 1960, average test scores on international student achievement tests, and average years of schooling in 1960. Author calculations; see table 2, column 2.



Notes: Added-variable plot of a regression of the average annual rate of growth (in percent) of real GDP per capita in 1960–2000 on the initial level of real GDP per capita in 1960, average test scores on international student achievement tests, and average years of schooling in 1960. Author calculations; see table 2, column 2.

property rights.³⁸ When we add these two institutional variables to our model, they are jointly highly significant (column 4 of table 2). But the positive effect of cognitive skills on economic growth is very robust to the inclusion of these controls, albeit somewhat reduced in magnitude to 1.26.

Other potential determinants of economic growth often discussed in the literature are fertility and geography. However, when we add the total fertility rate and common geographical proxies, such as latitude or the fraction of the land area of a country that is located within the geographic tropics, to the specification reported in column 4 of table 2, neither of these additional variables is statistically significantly associated with economic growth. Furthermore, none of the other results, in particular for cognitive skills, are qualitatively affected.

An important issue is whether the role of cognitive skills in the process of economic development differs between developing and developed countries. In table 3, we divide the sample of countries into two groups in two different ways. First, in columns 1 and 2, we subdivide the sample into OECD countries and non-OECD countries. Results are remarkably similar, with the point estimate of the effect of cognitive skills slightly larger in non-OECD countries. However, the effect of cognitive skills on economic growth does not differ significantly between the two groups of countries. The results remain qualitatively the same when openness and quality of institutions are again added as control variables.

Second, in columns 3 and 4, we subdivide the sample into countries above and below the sample median of initial GDP per capita. Again, the significant effect of cognitive skills remains robust in both subsamples. Here, the effect of test scores is considerably larger in the low-income countries, and the difference in the coefficients on test scores is statistically significant at the five percent level. Thus, if anything, the effect of cognitive skills is larger in developing countries than in developed countries. Furthermore, the robustness of the effect in the subsamples is remarkable, in particular considering the small sample sizes of the specifications reported in table 3. Similarly, the effect of cognitive skills remains robust in the two subsamples of countries above and below the median of economic growth over the considered period, with the point estimate larger in the high-growth sample.

5.4 Robustness Checks

Extensive robustness tests confirm the strong and significant relationship between cognitive skills and economic growth. Importantly, the results do not appear to be an artifact of the specific time period, set of countries, or achievement measurement decisions.

To start with, we can look at the association between school attainment and cognitive skills. The simple correlation coefficient between test scores and years of schooling is 0.64. Identification of the separate impacts of test scores and school attainment comes from divergences in the relationship

³⁸ The proxy for openness used here is the fraction of years between 1960 and 1998 that a country was classified as having an economy open to international trade, based on five factors including tariffs, quotas, exchange rate controls, export controls, and whether or not a socialist economy (cf. Jeffrey D. Sachs and Andrew M. Warner 1995). The proxy for security of property rights is an index of the protection against expropriation risk, averaged over 1985–95, from Political Risk Services (a private company which

assesses the risk that investments will be expropriated in different countries), ranging from 0 to 10 (high figures corresponding to low risk), as used by Acemoglu, Simon Johnson, and James A. Robinson (2001) and provided in John W. McArthur and Sachs (2001). This measure of the risk of confiscation and forced nationalization of property is often used as a summary variable for institutional quality, and similar data were first used in this framework by Stephen Knack and Philip Keefer (1995).

TABLE 3
EDUCATION AS DETERMINANT OF GROWTH OF INCOME PER CAPITA, 1960–2000: SUBSAMPLES

	(1)	(2)	(3)	(4)
	Developing countries ^a	OECD sample	Low-income countries ^b	High-income countries ^c
GDP per capita 1960	–0.262 (1.77)	–0.301 (5.81)	–0.063 (0.28)	–0.294 (6.38)
Years of schooling 1960	0.025 (0.20)	0.025 (0.26)	0.006 (0.05)	0.152 (1.70)
Test score (mean)	2.056 (6.10)	1.736 (4.17)	2.286 (6.98)	1.287 (5.37)
Constant	–5.139 (3.63)	–3.539 (1.96)	–6.412 (4.52)	–2.489 (2.86)
N	27	23	25	25
R ² (adj.)	0.676	0.830	0.707	0.783

Notes: Dependent variable: average annual growth rate in GDP per capita, 1960–2000. *t*-statistic in parentheses.

^a Non-OECD countries.

^b Countries below sample median of GDP per capita 1960.

^c Countries above sample median of GDP per capita 1960.

between the two, and it is useful to ensure that the results are not simply driven by patterns of measurement error or omitted factors that might underlie the divergences. To check the robustness of the estimates in this dimension, we begin with the countries which most distinguish the two measures from one another. When regressing years of schooling on test scores, among the countries with the highest years of schooling for their test-score level (the largest positive residuals) are Switzerland, the United States, South Africa, Peru, Australia, and Norway. Among the countries with the lowest years of schooling for their test-score level (the largest negative residuals) are China, Iran, Taiwan, Singapore, India, and Malaysia. The gaps between these two groups of countries are predictive of economic growth: When the sample is restricted just to the twenty countries with the largest differences between the two education measures (the ten countries with the largest positive residuals and

the ten countries with the largest negative residuals on the regression just mentioned), we find that test scores remain a strongly significant factor in growth while years of schooling are insignificant. But at the same time, these countries are also not driving the results: Dropping all these twenty countries, which give the most leverage for the identification of test scores from years of schooling, we still obtain the same qualitative result (significant test scores, insignificant years of schooling).

The results reported in tables 2 and 3 are also robust to several alternative approaches to measuring the cognitive skills. The results remain qualitatively the same when using only the tests performed at the level of lower secondary education, excluding any test in primary schooling or in the final year of secondary education. Arguably, test scores at the end of the secondary level, which combine the knowledge accumulated over primary and secondary schooling, may be

more relevant for the human capital of the labor force than test scores that capture only the knowledge at the end of either primary or lower secondary school. At the same time, the duration of secondary education differs across countries, so that tests performed in the final year of secondary schooling in each country may not be as readily comparable across countries as the grade-based target populations. Further, given differing school completion rates, the test for the final year of secondary schooling may imply cross-country samples with differential selectivity of test takers. Neither the primary-school tests nor the tests in the final secondary year are crucial for the results.

Furthermore, results are qualitatively the same when using only scores on tests performed since 1995. These recent tests have not been used in the previous analyses and are generally viewed as having the highest standard of sampling and quality control. Likewise, results are robust to using tests scores since 1995 for just lower secondary grades.

A drawback of using only the more recent tests is that such an approach requires a strong version of the assumption that test performance is reasonably constant over time, because it relates test performance measured since 1995 to the economic data for 1960–2000. To make sure that higher previous economic growth is not driving the measured test performance, we also used a test score measure that disregards all tests since the late 1990s. Our results turn out to be robust, with a point estimate on the test score variable that is significantly higher, when we restrict the tests to only those conducted until 1995 (sample reduced to thirty-four countries) and until 1984 (twenty-two countries). We can also use the average early test scores (either until 1984 or until 1995) as an instrument for the average of all test scores in a two-stage least-squares regression, in order to utilize only that part of the total test-score measure that can be

traced back to the early test scores. Again, our results are robust to such an instrumental-variable approach. In sum, the results are not driven by either early or late test scores alone.

The results are also robust to performing the analyses in two subperiods, 1960–80 and 1980–2000. The most recent period includes the Asian currency crisis and other major economic disruptions that could affect the apparent impact of cognitive skills on growth—but they do not. Test scores exert a statistically significant positive effect on growth in both subperiods, while years of schooling remain insignificant in both subperiods.

As discussed in the previous section, one may worry about the extent to which East Asian countries are driving the association between cognitive skills and economic growth. As is obvious from figure 7, several East Asian countries feature both high cognitive skills and high economic growth, and the top right corner of the figure is noticeably inhabited by East Asian countries. Still, the regression reported above that controls for regional dummies already showed that the association between cognitive skills and growth is not solely due to a difference between the group of East Asian countries and the rest of the countries. Furthermore, similar to the results reported in Hanushek and Kimko (2000), when we drop all ten East Asian countries from our sample of fifty countries, the estimate on cognitive skills remains statistically highly significant at a point estimate of 1.3. The significant effect in the sample without East Asian countries is also evident in the two separate subperiods, with the point estimates being larger in the separate regressions.

Finally, we can look at the different subjects separately. Thus, we can divide our combined test-score measure into one using only the math tests and one using only the science tests. All results remain qualitatively the same when we use the test scores in math

and science separately. Even more, both subject-specific test scores are significantly associated with growth when entered jointly. There is some tendency for math performance to dominate science performance in different robustness specifications but overall performance in math and science carry separate weight for economic growth.

So far, the growth analyses have not used performance on the reading tests, because they may be affected by testing in different languages and may not be easily combined into a common one-dimensional scale with math and science tests. However, the international reading tests are supposed to be designed to minimize the impact of variation in language, and we can use them separately from the math and science tests. Using reading performance in place of math and science performance yields the same qualitative results: Reading performance is strongly and significantly related to economic growth, rendering years of schooling insignificant. This result is robust to using reading tests only in lower secondary school, only up to 1991, or only since 1995, as well as in two subperiods 1960–80 and 1980–2000, with the impact of cognitive skills being uniformly statistically significant. When entering the reading score together with the math and science scores, reading is clearly dominated by the other subjects.

Thus, the math and science dimensions of performance seem to have independent effects on economic growth, while the reading effect is significant only without controlling for the other subjects. Because of the thin country samples, however, we trust the pattern of results more than the specific estimates.

5.5 *Distribution of Cognitive Skills and Economic Growth*

The results so far consider only the mean of cognitive skills in a country. From a policy viewpoint, though, it is important to know whether different parts of the distribution of

education affect growth differently. Loosely speaking, is it a few “rocket scientists” at the very top of the distribution who are needed to spur economic growth or is it “education for all” that is needed to lay a broad base at the lower parts of the educational distribution? Does educational performance at different points in the distribution of the population have separate effects on economic growth?

To estimate such effects, we measure the share of students in each country that reaches a certain threshold of basic skills at the international scale, as well as the share of students that surpasses an international threshold of top performance. As the two thresholds, we use 400 and 600 test-score points, respectively, on the transformed international scale as shown in figure 6.

The threshold of 400 points is meant to capture a notion of basic literacy. On the PISA 2003 math test, for example, this would correspond to the middle of the level 1 range (358 to 420 test-score points) which denotes that students can answer questions involving familiar contexts where all relevant information is present and the questions are clearly defined. While the PISA 2003 science test does not define a full set of proficiency levels, the threshold of 400 points is used as the lowest bound for a basic level of science literacy (Organisation for Economic Co-operation and Development 2004, p. 292). In general, a level of 400 points means performance at one standard deviation below the OECD mean. The share of students achieving this level ranges from 18 percent in Peru to 97 percent in the Netherlands and Japan, with an international median of 86 percent in our sample. The threshold of 600 points captures the notion of very high performers, performing at more than one standard deviation above the OECD mean. The share of students achieving this level ranges from below 0.1 percent in Colombia and Morocco to 18 percent in Singapore and Korea and 22 percent in Taiwan, with an international median of 5 percent in our sample.

TABLE 4
COGNITIVE SKILLS AND GROWTH: DISTRIBUTION AND INSTITUTIONAL INTERACTION

	Dependent variable: average annual growth rate in GDP per capita, 1960–2000.		
	(1)	(2)	(3)
GDP per capita 1960	–0.287 (5.12)	–0.297 (5.64)	–0.355 (6.03)
Years of schooling 1960	0.022 (0.28)	–0.031 (0.41)	–0.017 (0.22)
Share of students above threshold of 400	2.732 (3.61)		
Share of students above threshold of 600	12.880 (4.35)		
Test score (mean)		0.942 (2.30)	1.494 (4.46)
Openness		0.732 (2.13)	
Test score \times openness		1.609 (2.34)	
Protection against expropriation			0.485 (3.00)
Test score \times protection against expropriation			0.210 (1.19)
Constant	1.335 (2.97)	3.814 (11.24)	4.617 (16.18)
<i>N</i>	50	47	47
<i>R</i> ² (adj.)	0.719	0.785	0.781

Note: *t*-statistics in parentheses.

When we enter the share of students above the two thresholds jointly in our growth model (see column 1 of table 4), both turn out to be separately significantly related to economic growth. That is, both education for all and the share of absolutely top performers seem to exert separately identifiable effects on economic growth. These initial results should be viewed as suggestive rather than definite, not the least because of issues of multicollinearity between the two measures of cognitive skills which have a bivariate correlation of 0.73. Importantly, the relative size of the effects of performance at the bottom and at the top of the distribution depends on the specific specification used, and further research is needed to yield more detailed predictions.

Nonetheless, the evidence strongly suggests that both dimensions of educational performance count for the growth potential of an economy (see Hanushek and Woessmann forthcoming for greater detail).³⁹

Additional specifications using different points of the distribution of test scores support this general view. The positive effect of cognitive skills is highly robust to measuring test-score performance at different percentiles of the distribution, such as the

³⁹ In contrast to the result of Amparo Castelló and Doménech (2002) based on years of schooling, we do not find a significant effect of inequality of cognitive skills per se on economic growth, but rather significant effects at different points of the distribution.

twenty-fifth, seventy-fifth, and ninety-fifth percentile, rather than at the mean. When including two measures at a time, they are always jointly, and often separately, significant. When including two percentile measures, it is not always clear whether the higher ones tend to dominate the lower ones or vice versa in different specifications, which are again hampered by strong multicollinearity of the test-score measures. The highest bivariate correlation among the different test-score measures is between mean performance and the share of students in a country reaching the threshold of 400 test-score points, at 0.99. Thus, mean performance seems to capture mainly the pattern of basic literacy across the countries in our sample. The specifications including two test-score variables remain qualitatively the same when including five regional dummies, and the pattern of significance also holds when the other control variables are included.

In sum, both basic and top dimensions of cognitive skills seem to have independent positive effects on economic growth. However, as in the case of the math, science, and reading dimensions of performance, the relatively small sample of countries allows for an assessment of the general pattern of results more than of specific separate estimates.

5.6 *Institutions, Cognitive Skills, and Growth*

In recent years, there has been an increasing emphasis on the role of economic institutions as the fundamental cause of differences in economic development (cf. Acemoglu, Johnson, and Robinson 2001, 2002, 2005). As we saw in column 4 of table 2, the quality of institutions as measured by the protection against expropriation is indeed significantly related to economic growth in our model. A second measure of institutional quality, openness to international trade, also tends to be significantly related to economic growth, at least jointly with protection against expro-

priation. (Note that protection against expropriation and openness are strongly correlated, with a correlation coefficient of 0.71.) At the same time, though, the results show that, on average, cognitive skills exert a positive effect on economic growth independent of these measures of the quality of institutions. While Acemoglu, Johnson, and Robinson (2001, 2002, 2005) find that geographical features do not exert an effect on economic growth independent of institutions, this remains a disputed subject (cf., e.g., McArthur and Sachs 2001). When we add proxies for geography such as location in the geographic tropics or latitude to our basic specification, these do not enter significantly and do not change the findings on institutions and on cognitive skills.

While the evidence confirms an independent effect of cognitive skills on economic growth, this effect may differ depending on the economic institutions of a country. Douglass C. North (1990), for example, emphasizes that the institutional framework plays an important role in shaping the relative profitability of piracy versus productive activity. If the available knowledge and skills are used in the former rather than the latter activity, one may certainly expect the effect on economic growth to be substantially different, and maybe even to turn negative. Similarly, Murphy, Andrei Shleifer, and Robert W. Vishny (1991) show that the allocation of talent between rent-seeking and entrepreneurship matters for economic growth: countries with relatively more engineering college majors grow faster and countries with relatively more law concentrators grow more slowly. Easterly (2001) argues that education may not have much impact in less developed countries that lack other facilitating factors such as functioning institutions for markets and legal systems. In a similar way, Pritchett (2001, 2006) suggests that, due to deficiencies in the institutional environment, cognitive skills might have been applied to socially unproductive activities in

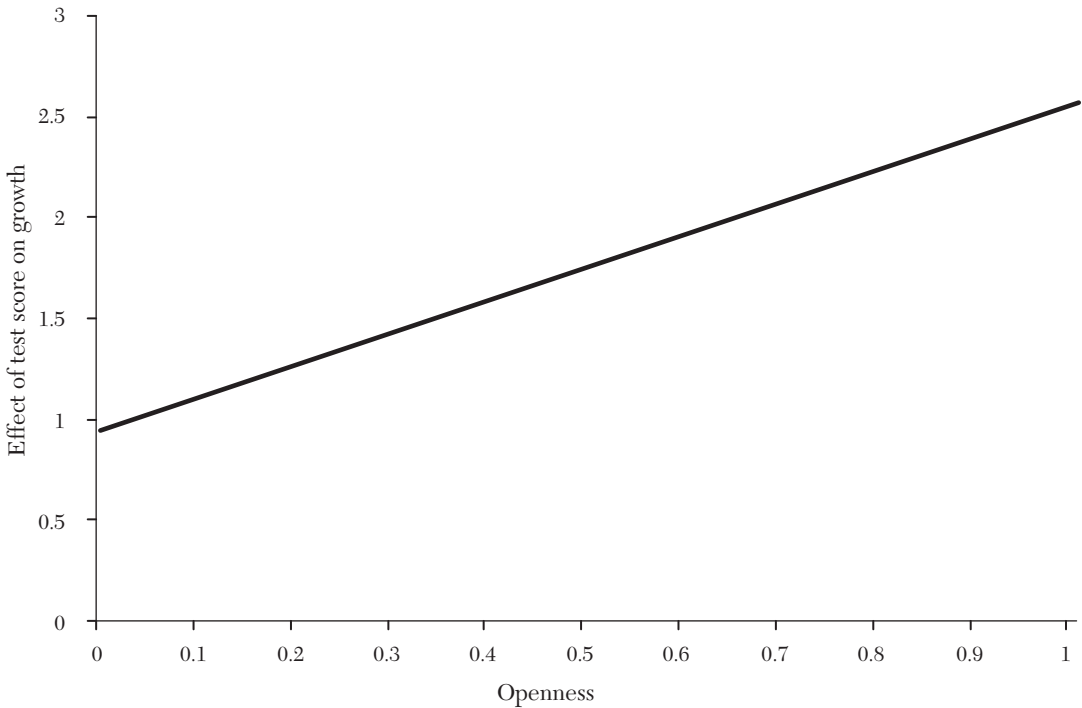


Figure 9. The Effect of Cognitive Skills on Growth Depending on Openness

Notes: Estimated effect of average achievement test scores on the average annual rate of growth of real GDP per capita in 1960–2000, depending on the degree of openness to international trade of a country. Author calculations; see table 4, column 2.

many developing countries, rendering the average effect of education on growth across all countries negligible. While his result of negligible average growth effects of increases in educational quantity may have more to do with issues of measuring education than with perverse economic institutions, his point that the social returns to education and skills may be low in countries with perverse institutional environments is certainly worth pursuing.

Thus, in column 2 of table 4, we add an interaction term between cognitive skills and one of our institutional measures, openness to international trade, to our growth specification (to facilitate interpretation, the test-score variable is centered in the specifications that include interactions). The results suggest that

openness and cognitive skills not only have significant individual effects on economic growth but also a significant positive interaction. This result is depicted in figure 9. The effect of cognitive skills on economic growth is indeed significantly higher in countries that have been fully open to international trade than in countries that have been fully closed. (Jamison, Jamison, and Hanushek 2007 find a similar result, in that the impact of cognitive skills on technical progress is strong in countries with open trade regimes and essentially zero in closed economies). The effect of cognitive skills on economic growth is significantly positive, albeit relatively low at 0.9, in closed economies, and it increases to a size of 2.5 in open economies. There is a similar

positive interaction effect between test scores and openness when openness is specified as a dummy for countries that have been closed for the majority of the time (openness below 0.3). The reported result is robust to including the measure of protection against expropriation. When using protection against expropriation rather than openness to trade as the measure of quality of institutions in column 3, there is similarly a positive interaction term with cognitive skills, although it lacks statistical significance.

In sum, both the quality of the institutional environment and the level of cognitive skills seem important for economic development. Furthermore, the effect of cognitive skills on economic growth seems to be significantly larger in countries with a productive institutional framework, so that good institutional quality and good cognitive skills can reinforce each other in advancing economic development. Thus, the macroeconomic effect of education depends on other complementary growth-enhancing policies and institutions. Nonetheless, we still also find a significant positive growth effect of cognitive skills even in countries with a poor institutional environment.

5.7 *The Implications of Improved Cognitive Skills*

It is important to understand the implications of policies designed to improve educational outcomes. The previous estimation provides information about the long-run economic implications of improvements in cognitive skills. To understand better the impact of improved achievement, it is useful to relate policy reforms directly to the pattern of economic outcomes that are consistent with feasible improvements. For this exercise, we assume that the estimated coefficients provide the causal impact of differences in cognitive skills. As discussed in section 2, this interpretation is threatened by a variety of factors. Nonetheless, given

the robustness of the estimates to alternative samples and specifications and the added support from tests of major threats to identification, we believe that this is a useful and potentially important exercise.

Two aspects of any educational reform plan are important. First, what is the magnitude of the reform that is accomplished? Second, how fast does any reform achieve its results? Without being specific about the potential schooling reforms, here we simply investigate the economic results that might be anticipated on the assumption that some set of schooling reforms actually leads to substantial achievement gains over an identified time period.

Our analysis puts the economic implications in terms of standard deviations of test scores (measured at the student level, as throughout this paper). To provide a benchmark, we consider a reform that yields a 0.5 standard deviation improvement in average achievement of school completers. This metric is hard to understand intuitively, in part because most people have experiences within a single country. It is possible, however, to put this in the context of the previous estimation. Consider a developing country with average performance at roughly 400 test-score points, what we described as approximately minimal literacy on these tests. For example, on the PISA 2003 examinations, average achievement in Brazil, Indonesia, Mexico, and Thailand fell close to this level. An aggressive reform plan would be to close half the gap with the average OECD student, which would be a half standard deviation improvement.

As an alternative policy change, consider what it would mean if a country currently performing near the mean of OECD countries in PISA at 500 test-score points (for example, Norway or the United States in PISA 2000 or Germany in PISA 2003, see figure 6) would manage to increase its cognitive skills to the level of top performers in PISA at roughly

540 test-score points (for example, Finland or Korea on either PISA test).⁴⁰ Such an increase of 40 test-score points amounts to 0.4 standard deviation. These calculations also point out the asymmetry of the test score distribution with a considerably longer left tail of the country distribution.

The timing of the reform is also important. Two aspects of timing enter. First, such movement of student performance cannot be achieved instantaneously but requires changes in schools that will be accomplished over some time (say, through systematic replacement of teachers through retirements and subsequent hiring). The time path of any reform is difficult to specify, but achieving the change of 0.5 standard deviations described above for an entire nation may realistically take twenty to thirty years.⁴¹

Second, if the reforms succeed, their impact on the economy will not be immediate. In particular, the new graduates from school will initially be a small to negligible portion of the labor force. It will be sometime after the reform of the schools before the impact on the economy is realized. In other words, the prior estimates are best thought of as the long run, or equilibrium, outcomes of a labor force with a given cognitive skills.

To show the impact of these elements of reform, figure 10 simulates the impact on the economy of reform policies taking ten, twenty, or thirty years for a 0.5 standard deviation improvement in student outcomes at the end of upper secondary schooling—what we label as a “moderately strong knowledge

improvement.” For the calibration, policies are assumed to begin in 2005—so that a twenty-year reform would be complete in 2025. The actual reform policy is presumed to operate linearly such that, for example, a twenty-year reform that ultimately yielded one-half standard deviation higher achievement would see the performance of graduates increasing by 0.025 standard deviations each year over the period. It is also necessary to characterize the impact on the economy, which we assume is proportional to the average achievement levels of prime age workers.⁴² Finally, for this exercise we project the growth impact according to the basic achievement model that also includes the independent impact of economic institutions—column 4 of table 2.

The figure indicates how much larger the level of GDP is at any point after the reform policy is begun as compared to that with no reform. In other words, the estimates suggest the increase in GDP expected over and above any growth resulting from other factors.

Obviously, for any magnitude of achievement improvement, a faster reform will have larger impacts on the economy, simply because the better workers become a dominant part of the workforce sooner. But, the figure shows that even a twenty- or thirty-year reform plan has a powerful impact on GDP.

⁴⁰ Differences among nations do vary somewhat across the separate tests. For example, by the PISA 2006 tests, the United States scores were somewhat farther behind Finland and other top performers than in 2003. The important point here is demonstrating the impact of substantial performance improvements, and not necessarily moving to the very top of the distribution.

⁴¹ Rough calculations of the relationship between changes in teacher quality and results are found in Hanushek (2005). These are based on assumptions of teacher turnover that mirror the U.S. experience.

⁴² We specifically assume that the relevant achievement levels depend on workers in the first thirty-five years of their work life and calculate the average achievement levels based upon the progressive improvements of school completers under the different reform periods. The full impact of an educational reform is not felt until thirty-five years past completion of the reform, e.g., for forty-five years with a ten-year reform period. To our knowledge, no past work has indicated how achievement impacts would be felt on the economy. Our linear impact that depends on the workforce average is probably conservative, because new technologies that rely on better trained workers could probably be introduced once there is a substantial number of more skilled workers available instead of relying on improvement throughout the workforce. Alternatively, improvements that depend on innovation may depend most on the stock of young, very highly skilled workers, and the impact of educational improvements might be quite quick.

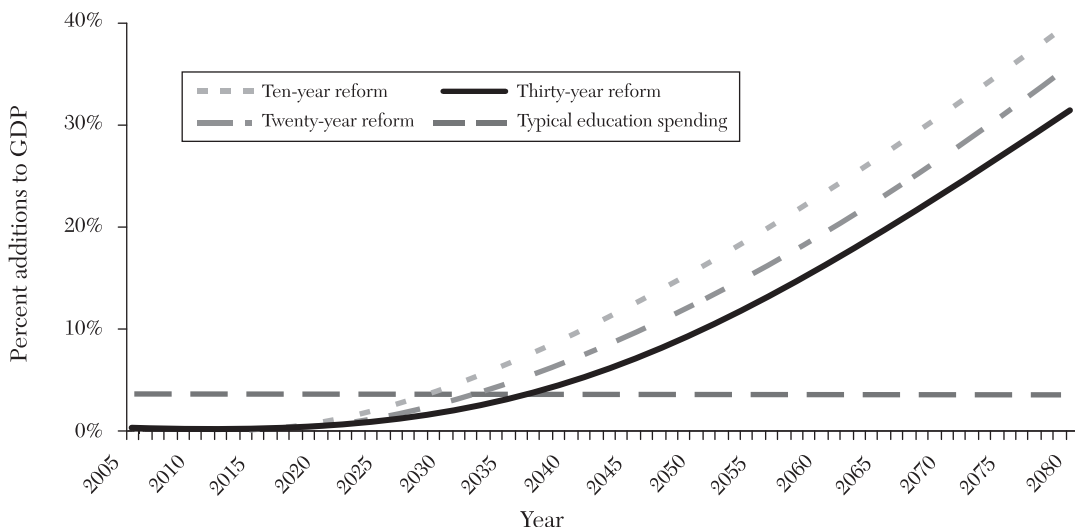


Figure 10. Improved GDP with Moderately Strong Knowledge Improvement (0.5 s.d.)

For example, a twenty-year plan would yield a GDP that was five percent greater in 2037 (compared with an economy with no increase in cognitive skills). The figure also plots 3.5 percent of GDP, an aggressive spending level for education in many countries of the world. Five percent of GDP is significantly greater than the typical country's spending on all primary and secondary schooling, so that it is truly a significant change that would permit the growth dividend to more than cover *all* of primary and secondary school spending. But even a thirty-year reform program (that would not be fully accomplished until 2035) would yield more than five percent higher real GDP by 2041.

Projecting these net gains from improved achievement further past the reform period shows vividly the long run impacts of reform. Over a seventy-five year horizon, a twenty-year reform yields a real GDP that is 36 percent higher than would be with no change in cognitive skills.

It must nonetheless be clear that these effects represent the result from *actual gains* in cognitive skills. There have been many attempts around the world to improve student outcomes, and many of these have failed to yield actual gains in student performance. Bad reforms, those without impacts on students, will not have these impacts.

This simulation shows that the previous estimates of impacts of cognitive skills on growth have really large impacts on national economies. At the same time, while the rewards are large, they also imply that policies must be considered across lengthy time periods and require patience—a patience that is not always clear in national policy making.

These reforms must also be put in a broader perspective, because other kinds of institutional changes and investments will also take substantial time. Changing basic economic institutions, for example, can seldom be accomplished over night, and their

impacts will take time before the economy adjusts. Thus, in large part, our calculations about the time path of benefits differ more in the fact that we make it explicit than in its pattern compared to a variety of other economic policies.

6. *Where Does the Developing World Stand?*²

Given the crucial importance of cognitive skills for economic development, it is telling to document how the developing countries fare in this regard. In the following, we document both the quantity of schooling and cognitive skills achieved by developing countries from an international perspective, and this vividly illustrates the magnitude of the task at hand.

6.1 *Lack of Quantity of Schooling*

The disadvantages of less developed countries in terms of educational enrollment and attainment have been well documented and are well known. As noted, current international policy initiatives—the Millennium Development Goals and the Education for All initiative—focus on the importance of expanded school attainment in developing countries.

To provide an aggregate picture, figure 11 presents the share of children aged fifteen to nineteen who have completed grade 9, dropped out between grades 5 and 9 or between grades 1 and 5, or never enrolled, for eight regions of developing countries. Grades 5 and 9 are chosen as two possible definitions of basic schooling. The age range of fifteen to nineteen is chosen to balance the relevance of the data for most recent conditions against the censoring problem of some children still being in school. The basic patterns observed are, however, the same when using estimates adjusted for the censoring (Pritchett 2004). The shares are unweighted averages of the available

countries in the Demographic and Health Surveys (DHS) and similar surveys (cf. Deon Filmer 2006), conducted in a large number of developing countries. These household survey data are much more reliable than the administrative data on school enrollment rates. Administrative data have traditionally been used in country reporting as well as in a variety of recent studies that try to evaluate progress on the quantitative development goals, but it appears that the administrative data available in many developing countries often overstate actual enrollment and completion rates. Further, the self-reported data on the highest grade completed is more relevant for actual education than enrollment rates, which are affected by grade repetition and the like.

While almost all OECD countries have universal school attainment to grade 9, essentially all developing regions are far from that. In the average African country in the data, only 13 percent of each cohort finishes grade 9, and less than 30 percent in Central America and South and East Asia. Even in South America, this figure is only 43 percent, although on the other hand only 17 percent of a cohort do not complete grade 5 (which often serves as an initial indication of basic literacy and numeracy rates). In West and Central Africa, 59 percent of each cohort do not even complete grade 5, and 44 percent never enroll in school in the first place.⁴³ It is notable across countries, however, that the lack of grade 5 attainment is at least as often due to dropping out of school than due to never enrolling. In any event, while the pattern of educational attainment varies greatly across countries and regions, the lack of quantitative educational attainment from universal completion of basic education—

⁴³ These household survey data are corroborated by UNESCO data that show net enrollment rates in primary schools in the region to be 55 percent in 1999 and 65 percent in 2004 (UNESCO 2007).

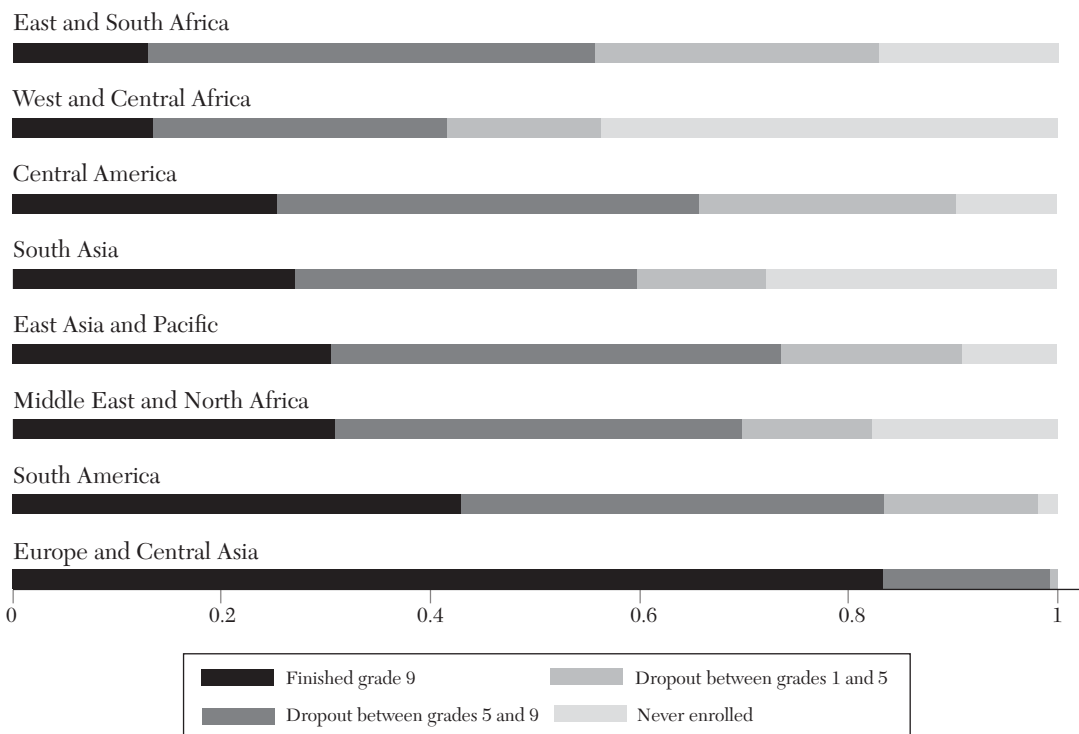


Figure 11. Lack of Educational Attainment in Developing Countries

Note: Based on Pritchett (2004).

be it grade 5 or grade 9—is immense in the majority of developing countries.

Focusing on this dimension of schooling quantity, many policy initiatives of national governments and international development agencies have tried to increase the educational attainment of the population. The data in figure 11 show that there remains a long way to go. But even this dire picture may understate the challenge that becomes apparent when cognitive achievement is also considered.

6.2 Lack of Achievement Outcomes

The description of school completion unfortunately ignores the level of cognitive skills actually acquired. Completing five or even nine years of schooling in the

average developing country does not necessarily mean that the students have become functionally literate in terms of basic cognitive skills. As a recent report by the World Bank Independent Evaluation Group (2006) documents, high priority was accorded to increasing enrollment in primary schools in developing countries over the past fifteen years, but much less attention was directed to whether children are learning adequately. In figure 6 above, we have already documented the particularly low levels of mean performance of students attending school in basically all the developing countries that have participated in at least one of the international student achievement tests. But of course, mean performance can hide a lot of

dispersion that exists within countries, and the prior analyses of growth (section 5.5) show that there is separate information at different percentiles of the test-score data.

Figures 12 and 13 depict the share of students in a country that surpasses the thresholds of 400 and 600 test-score points on the transformed scale of the combined international tests—the same measure and thresholds that we used in the growth analyses of section 5.5. Figure 12 shows the sample of fifty countries which forms the basis of our growth analyses, and figure 13 shows the remaining twenty-seven countries that participated in one of the international student achievement tests but lack internationally comparable GDP data for the 1960–2000 period that would allow them to be included in the growth analyses.

When considering the basic educational achievement of students, we are interested in the share of students who surpass the threshold of 400 test-score points, which may be viewed as a rough threshold of basic literacy in mathematics and science. As is evident from the figures, this share varies immensely across countries. In countries such as Japan, the Netherlands, Korea, Taiwan, and Finland, less than 5 percent of tested students fall below this literacy threshold. By contrast, in many of the developing countries participating in the international achievement tests, more than half of the tested students do not reach this threshold of literacy. The countries with the largest shares of test-taking students who are functionally illiterate by this definition are Peru (82 percent), Saudi Arabia (67 percent), Brazil (66 percent), Morocco (66 percent), South Africa (65 percent), Botswana (63 percent), and Ghana (60 percent). In these countries, more than 60 percent of those in school do not reach a level of basic literacy in cognitive skills. It should be noted that the group of developing countries participating in the international tests is probably already a select sample from all

developing countries, and, furthermore, the children enrolled in school at the different testing grades are probably only a select group of all children of the respective age in these countries.

6.3 *The Size of the Task at Hand: Schooling Quantity and Cognitive Skills Combined*

We have seen that developing countries are severely lacking in terms of both schooling quantity and student outcomes. Figure 14 shows the combination of the two. For the fourteen countries that both have reliable attainment data from the household surveys and have participated in the international student achievement tests, we combine educational attainment of fifteen to nineteen-year-olds from the latest available year with test scores at the end of lower secondary education (eighth grade or fifteen-year-olds) from a year close by.⁴⁴ This allows us to calculate rough shares among recent cohorts of school-leaving age of how many were never enrolled in school, how many dropped out of school by grade 5 and by grade 9, how many finished grade 9 with a test-score performance below 400 which signals functional illiteracy, and finally how many finished grade 9 with a test-score performance above 400. Only the last group can be viewed as having reached basic literacy in cognitive skills (cf. Pritchett 2004, Woessmann 2004).

Figure 14 presents the countries in increasing order of the share of students mastering basic skills. In eleven of the

⁴⁴ Specifically, the years of the household survey data and the associated tests (where TIMSS always refers to the respective eighth grade subtests) are as follows: Albania and Peru: attainment data for 2000, combined with test scores from PISA 2002; Armenia: 2000 and TIMSS 2003; Brazil: 1996 and PISA 2000; Colombia: 2000 and TIMSS 1995; Egypt, Ghana, and Morocco: 2003 and TIMSS 2003; Indonesia: 2002 and average of TIMSS 2003 and PISA 2003; Moldova: 2000 and average of TIMSS 1999 and TIMSS 2003; Philippines: 2003 and average of TIMSS 1999 and TIMSS 2003; South Africa: 1999 and TIMSS 1999; Thailand: 2002 and PISA 2003; Turkey: 1998 and TIMSS 1999.



Figure 12. Share of Students below 400 (“Illiterate”), between 400 and 600, and above 600 Test-Score Points, Countries in Growth Analysis

Source: Hanushek and Woessmann (forthcoming), based on several international tests; see text for details.

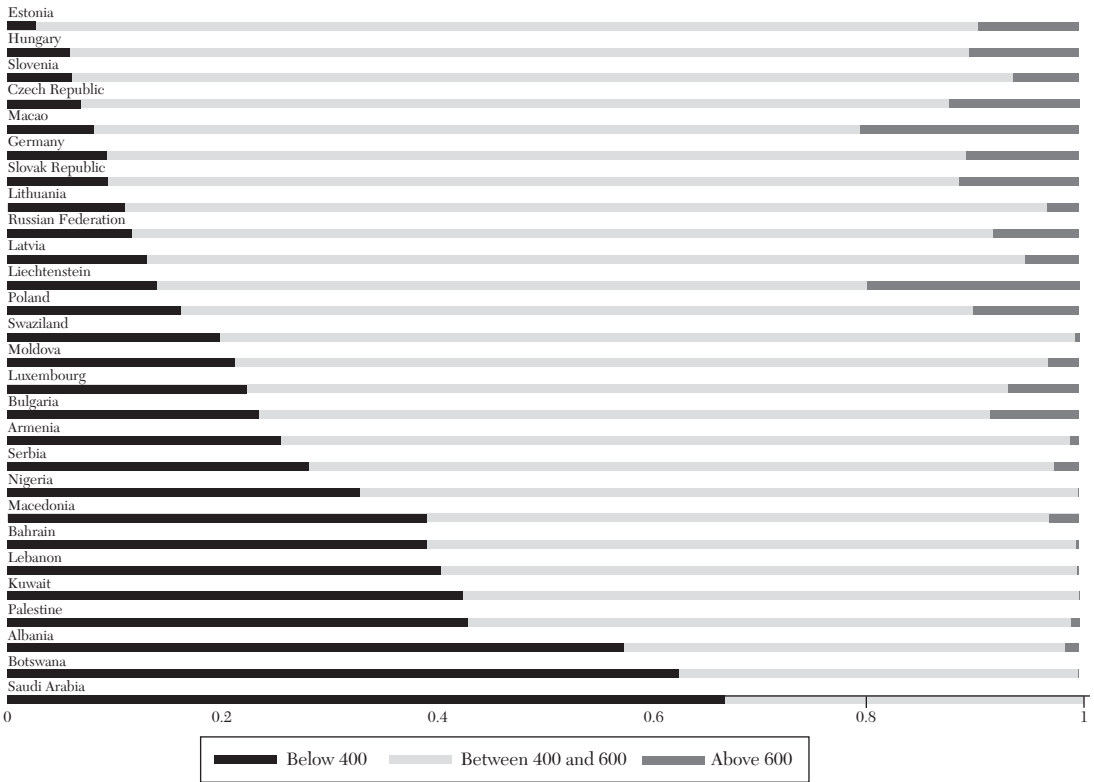


Figure 13. Share of Students below 400 (“Illiterate”), between 400 and 600, and above 600 Test-Score Points, Countries Not in Growth Analysis

Source: Hanushek and Woessmann (forthcoming), based on several international tests; see text for details.

fourteen countries, the share of fully literate students in recent cohorts is less than one third. In Ghana, South Africa, and Brazil, only 5 percent, 7 percent, and 8 percent of a cohort, respectively, reach literacy. The remaining more than 90 percent of the population are illiterate because they never enrolled in school; because they dropped out of school at the primary or early secondary level; or because, even after completing lower secondary education, their grasp of basic cognitive skills was so low that they have to be viewed as fundamentally illiterate. In contrast, 55 percent of a cohort in

Armenia and 63 percent in Moldova can be viewed as literate at the end of lower secondary schooling.

An example of a basic test question from one of the international achievement tests can, perhaps better than anything, illustrate the scope of the problem in developing countries. One question asked to eighth graders in the Trends in International Mathematics and Science Study (TIMSS) 2003 was: “Alice ran a race in 49.86 seconds. Betty ran the same race in 52.30 seconds. How much longer did it take Betty to run the race than Alice? (a) 2.44 seconds (b)

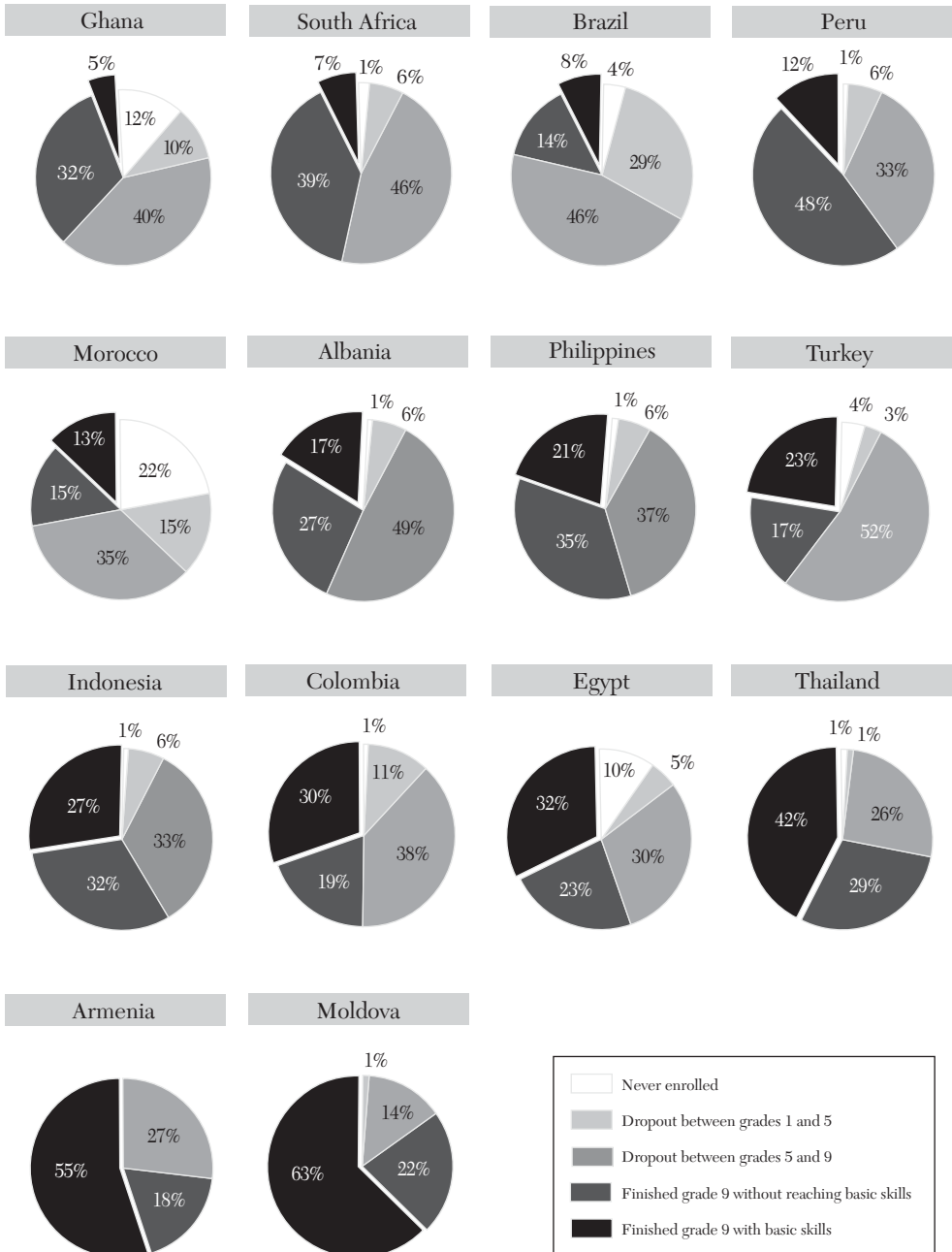


Figure 14. Types of Lack of Education among 15–19-Year-Olds in Developing Countries

Note: Own calculations for all countries that have consistent World Bank survey data on educational attainment (Filmer 2006) along with micro data from at least one international student achievement test.

2.54 seconds (c) 3.56 seconds (d) 3.76 seconds.” While 88 percent of eighth-grade students in Singapore, 80 percent in Hungary, and 74 percent in the United States got the correct answer (a), only 19 percent of students in eighth grade in Saudi Arabia, 29 percent in South Africa, and 32 percent in Ghana got the correct answer (cf. Pritchett 2004 for a similar example). Random guessing would have yielded 25 percent correct on average.

When we combine data on quantitative educational attainment and cognitive skills for the countries with reliable data on both dimensions, it becomes apparent that the task at hand is truly staggering in most developing countries. In many developing countries, the share of any cohort that completes lower secondary education and passes at least a low benchmark of basic literacy in cognitive skills is *below one person in ten*. Thus, the education deficits in developing countries seem even larger than generally appreciated. Several additional references for examples of extremely low educational performance of children even after years of schooling from different developing countries are provided in Pritchett (2004). The state of the quantity and quality of education and skills in most developing countries is truly dismal.

7. Conclusion

This study was motivated by doubts that have been raised about the role of education and human capital in economic development. These doubts come from a variety of vantage points ranging from whether the research has correctly identified the impact of education to whether other institutional aspects of countries might be more important. They also encompass concerns about whether or not we really know how to change educational outcomes, particularly in developing countries.

7.1 Summary of Main Results

Our analysis has produced two remarkably simple but clear conclusions.

1. Cognitive skills have powerful effects on individual earnings, on the distribution of income, and on economic growth.

The accumulated evidence from analyses of economic outcomes is that cognitive skills have powerful economic effects. Much of the earlier discussion has concentrated solely on school attainment, or the quantity of schooling. This focus is unfortunate, because it distorts both the analysis and the policy discussions.

Individual earnings are systematically related to cognitive skills. The distribution of skills in society appears closely related to the distribution of income. And, perhaps most importantly, economic growth is strongly affected by the skills of workers.

Other factors obviously also enter into growth and may well have stronger effects. For example, having well-functioning economic institutions such as established property rights, open labor and product markets, and participation in international markets have clear importance for economic development and may also magnify the benefits of cognitive skills. Nonetheless, existing evidence suggests that cognitive skills independently affect economic outcomes even after allowing for these other factors.

Moreover, the evidence on the strong relationship between cognitive skills and economic outcomes is remarkably robust. While it is difficult to establish conclusively that this is a causal relationship, the robustness of the result lends considerable credence to such an interpretation. The relationship does not appear to result from particular data samples or model specifications. Nor can it be explained away by a set of plausible alternative

hypotheses about other forces or mechanisms that might lie behind the relationship.

To be sure, cognitive skills may come from formal schools, from parents, or from other influences on students. But, a more skilled population—almost certainly including both a broadly educated population and a cadre of top performers—results in stronger economic performance for nations.

2. The current situation in developing countries is much worse than generally pictured on the basis just of school enrollment and attainment.

Available measures of school attainment uniformly indicate that developing countries lag dramatically behind developed countries. This fact has driven a variety of efforts to expand schooling in developing countries, including the Education for All initiative. Yet, much of the discussion and much of the policy making has tended to downplay the issues of cognitive skills.

International testing indicates that, even among those attaining lower secondary schooling, literacy rates (by international standards) are very low in many developing countries. By reasonable calculations, a range of countries has fewer than 10 percent of its youth currently reaching minimal literacy and numeracy levels, even when school attainment data look considerably better.

Because of the previous findings—that knowledge rather than just time in school is what counts—policies must pay more attention to the quality of schools. Particularly in terms of aggregate growth, school attainment has a positive impact only if it raises the cognitive skills of students—something that does not happen with sufficient regularity in many developing countries.

For developing countries, the sporadic or nonexistent assessment of student knowledge is an especially important issue—cor-

recting this shortcoming should have the highest priority. It is impossible to develop effective policies without having a good understanding of which work and which do not. Currently available measures of program “quality” frequently rely upon various input measures that unfortunately are not systematically related to student learning. Moreover, the existing international tests—such as the PISA tests of the OECD—may not be best suited to provide accurate assessments of student performance in developing countries. The evolving capacity for adaptive testing that can adjust test content to the student’s ability level seems particularly important in the developing country context. Adaptive testing offers the possibility of meaningful within-country variation in scores along with the ability to link overall performance with global standards.

7.2 Implications for Policy

The economic importance of cognitive skills of students and its dismal level in most developing countries inevitably lead to questions about whether it can be affected by policy. The shift of focus from years of schooling to cognitive skills has important policy implications because policies that extend schooling may be very different from the best policies to improve skills. The policy conundrum is that student achievement has been relatively impervious to a number of interventions that have been tried by countries around the world.⁴⁵

As we discussed in section 2, the relevant cognitive skills are the product of a variety of influences. A wide body of literature emphasizes the key impacts of families,

⁴⁵ A substantial portion of the policy conundrums of the past is the lack of reliable evaluations of alternative programs. See the discussion in Glewwe and Michael Kremer (2006) about how better information can be developed through random assignment experimentation or other approaches that better identify the causal impacts of various factors.

peers, schools, and ability (cf. Hanushek 2002). From the standpoint of economic impacts, the source of any change in cognitive skills does not matter. For example, a health and nutrition program that improves children's ability to concentrate and thus leads to gains in basic achievement is as relevant as an improvement in the quality of teachers in the child's school.

At the same time, most societies are more willing to intervene through schooling—which has been a domain of generally recognized public involvement—than through policies that become intertwined with the family. Thus, policy attention has focused largely on what can be done through schools.

The important thing for policy is simply that the intervention actually improves achievement. Many of the policy initiatives, both in developed and developing countries, have not proved successful in improving achievement, and this has led to some cynicism about the efficacy of interventions.

While an in-depth discussion of the school policy issues goes beyond the scope of this paper, the existing research strongly suggests that getting the substantial improvements in the quality of schools that are necessary requires structural changes in schooling institutions. The research on the potential impact of increased school resources has been controversial. Our own assessment is that the extensive research has shown that simply putting more resources into schools—pure spending, reduced class sizes, increased teacher training, and the like—will not reliably lead to improvements in student outcomes when the overall institutional structure is not changed (see, for example, Hanushek 1995, 2003 and Woessmann 2005, 2007). But, the magnitude of the challenge—particularly in developing countries—makes it unnecessary to replay these arguments. Even those who argue that general resource policies are efficacious would not argue that the

currently existing gaps could reasonably be significantly reduced by resource policies within existing institutional structures.

Although uncertainty exists about the best set of policies, our candidate for the fundamental failure of current school policy is the lack incentives for improved student performance. Moreover, recent research suggests that three sets of policies can help to improve the overall incentives in schools: strong accountability systems that accurately measure student performance, local autonomy that allows schools to make appropriate educational choices, and choice and competition in schools so that parents can enter into determining the incentives that schools face. Hanushek and Woessmann (2007) provide a more detailed discussion of policy options to improve cognitive skills along with reviewing the existing evidence.

When asking how education policies in developing countries can create the competencies and learning achievements required for their citizens to prosper in the future, the binding constraint seems to be institutional reforms, not resource expansions within the current institutional systems. For educational investments to translate into student learning, all the people involved in the education process have to face the right incentives that make them act in ways that advance student performance.

Appendix: Data on Cognitive Skills

The analysis in this paper relies upon a variety of cognitive achievement tests. The central analysis of growth and macroeconomic performance uses information from the international tests of a set of nations voluntarily participating in a cooperative venture under the International Association for the Evaluation of Educational Achievement (IEA) and from the OECD. The most recent of the IEA tests is the TIMSS for 2003, although there is a much longer history identified below along with its history in

testing reading (PIRLS). The OECD tests, called the PISA, began in 2000 and cover all OECD countries plus others.

These tests have different groups of countries, sampling of students, and perspectives on what should be tested (see Teresa Smith Neidorf et al. 2006). Our approach is to aggregate across the variety of tests for each country in order to develop a composite measure of performance. Perhaps the most important issue is whether or not the tests are measuring a common dimension of cognitive skills. The TIMSS tests of math and science are developed by an international panel but are related to common elements of primary and secondary school curriculum, while the PISA tests are designed to be assessments of more applied ideas. In our development of a common metric we also employ data from the U.S. National Assessment of Educational Progress (NAEP). That test, which is conceptually closest to the TIMSS tests except that it relates more directly to U.S. curriculum, provides information over time on a consistent basis.

Part of the analysis on individual returns relied on the IALS, a set of tests given to twenty countries between 1994–98. These tests cover several functional areas including: prose literacy—the knowledge and skills needed to understand and use information from texts including editorials, news stories, poems, and fiction; document literacy—the knowledge and skills required to locate and use information contained in various formats, including job applications, payroll forms, transportation schedules, maps, tables, and graphics; and quantitative literacy—the knowledge and skills required to apply arithmetic operations, either alone or sequentially, to numbers embedded in printed materials, such as balancing a checkbook, calculating a tip, completing an order form, or determining the amount of interest on a loan from an advertisement. They were designed to be very practical.

Interestingly, the TIMSS tests with their curricular focus and the PISA tests with their real-world application focus are highly correlated at the country level. For example, the correlation coefficients between the TIMSS 2003 tests of eighth graders and PISA 2003 tests of fifteen-year-olds across the nineteen countries participating in both are 0.87 in math and 0.97 in science, and they are 0.86 in both math and science across the twenty-one countries participating both in the TIMSS 1999 tests and the PISA 2000/02 tests. Similarly, there is a high correlation at the country level between the curriculum based student tests of TIMSS and the practical literacy adult examinations of IALS (Hanushek and Zhang 2008). Tests with very different foci and perspectives tend, nonetheless, to be highly related, lending support to our approach of aggregating different tests for each country.

The general idea behind our approach to aggregation is that of empirical calibration. We rely upon information about the overall distribution of scores on each test to compare national responses. This contrasts with the psychometric approach to scaling that calls for calibrating tests through use of common elements on each test. In reality, each of the testing situations described below is a separate activity with no general attempt to provide common scaling.

The strength of our approach is that different tests across a common subject matter tend to be highly correlated at both the individual and aggregate level. Thus, the distributional information that we use is closely related to variations in individual performance levels.

As shown in table A1, there are data from international student achievement tests on twelve international testing occasions. Containing separate tests in different subjects and at different age groups, these testing occasions yield thirty-six separate test observations altogether, each with

TABLE A1
THE INTERNATIONAL STUDENT ACHIEVEMENT TESTS

	Abbr.	Study	Year	Subject	Age ^{a,b}	Countries ^c
1	FIMS	First International Mathematics Study	1964	Math	13,FS	11
2	FISS	First International Science Study	1970–71	Science	10,14,FS	14,16,16
3	FIRS	First International Reading Study	1970–72	Reading	13	12
4	SIMS	Second International Mathematics Study	1980–82	Math	13,FS	17,12
5	SISS	Second International Science Study	1983–84	Science	10,13,FS	15,17,13
6	SIRS	Second International Reading Study	1990–91	Reading	9,13	26,30
7	TIMSS	Third International Mathematics and Science Study	1994–95	Math/Science	9(3+4), 13(7+8),FS	25,39,21
8	TIMSS-Repeat	TIMSS-Repeat	1999	Math/Science	13(8)	38
9	PISA 2000/02	Programme for International Student Assessment	2000+02	Reading/ Math/ Science	15	31+10
10	PIRLS	Progress in International Reading Literacy Study	2001	Reading	9(4)	34
11	TIMSS 2003	Trends in International Mathematics and Science Study	2003	Math/Science	9(4),13(8)	24,45
12	PISA 2003	Programme for International Student Assessment	2003	Reading/ Math/ Science	15	40

Notes: ^a Grade in parentheses where grade level was target population.

^b FS = final year of secondary education.

^c Number of participating countries that yielded internationally comparable performance data.

between eleven and forty-five participating countries with internationally comparable performance data. Most of the tests were conducted by the IEA, with the exception of the OECD-conducted PISA tests.⁴⁶

In order to make performance on the different international tests comparable, Hanushek and Woessmann (forthcoming) develop a common metric to adjust both the level of test performance and the

⁴⁶ In this study, we do not include the two tests conducted by the International Assessment of Educational Progress (IAEP) in 1988 and 1991, because they used the U.S. NAEP test as their testing instrument, which is geared to the U.S. curriculum and may thus introduce

bias to the international testing. By contrast, the tests included here are not associated with the curriculum in any particular country, but have been devised in an international cooperative process between all participating countries.

variation of test performance through two data transformations. First, because the United States has both participated in all of the international tests and has maintained its own longitudinal testing (the NAEP), Hanushek and Woessmann (forthcoming) calibrate the U.S. international performance over time to the external standard—thus benchmarking each of the separate international tests to a comparable level. Second, while this provides a relative comparison of countries taking each test over time, it is also necessary to establish the variance on the tests so that direct compatibility of countries taking different tests can be established. The calibration of the dispersion of the tests relies on holding the score variance constant within a group of countries with stable education systems (defined in terms of secondary school attendance rates) over time. For this, Hanushek and Woessmann (forthcoming) use the thirteen OECD countries who had half or more students completing upper secondary education around the beginning of international testing in the 1970s as the “stable” country group, and standardize variances to their group performance on the 2000 PISA tests. The details of the transformation are found in Hanushek and Woessmann (forthcoming).

To create our measure of cognitive skills employed in this study, we use a simple average of the transformed mathematics and science scores over all the available international tests in which a country participated, combining data from up to nine international testing occasions and thirty individual test point observations. This procedure of averaging performance over a forty year period is meant to proxy the educational performance of the whole labor force, because the basic objective is not to measure the skills of students but to obtain an index of the skills of the workers in a country. If the quality of schools and

skills of graduates are constant over time, this averaging is appropriate and uses the available information to obtain the most reliable estimate of skills. If on the other hand there is changing performance, this averaging will introduce measurement error of varying degrees over the sample of economic data (1960–2000). The analysis in Hanushek and Woessmann (forthcoming) shows some variation over time, but there is no clear way to deal with this here.

When looking at effects of the distribution of cognitive skills, we go beyond the mean performance of a country’s students and calculate the share of students above a certain test-score threshold, as well as the performance of students at different percentiles of a country, both based on our transformed metric of scores. This requires going into the details of the student-level micro data for each international test, which we can do for each test in mathematics and science with the exception of FIMS, where the micro data seem no longer accessible. See Hanushek and Woessmann (forthcoming) for details.

We observe a total of seventy-seven countries that have ever participated in any of the nine international student achievement tests in mathematics and science.⁴⁷ Fifty of these are included in the analyses of economic growth.⁴⁸ Twenty-five countries are

⁴⁷ The latest round of PISA results, conducted in 2006 and released in December 2007, is not contained in our analyses because it substantially postdates our 1960–2000 period of observation. There are five countries participating in PISA 2006 that had never participated on a previous international test. Likewise, the 2006 round of the PIRLS primary-school reading test includes three additional participants without prior international achievement data.

⁴⁸ There are four countries with test-score data which have a few years missing at the beginning or end of the 1960–2000 period on the income data in the Penn World Tables. In particular, data for Tunisia starts in 1961 rather than 1960, and data for Cyprus (1996), Singapore (1996), and Taiwan (1998) end slightly earlier than in 2000. These countries were included in the growth regressions by estimating average annual growth over the available thirty-six–thirty-nine year period rather than the whole forty year period.

not included in the growth database due to lack of data on economic output or because they drop out of the sample for a standard exclusion criterion in growth analyses (fifteen former communist countries, three countries for which oil production is the dominant industry, two small countries, three newly created countries, two further countries lacking early output data). Two countries (Nigeria and Botswana) turn out to be strong outliers in the growth regressions and are therefore dropped from the sample.⁴⁹

REFERENCES

- Acemoglu, Daron, and Joshua D. Angrist. 2001. "How Large Are Human-Capital Externalities? Evidence from Compulsory Schooling Laws." In *NBER Macroeconomics Annual 2000*, ed. Ben S. Bernanke and Kenneth Rogoff, 9–59. Cambridge and London: MIT Press.
- Acemoglu, Daron, Simon Johnson, and James A. Robinson. 2001. "The Colonial Origins of Comparative Development: An Empirical Investigation." *American Economic Review*, 91(5): 1369–1401.
- Acemoglu, Daron, Simon Johnson, and James A. Robinson. 2002. "Reversal of Fortune: Geography and Institutions in the Making of the Modern World Income Distribution." *Quarterly Journal of Economics*, 117(4): 1231–94.
- Acemoglu, Daron, Simon Johnson, and James A. Robinson. 2005. "Institutions as a Fundamental Cause of Long-Run Growth." In *Handbook of Economic Growth, Volume 1a*, ed. Philippe Aghion and Steven N. Durlauf, 385–472. Amsterdam and San Diego: Elsevier, North-Holland.
- Aghion, Philippe, and Peter Howitt. 1998. *Endogenous Growth Theory*. Cambridge and London: MIT Press.
- Alderman, Harold, Jere R. Behrman, David R. Ross, and Richard Sabot. 1996. "The Returns to Endogenous Human Capital in Pakistan's Rural Wage Labour Market." *Oxford Bulletin of Economics and Statistics*, 58(1): 29–55.
- Altonji, Joseph G., and Charles R. Pierret. 2001. "Employer Learning and Statistical Discrimination." *Quarterly Journal of Economics*, 116(1): 313–50.
- Angrist, Joshua D., and Victor Lavy. 1997. "The Effect of a Change in Language of Instruction on the Returns to Schooling in Morocco." *Journal of Labor Economics*, 15(1): S48–76.
- Ashenfelter, Orley, and Alan B. Krueger. 1994. "Estimates of the Economic Returns to Schooling from a New Sample of Twins." *American Economic Review*, 84(5): 1157–73.
- Azariadis, Costas, and Allan Drazen. 1990. "Threshold Externalities in Economic Development." *Quarterly Journal of Economics*, 105(2): 501–26.
- Barro, Robert J. 1991. "Economic Growth in a Cross Section of Countries." *Quarterly Journal of Economics*, 106(2): 407–43.
- Barro, Robert J. 1997. *Determinants of Economic Growth: A Cross-Country Empirical Study*. Cambridge and London: MIT Press.
- Barro, Robert J. 2001. "Human Capital and Growth." *American Economic Review*, 91(2): 12–17.
- Barro, Robert J., and Jong-Wha Lee. 1993. "International Comparisons of Educational Attainment." *Journal of Monetary Economics*, 32(3): 363–94.
- Barro, Robert J., and Jong-Wha Lee. 2001. "International Data on Educational Attainment: Updates and Implications." *Oxford Economic Papers*, 53(3): 541–63.
- Barro, Robert J., and Xavier Sala-i-Martin. 2004. *Economic Growth*. Second edition. Cambridge and London: MIT Press.
- Behrman, Jere R., Lori Kletzer, Michael McPherson, and Morton Owen Schapiro. 1998. "Microeconomics of College Choice, Careers, and Wages." *Annals of the American Academy of Political and Social Science*, 559(1): 12–23.
- Behrman, Jere R., David R. Ross, and Richard Sabot. 2008. "Improving Quality versus Increasing the Quantity of Schooling: Estimates of Rates of Return from Rural Pakistan." *Journal of Development Economics*, 85(1–2): 94–104.
- Benhabib, Jess, and Mark M. Spiegel. 1994. "The Role of Human Capital in Economic Development: Evidence from Aggregate Cross-Country Data." *Journal of Monetary Economics*, 34(2): 143–73.
- Benhabib, Jess, and Mark M. Spiegel. 2005. "Human Capital and Technology Diffusion." In *Handbook of Economic Growth, Volume 1a*, ed. Philippe Aghion and Steven N. Durlauf, 935–66. Amsterdam and San Diego: Elsevier, North-Holland.
- Ben-Porath, Yoram. 1967. "The Production of Human

⁴⁹ The qualitative results of the growth regressions are the same when the two outliers are included, but they are excluded in order to ensure that results are not driven by them. Results are also robust to using median regressions, which are less sensitive to outliers, and to using robust regression techniques such as the rreg robust estimation command implemented in Stata that drop or downweight

outliers based on specific rules. The rreg method starts by eliminating gross outliers for which Cook's distance measure is greater than one, and then iteratively downweights observations with large absolute residuals. It turns out that this method assigns weights of 0.000 and 0.004, respectively, to Nigeria and Botswana, while the next lowest weight that any country receives is bigger than 0.5.

- Capital and the Life Cycle of Earnings." *Journal of Political Economy*, 75(4): 352–65.
- Ben-Porath, Yoram. 1970. "The Production of Human Capital over Time." In *Education, Income and Human Capital*, ed. W. Lee Hansen, 129–47. New York: National Bureau of Economic Research.
- Betts, Julian R. 1996. "Is There a Link between School Inputs and Earnings? Fresh Scrutiny of an Old Literature." In *Does Money Matter? The Effect of School Resources on Student Achievement and Adult Success*, ed. Gary Burtless, 141–91. Washington, D.C.: Brookings Institution Press.
- Bils, Mark, and Peter J. Klenow. 2000. "Does Schooling Cause Growth?" *American Economic Review*, 90(5): 1160–83.
- Bishop, John Hillman. 1989. "Is the Test Score Decline Responsible for the Productivity Growth Decline?" *American Economic Review*, 79(1): 178–97.
- Bishop, John Hillman. 1991. "Achievement, Test Scores, and Relative Wages." In *Workers and Their Wages: Changing Patterns in the United States*, ed. Marvin H. Koster, 146–86. Washington, D.C.: AEI Press.
- Blackburn, McKinley L., and David Neumark. 1993. "Omitted-Ability Bias and the Increase in the Return to Schooling." *Journal of Labor Economics*, 11(3): 521–44.
- Blackburn, McKinley L., and David Neumark. 1995. "Are OLS Estimates of the Return to Schooling Biased Downward? Another Look." *Review of Economics and Statistics*, 77(2): 217–30.
- Bloom, David E. 2006. *Measuring Global Educational Progress*. Cambridge, Mass.: American Academy of Arts and Sciences.
- Boissiere, M., John B. Knight, and Richard Sabot. 1985. "Earnings, Schooling, Ability, and Cognitive Skills." *American Economic Review*, 75(5): 1016–30.
- Bosworth, Barry P., and Susan M. Collins. 2003. "The Empirics of Growth: An Update." *Brookings Papers on Economic Activity*, 2: 113–79.
- Bowles, Samuel, and Herbert Gintis. 1976. *Schooling in Capitalist America: Educational Reform and the Contradictions of Economic Life*. New York: Basic Books.
- Bowles, Samuel, Herbert Gintis, and Melissa Osborne. 2001. "The Determinants of Earnings: A Behavioral Approach." *Journal of Economic Literature*, 39(4): 1137–76.
- Card, David. 1999. "The Causal Effect of Education on Earnings." In *Handbook of Labor Economics, Volume 3a*, ed. Orley Ashenfelter and David Card, 1801–63. Amsterdam; New York and Oxford: Elsevier Science, North-Holland.
- Card, David, and Alan B. Krueger. 1992. "Does School Quality Matter? Returns to Education and the Characteristics of Public Schools in the United States." *Journal of Political Economy*, 100(1): 1–40.
- Castello, Amparo, and Rafael Domenech. 2002. "Human Capital Inequality and Economic Growth: Some New Evidence." *Economic Journal*, 112(478): C187–200.
- Ciccone, Antonio, and Elias Papaioannou. 2005. "Human Capital, the Structure of Production, and Growth." Department of Economics and Business, Universitat Pompeu Fabra Economics Working Papers.
- Ciccone, Antonio, and Giovanni Peri. 2006. "Identifying Human-Capital Externalities: Theory with Applications." *Review of Economic Studies*, 73(2): 381–412.
- Cohen, Daniel, and Marcelo Soto. 2007. "Growth and Human Capital: Good Data, Good Results." *Journal of Economic Growth*, 12(1): 51–76.
- Coulombe, Serge, and Jean-François Tremblay. 2006. "Literacy and Growth." *B.E. Journals in Macroeconomics: Topics in Macroeconomics*, 6(2): 1–32.
- Coulombe, Serge, Jean-François Tremblay, and Sylvie Marchand. 2004. *Literacy Scores, Human Capital and Growth across Fourteen OECD Countries*. Ottawa: Statistics Canada.
- Cunha, Flavio, James J. Heckman, Lance J. Lochner, and Dimitriy V. Masterov. 2006. "Interpreting the Evidence on Life Cycle Skill Formation." In *Handbook of the Economics of Education, Volume 1*, ed. Eric A. Hanushek and Finis Welch, 697–805. Amsterdam and Oxford: Elsevier, North-Holland.
- Currie, Janet, and Enrico Moretti. 2003. "Mother's Education and the Intergenerational Transmission of Human Capital: Evidence from College Openings." *Quarterly Journal of Economics*, 118(4): 1495–1532.
- Dee, Thomas S. 2004. "Are There Civic Returns to Education?" *Journal of Public Economics*, 88(9–10): 1697–1720.
- De Gregorio, Jose, and Jong-Wha Lee. 2002. "Education and Income Inequality: New Evidence from Cross-Country Data." *Review of Income and Wealth*, 48(3): 395–416.
- De la Fuente, Angel, and Rafael Domenech. 2001. "Schooling Data, Technological Diffusion, and the Neoclassical Model." *American Economic Review*, 91(2): 323–27.
- De la Fuente, Angel, and Rafael Domenech. 2006. "Human Capital in Growth Regressions: How Much Difference Does Data Quality Make?" *Journal of the European Economic Association*, 4(1): 1–36.
- Dugan, Dennis J. 1976. "Scholastic Achievement: Its Determinants and Effects in the Education Industry." In *Education as an Industry*, ed. Joseph T. Froomkin, Dean T. Jamison and Roy Radner, 53–83. Cambridge, Mass.: Ballinger.
- Easterly, William. 2001. *The Elusive Quest for Growth: Economists' Adventures and Misadventures in the Tropics*. Cambridge and London: MIT Press.
- Filmer, Deon. 2006. *Educational Attainment and Enrollment around the World. Development Research Group*. World Bank 2006 [cited 2006]. Available from econ.worldbank.org/projects/edattain.
- Finnie, Ross, and Ronald Meng. 2002. "Minorities, Cognitive Skills and Incomes of Canadians." *Canadian Public Policy*, 28(2): 257–73.
- Gemmell, Norman. 1996. "Evaluating the Impacts of

- Human Capital Stocks and Accumulation on Economic Growth: Some New Evidence." *Oxford Bulletin of Economics and Statistics*, 58(1): 9–28.
- Glewwe, Paul. 1996. "The Relevance of Standard Estimates of Rates of Return to Schooling for Education Policy: A Critical Assessment." *Journal of Development Economics*, 51(2): 267–90.
- Glewwe, Paul. 2002. "Schools and Skills in Developing Countries: Education Policies and Socioeconomic Outcomes." *Journal of Economic Literature*, 40(2): 436–82.
- Glewwe, Paul, and Michael Kremer. 2006. "Schools, Teachers, and Education Outcomes in Developing Countries." In *Handbook of the Economics of Education*, Volume 2, ed. Eric A. Hanushek and Finish Welch, 945–1017. Amsterdam and Oxford: Elsevier, North-Holland.
- Goldin, Claudia and Lawrence F. Katz. 2008. *The Race Between Education and Technology*. Cambridge and London: Harvard University Press, Belknap Press.
- Green, David A., and W. Craig Riddell. 2003. "Literacy and Earnings: An Investigation of the Interaction of Cognitive and Unobserved Skills in Earnings Generation." *Labour Economics*, 10(2): 165–84.
- Griliches, Zvi. 1977. "Estimating the Returns to Schooling: Some Econometric Problems." *Econometrica*, 45(1): 1–22.
- Grogger, Jeff, and Eric Eide. 1995. "Changes in College Skills and the Rise in the College Wage Premium." *Journal of Human Resources*, 30(2): 280–310.
- Gundlach, E., D. Rudman, and Ludger Woessmann. 2002. "Second Thoughts on Development Accounting." *Applied Economics*, 34(11): 1359–69.
- Hall, Robert E., and Charles I. Jones. 1999. "Why Do Some Countries Produce So Much More Output per Worker than Others?" *Quarterly Journal of Economics*, 114(1): 83–116.
- Hanousek, Jan, Dana Hajkova, and Randall K. Filer. 2004. "The Other Side of the Moon: The Data Problem in Analyzing Growth Determinants." William Davidson Institute Working Paper 682.
- Hansen, W. Lee, Burton A. Weisbrod, and William J. Scanlon. 1970. "Schooling and Earnings of Low Achievers." *American Economic Review*, 60(3): 409–18.
- Hanushek, Eric A. 1979. "Conceptual and Empirical Issues in the Estimation of Educational Production Functions." *Journal of Human Resources*, 14(3): 351–88.
- Hanushek, Eric A. 1995. "Interpreting Recent Research on Schooling in Developing Countries." *World Bank Research Observer*, 10(2): 227–46.
- Hanushek, Eric A. 2002. "Publicly Provided Education." In *Handbook of Public Economics*, Volume 4, ed. Alan J. Auerbach and Martin Feldstein, 2045–2141. Amsterdam; London and New York: Elsevier Science, North-Holland.
- Hanushek, Eric A. 2003. "The Failure of Input-Based Schooling Policies." *Economic Journal*, 113(485): F64–98.
- Hanushek, Eric A. 2005. "The Economics of School Quality." *German Economic Review*, 6(3): 269–86.
- Hanushek, Eric A., and Dongwook Kim. 1995. "Schooling, Labor Force Quality, and Economic Growth." National Bureau of Economic Research Working Paper 5399.
- Hanushek, Eric A., and Dennis D. Kimko. 2000. "Schooling, Labor-Force Quality, and the Growth of Nations." *American Economic Review*, 90(5): 1184–1208.
- Hanushek, Eric A., Victor Lavy, and Kohtaro Hitomi. 2008. "Do Students Care about School Quality? Determinants of Dropout Behavior in Developing Countries." *Journal of Human Capital*, 2(1): 69–105.
- Hanushek, Eric A., and Richard R. Pace. 1995. "Who Chooses to Teach (and Why)?" *Economics of Education Review*, 14(2): 101–17.
- Hanushek, Eric A., Steven G. Rivkin, and Lori L. Taylor. 1996. "Aggregation and the Estimated Effects of School Resources." *Review of Economics and Statistics*, 78(4): 611–27.
- Hanushek, Eric A., and Ludger Woessmann. 2007. "The Role of School Improvement in Economic Development." National Bureau of Economic Research Working Paper 12832.
- Hanushek, Eric A., and Ludger Woessmann. Forthcoming. *The Human Capital of Nations*.
- Hanushek, Eric A., and Lei Zhang. 2008. "Quality-Consistent Estimates of International Returns to Skill." Unpublished.
- Harbison, Ralph W., and Eric A. Hanushek. 1992. *Educational Performance of the Poor: Lessons from Rural Northeast Brazil*. Oxford; New York; Toronto and Melbourne: Oxford University Press.
- Harmon, Colm, Hessel Oosterbeek, and Ian Walker. 2003. "The Returns to Education: Microeconomics." *Journal of Economic Surveys*, 17(2): 115–55.
- Heckman, James J. 1976. "A Life-Cycle Model of Earnings, Learning, and Consumption." *Journal of Political Economy*, 84(4): S11–44.
- Heckman, James J., Anne Layne-Farrar, and Petra E. Todd. 1996. "Human Capital Pricing Equations with an Application to Estimating the Effect of Schooling Quality on Earnings." *Review of Economics and Statistics*, 78(4): 562–610.
- Heckman, James J., Lance J. Lochner, and Petra E. Todd. 2006. "Earnings Functions, Rates of Return and Treatment Effects: The Mincer Equation and Beyond." In *Handbook of the Economics of Education*, Volume 1, ed. Eric A. Hanushek and Finish Welch, 307–458. Amsterdam and Oxford: Elsevier, North-Holland.
- Heckman, James J., Jora Stixrud, and Sergio Urzua. 2006. "The Effects of Cognitive and Noncognitive Abilities on Labor Market Outcomes and Social Behavior." *Journal of Labor Economics*, 24(3): 411–82.
- Heckman, James J., and Edward Vytlacil. 2001. "Identifying the Role of Cognitive Ability in Explaining the Level of Change in the Return to Schooling." *Review of Economics and Statistics*, 83(1): 1–12.
- Heston, Alan, Robert Summers, and Bettina Aten.

2002. "Penn World Table Version 6.1" Center for International Comparisons at the University of Pennsylvania (CICUP).
- Jamison, Eliot A., Dean T. Jamison, and Eric A. Hanushek. 2006. "The Effects of Education Quality on Income Growth and Mortality Decline." National Bureau of Economic Research Working Paper 12652.
- Jamison, Eliot A., Dean T. Jamison, and Eric A. Hanushek. 2007. "The Effects of Education Quality on Income Growth and Mortality Decline." *Economics of Education Review*, 26(6): 771–88.
- Jolliffe, Dean. 1998. "Skills, Schooling, and Household Income in Ghana." *World Bank Economic Review*, 12(1): 81–104.
- Juhn, Chinhui, Kevin M. Murphy, and Brooks Pierce. 1993. "Wage Inequality and the Rise in Returns to Skill." *Journal of Political Economy*, 101(3): 410–42.
- Katz, Lawrence F., and Kevin M. Murphy. 1992. "Changes in Relative Wages, 1963–1987: Supply and Demand Factors." *Quarterly Journal of Economics*, 107(1): 35–78.
- Klenow, Peter J., and Andres Rodriguez-Clare. 1997. "The Neoclassical Revival in Growth Economics: Has It Gone Too Far?" In *NBER Macroeconomics Annual 1997*, ed. Ben S. Bernanke and Julio J. Rotemberg, 73–103. Cambridge and London: MIT Press.
- Knack, Stephen, and Philip Keefer. 1995. "Institutions and Economic Performance: Cross-Country Tests Using Alternative Institutional Measures." *Economics and Politics*, 7(3): 207–27.
- Knight, John B., and Richard Sabot. 1990. *Education, Productivity, and Inequality: The East African Natural Experiment*. Oxford; New York; Toronto and Melbourne: Oxford University Press.
- Knighton, Tamara, and Patrick Bussière. 2006. "Educational Outcomes at Age 19 Associated with Reading Ability at Age 15." Culture, Tourism and the Centre for Education Statistics Research Paper 43.
- Krueger, Alan B., and Mikael Lindahl. 2001. "Education for Growth: Why and for Whom?" *Journal of Economic Literature*, 39(4): 1101–36.
- Krueger, Anne O. 1974. "The Political Economy of the Rent-Seeking Society." *American Economic Review*, 64(3): 291–303.
- Lange, Fabian, and Robert Topel. 2006. "The Social Value of Education and Human Capital." In *Handbook of the Economics of Education, Volume 1*, ed. Eric A. Hanushek and Finis Welch, 459–509. Amsterdam and Oxford: Elsevier, North-Holland.
- Lazear, Edward P. 2003. "Teacher Incentives." *Swedish Economic Policy Review*, 10(3): 179–214.
- Lee, Doo Won, and Tong Hun Lee. 1995. "Human Capital and Economic Growth Tests Based on the International Evaluation of Educational Achievement." *Economics Letters*, 47(2): 219–25.
- Levine, Ross, and David Renelt. 1992. "A Sensitivity Analysis of Cross-Country Growth Regressions." *American Economic Review*, 82(4): 942–63.
- Levy, Frank, and Richard J. Murnane. 1992. "U.S. Earnings Levels and Earnings Inequality: A Review of Recent Trends and Proposed Explanations." *Journal of Economic Literature*, 30(3): 1333–81.
- Lochner, Lance J., and Enrico Moretti. 2004. "The Effect of Education on Crime: Evidence from Prison Inmates, Arrests, and Self-Reports." *American Economic Review*, 94(1): 155–89.
- Louat, Frederic F., Dean T. Jamison, and Lawrence J. Lau. 1991. "Education and Productivity in Developing Countries: An Aggregate Production Function Approach." World Bank Policy Research Working Paper 612.
- Lucas, Robert E., Jr. 1988. "On the Mechanics of Economic Development." *Journal of Monetary Economics*, 22(1): 3–42.
- Mankiw, N. Gregory, David Romer, and David N. Weil. 1992. "A Contribution to the Empirics of Economic Growth." *Quarterly Journal of Economics*, 107(2): 407–37.
- Manski, Charles F., and David A. Wise. 1983. *College Choice in America*. Cambridge and London: Harvard University Press.
- McArthur, John W., and Jeffrey D. Sachs. 2001. "Institutions and Geography: Comment on Acemoglu, Johnson and Robinson (2000)." National Bureau of Economic Research Working Paper 8114.
- McIntosh, Steven, and Anna Vignoles. 2001. "Measuring and Assessing the Impact of Basic Skills on Labour Market Outcomes." *Oxford Economic Papers*, 53(3): 453–81.
- Milligan, Kevin, Enrico Moretti, and Philip Oreopoulos. 2004. "Does Education Improve Citizenship? Evidence from the United States and the United Kingdom." *Journal of Public Economics*, 88(9–10): 1667–95.
- Mincer, Jacob. 1970. "The Distribution of Labor Incomes: A Survey with Special Reference to the Human Capital Approach." *Journal of Economic Literature*, 8(1): 1–26.
- Mincer, Jacob. 1974. *Schooling, Experience, and Earnings*. New York: National Bureau of Economic Research.
- Moll, Peter G. 1998. "Primary Schooling, Cognitive Skills and Wages in South Africa." *Economica*, 65(258): 263–84.
- Moretti, Enrico. 2004. "Workers' Education, Spillovers, and Productivity: Evidence from Plant-Level Production Functions." *American Economic Review*, 94(3): 656–90.
- Mulligan, Casey B. 1999. "Galton versus the Human Capital Approach to Inheritance." *Journal of Political Economy*, 107(6): S184–224.
- Murnane, Richard J., John B. Willett, M. Jay Braatz, and Yves Duhaldeborde. 2001. "Do Different Dimensions of Male High School Students' Skills Predict Labor Market Success a Decade Later? Evidence from the NLSY." *Economics of Education Review*, 20(4): 311–20.
- Murnane, Richard J., John B. Willett, Yves Duhaldeborde, and John H. Tyler. 2000. "How Important

- Are the Cognitive Skills of Teenagers in Predicting Subsequent Earnings." *Journal of Policy Analysis and Management*, 19(4): 547–68.
- Murnane, Richard J., John B. Willett, and Frank Levy. 1995. "The Growing Importance of Cognitive Skills in Wage Determination." *Review of Economics and Statistics*, 77(2): 251–66.
- Murphy, Kevin M., Andrei Shleifer, and Robert W. Vishny. 1991. "The Allocation of Talent: Implications for Growth." *Quarterly Journal of Economics*, 106(2): 503–30.
- Neal, Derek A., and William R. Johnson. 1996. "The Role of Premarket Factors in Black–White Wage Differences." *Journal of Political Economy*, 104(5): 869–95.
- Nehru, Vikram, Eric Swanson, and Ashutosh Dubey. 1995. "A New Database on Human Capital Stock in Developing and Industrial Countries: Sources, Methodology, and Results." *Journal of Development Economics*, 46(2): 379–401.
- Neidorf, Teresa Smith, Marilyn Binkley, Kim Gattis, and David Nohara. 2006. *Comparing Mathematics Content in the National Assessment of Educational Progress (NAEP), Trends in International Mathematics and Science Study (TIMSS), and Program for International Student Assessment (PISA) 2003 Assessments*. Washington, D.C.: National Center for Education Statistics.
- Nelson, Richard R., and Edmund Phelps. 1966. "Investment in Humans, Technology Diffusion, and Economic Growth." *American Economic Review*, 56(2): 69–75.
- Nickell, Stephen. 2004. "Poverty and Worklessness in Britain." *Economic Journal*, 114(494): C1–25.
- North, Douglass C. 1990. *Institutions, Institutional Change and Economic Performance*. Cambridge; New York and Melbourne: Cambridge University Press.
- O'Neill, June. 1990. "The Role of Human Capital in Earnings Differences between Black and White Men." *Journal of Economic Perspectives*, 4(4): 25–45.
- Oreopoulos, Philip. 2006. "Estimating Average and Local Average Treatment Effects of Education When Compulsory Schooling Laws Really Matter." *American Economic Review*, 96(1): 152–75.
- Organisation for Economic Co-operation and Development. 2003. *Education at a Glance: OECD Indicators 2003*. Paris and Washington, D.C.: Organisation for Economic Co-operation and Development.
- Organisation for Economic Co-operation and Development. 2004. *Learning for Tomorrow's World: First Results from PISA 2003*. Paris and Washington, D.C.: Organisation for Economic Co-operation and Development.
- Parente, Stephen L., and Edward C. Prescott. 1994. "Barriers to Technology Adoption and Development." *Journal of Political Economy*, 102(2): 298–321.
- Parente, Stephen L., and Edward C. Prescott. 1999. "Monopoly Rights: A Barrier to Riches." *American Economic Review*, 89(5): 1216–33.
- Pritchett, Lant. 2001. "Where Has All the Education Gone?" *World Bank Economic Review*, 15(3): 367–91.
- Pritchett, Lant. 2004. "Access to Education." In *Global Crises, Global Solutions*, ed. Bjorn Lomborg, 175–234. Cambridge; New York and Melbourne: Cambridge University Press.
- Pritchett, Lant. 2006. "Does Learning to Add Up Add Up? The Returns to Schooling in Aggregate Data." In *Handbook of the Economics of Education, Volume 1*, ed. Eric A. Hanushek and Finis Welch, 635–95. Amsterdam and Oxford: Elsevier, North-Holland.
- Psacharopoulos, George. 1994. "Returns to Investment in Education: A Global Update." *World Development*, 22(9): 1325–43.
- Psacharopoulos, George, and Harry Anthony Patrinos. 2004. "Returns to Investment in Education: A Further Update." *Education Economics*, 12(2): 111–34.
- Rivkin, Steven G. 1995. "Black/White Differences in Schooling and Employment." *Journal of Human Resources*, 30(4): 826–52.
- Romer, Paul M. 1990a. "Endogenous Technological Change." *Journal of Political Economy*, 98(5): S71–102.
- Romer, Paul M. 1990b. "Human Capital and Growth: Theory and Evidence." *Carnegie-Rochester Conference Series on Public Policy*, 32: 251–86.
- Sachs, Jeffrey D., and Andrew M. Warner. 1995. "Economic Reform and the Process of Global Integration." *Brookings Papers on Economic Activity*, 1: 1–95.
- Sala-i-Martin, Xavier, Gernot Doppelhofer, and Ronald I. Miller. 2004. "Determinants of Long-Term Growth: A Bayesian Averaging of Classical Estimates (BACE) Approach." *American Economic Review*, 94(4): 813–35.
- Sianesi, Barbara, and John Van Reenen. 2003. "The Returns to Education: Macroeconomics." *Journal of Economic Surveys*, 17(2): 157–200.
- Temple, Jonathan. 1999. "A Positive Effect of Human Capital on Growth." *Economics Letters*, 65(1): 131–34.
- Temple, Jonathan. 2001. "Growth Effects of Education and Social Capital in the OECD Countries." *OECD Economic Studies*, 33: 57–101.
- Temple, Jonathan, and Ludger Woessmann. 2006. "Dualism and Cross-Country Growth Regressions." *Journal of Economic Growth*, 11(3): 187–228.
- Topel, Robert. 1999. "Labor Markets and Economic Growth." In *Handbook of Labor Economics, Volume 3c*, ed. Orley Ashenfelter and David Card, 2943–84. Amsterdam; New York and Oxford: Elsevier Science, North-Holland.
- UNESCO. 2005. *Education for All: The Quality Imperative, EFA Global Monitoring Report*. Paris: UNESCO.
- UNESCO. 2007. *EFA Global Monitoring Report: Strong Foundations: Early Childhood Care and Education*. Paris: UNESCO.

- Vandenbussche, Jerome, Philippe Aghion, and Costas Meghir. 2006. "Growth, Distance to Frontier and Composition of Human Capital." *Journal of Economic Growth*, 11(2): 97–127.
- Vijverberg, Wim P. M. 1999. "The Impact of Schooling and Cognitive Skills on Income from Non-farm Self-Employment." In *The Economics of School Quality Investments in Developing Countries: An Empirical Study of Ghana*, ed. Paul Glewwe, 206–52. New York: St. Martin's Press; London: Macmillan Press.
- Woessmann, Ludger. 2002. *Schooling and the Quality of Human Capital*. Heidelberg and New York: Springer.
- Woessmann, Ludger. 2003. "Specifying Human Capital." *Journal of Economic Surveys*, 17(3): 239–70.
- Woessmann, Ludger. 2004. "Access to Education: Perspective Paper." In *Global Crises, Global Solutions*, ed. Bjorn Lomborg, 241–50. Cambridge; New York and Melbourne: Cambridge University Press.
- Woessmann, Ludger. 2005. "Educational Production in Europe." *Economic Policy*, 43: 445–93.
- Woessmann, Ludger. 2007. "International Evidence on Expenditures and Class Size: A Review." In *Brookings Papers on Education Policy: 2006–2007*, ed. Tom Loveless and Frederick Hess, 245–72. Washington, D.C.: Brookings Institution Press.
- World Bank. 1993. *The East Asian Miracle: Economic Growth and Public Policy*. Oxford and New York: Oxford University Press.
- World Bank Independent Evaluation Group. 2006. *From Schooling Access to Learning Outcomes: An Unfinished Agenda: An Evaluation of World Bank Support to Primary Education*. Washington, D.C.: World Bank.