Annex A

Review of knowledge capital and growth

This annex provides a more technical overview of the estimates of growth models that are relied upon in the text. It also describes the various tests used to judge whether the estimates can be interpreted as causal estimates of the effect of knowledge capital. More detail is found in Hanushek and Woessmann (2015).

Basic growth model estimates

Prior theoretical and empirical work has pursued a variety of specifications of the underlying growth process.[1] Because the economic analysis of this report relies heavily on the estimates of growth models, it is useful to have an overview of these.

A country's growth rate can be considered as a function of workers' skills along with other systemic factors, including economic institutions and initial levels of income and technology. Skills are frequently referred to simply as the workers' human capital stock.

$$growth = \alpha_1 human\ capital + \alpha_2 other\ factors + \varepsilon \quad (1)$$

This formulation suggests that nations with more human capital tend to continue to make greater productivity gains than nations with less human capital, although the possibility is considered that the induced growth in productivity disappears over time.[2]

The empirical macroeconomic literature focusing on cross-country differences in economic growth has overwhelmingly employed measures related to school attainment, or years of schooling, to test the human capital aspects of growth models. It has tended to find a significant positive association between quantitative measures of schooling and economic growth.[3]

Nevertheless, these formulations introduce substantial bias into the picture of economic growth. Average years of schooling is a particularly incomplete and potentially misleading measure of education for comparing the impacts of human capital on the economies of different countries. It 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 Brazil is assumed to create the same increase in productive human capital as a year of schooling in Korea.[4] Formulations relying on this measure also assume that formal schooling is the only source of education, and that variations in non-school factors have negligible effects on education outcomes and skills. This neglect of cross-country differences in the quality of schools and in the strength of family, health and other influences is probably the major drawback of such a quantitative measure of schooling.

The role of other influences is in fact acknowledged in a standard version of an education production function as employed in extensive literature.[5] This formula expresses skills as a function of a range of factors:

$$human\ capital = \beta_1 schools + \beta_2 families + \beta_3 ability + \beta_4 health + \beta_5 other\ factors + \upsilon \quad (2)$$

In general, human capital combines both school attainment and school quality with the other relevant factors, including education in the family, health, labour market experience and so forth.

Thus, while school attainment has been a convenient measure to use in empirical work because the data are readily available across countries, its use ignores differences in school quality in addition to other important determinants of people's skills. A more satisfying alternative is to incorporate variations in cognitive skills, which can be determined through international assessments of mathematics, science and reading achievement, as a direct measure of the human capital input into empirical analyses of economic growth.

The focus on cognitive skills has a number of potential advantages. First, it captures variations in the knowledge and ability that schools strive to produce, and thus relates the putative outputs of schooling to subsequent economic success. Second, by emphasising total outcomes of education, it incorporates skills from any source – including families and innate ability as well as schools. Third, by allowing for differences in performance among students whose schooling differs in quality (but possibly not in quantity), it acknowledges – and invites investigation of – the effect of different policies on school quality. Fourth, it is practical in that data are readily available through consistent and reliable cross-country assessments.

The growth analysis relies on the measures of cognitive skills developed in Hanushek and Woessmann (2015). Between 1964 and 2003, 12 different international tests of math, science or reading were administered to a voluntarily participating group of countries.[6] These tests produce 36 different possible scores for subject-year-age combinations (e.g. science for students of grade 8 in 1972 as part of the First International Science Study, or mathematics for 15-year-olds in 2000 as a part of the first test in the Programme for International Student Assessment [PISA]). The assessments were designed to identify a common set of expected skills, which were then tested in the local language. Each test is newly constructed, until recently with no effort to link to any of the other tests. Hanushek and Woessmann (2015) describe the construction of consistent measures at the national level across countries through empirical calibration of the different tests.[7] These measures of knowledge capital for nations rely on the average (standardised) test scores for each country's historical participation in the tests. The aggregate scores are scaled (like PISA today) to have a mean of 500 and a standard deviation at the individual level of 100 across OECD countries.

The test scores can be interpreted as an index of the human capital of the population of each country. This interpretation of averages over different cohorts is reasonable if a country's scores have been stable across time – that is, if estimates from recent school-aged populations provide an estimate of the older working population.[8] If scores (and skills) change over time, some measurement error is clearly introduced. Scores have, in fact, changed somewhat, but within the period of observations, differences in levels across countries dominate any intertemporal score changes.[9]

Based on the more refined measure of human capital found in the aggregate test scores for each country, equation (1) can be estimated.[10] Table A.1 presents the basic results on the association between education outcomes and long-run economic growth in the sample of 50 countries for which both economic growth data and measures of knowledge capital are available.[11] The inclusion of initial per capita GDP in all specifications simply reflects the fact that it is easier for countries to grow when they are farther from the technology frontier, because they need only imitate others rather than invent new things.

TABLE A.1 BASIC GROWTH REGRESSIONS: LONG-RUN GROWTH IN PER CAPITA GDP, 1960-2000

	(1)	(2)	(3)
Cognitive skills		2.015***	1.980***
		(10.68)	(9.12)
Initial years of schooling (1960)	0.369***		0.026
	(3.23)		(0.34)
Initial per capita GDP (1960)	-0.379***	-0.287***	-0.302***
	(4.24)	(9.15)	(5.54)
Constant	2.785***	-4.827***	-4.737***
	(7.41)	(6.00)	(5.54)
Number of countries	50	50	50
R^2 (adj.)	0.252	0.733	0.728

Notes: Dependent variable: average annual growth rate in per capita GDP, 1960 to 2000. Cognitive skill measure refers to average score on all international tests 1964 to 2003 in mathematics and science, primary through end of secondary school. t-Statistics in parentheses: statistical significance at *** 1%. Source: Hanushek and Woessmann (2015).

When knowledge capital is ignored (column 1 of Table A.1), years of schooling in 1960 is significantly associated with average annual growth rates in real per capita GDP in 1960-2000.[12] However, once the test measure of human capital is included (columns 2 and 3), cognitive skills are highly significant, and years of schooling become statistically insignificant, as the estimated coefficient drops to close to zero. Furthermore, the variation in cross-country growth explained by the model increases from 25% to 73% when human capital is measured by cognitive skills rather than years of schooling. Note that the bivariate association with initial per capita GDP already accounts for 7% of the variance in subsequent growth. All the more remarkable, then, is the relative increase in understanding growth that comes from including cognitive skills over what would be seen from just the natural convergence of growth as countries move toward greater development.

The estimated coefficient on cognitive skills implies that an increase of one standard deviation in educational achievement (i.e. 100 score points on the PISA scale) yields an average annual growth rate over the 40 years of observation that is two percentage points higher. This historical experience suggests a very powerful response to improvements in education outcomes, particularly when compared to the average 2.3% annual growth within the sampled countries over the past two decades.

Causality in brief

The fundamental question the analysis raises is this: should this tight relationship between cognitive skills and economic growth be interpreted as a causal one that can support direct policy actions?[13] In other words, if achievement were raised, would growth rates be expected to go up by a commensurate amount?

Work on differences in growth among countries, while extensive over the past two decades, has been plagued by legitimate questions about whether any truly causal effects have been identified, or whether the estimated statistical analyses simply pick up a correlation that emerges for other reasons.

Knowing that the relationship is causal, and not simply a byproduct of some other factors, is clearly important from a policy standpoint. Policymaking requires confidence that by improving academic achievement, countries will bring about a corresponding improvement in the long-run growth rate. If the relationship between test scores and growth rates simply reflects other factors that are correlated with both test scores and growth rates, policies designed to raise test scores may have little or no impact on the economy.

The early studies that found positive effects of years of schooling on economic growth may well have been suffering from reverse causality; they correctly identified a relationship between improved growth and more schooling, but incorrectly saw the latter as the cause and not the effect.[14] In this case, the data may have reflected the fact that as a country gets richer, it tends to buy more of many things, including more years of schooling for its population.

There is less reason to think that higher student achievement is caused by economic growth. For one thing, scholars have found little impact of additional education spending on achievement outcomes, so it is unlikely that the relationship comes from growth-induced resources lifting student achievement.[15] Still, it remains difficult to develop conclusive tests of causality with the limited sample of countries included in the analysis.

The best way to increase the confidence that higher student achievement results in economic growth is explicitly to consider alternative explanations of the observed achievement-growth relationship to determine whether plausible alternatives that could confound the results can be ruled out. No single approach can address all of the important concerns. But a combination of approaches – if together they provide support for a causal relationship between achievement and growth – can offer some assurance that the potentially problematic issues are not affecting the results.

POTENTIAL PROBLEMS IN IDENTIFYING CAUSALITY

The following summarises the authors' investigations into the potential problems with the prior estimation and their likely severity. These have been more fully reported elsewhere.[16]

First, other factors besides cognitive skills may be responsible for countries' economic growth. In an extensive investigation of alternative model specifications, different measures of cognitive skills, various groupings of countries (including some that eliminate regional differences), and specific sub-periods of economic growth have been employed. But the results show a consistency in the alternative estimates, in both quantitative impacts and statistical significance, that is uncommon in cross-country growth modeling. Nor do measures of geographical location, political stability, capital stock and population growth significantly affect the estimated impact of cognitive skills. These specification tests rule out some basic problems attributable to omitted causal factors that have been noted in prior growth work. Of course, there are other possible omitted factors, leading to a deeper investigation of the details of international differences.

Second, the most obvious reverse-causality issues arise because the analysis relates growth rates over the period 1960 to 2000 to test scores for roughly the same period. To address this directly, the period of the testing is separated from the period of observed economic impacts. Test scores through 1984 are related to economic growth in the period since 1985 (until 2009). In this analysis, available for a sample of 25 countries only, test scores strictly pre-date the growth period, making it clear that increased growth could not be causing the higher test scores. This estimation shows a positive effect of early test scores on subsequent growth rates that is almost twice as large as that displayed above. Indeed, this fact itself may be significant, because it is consistent with the possibility that skills have become even more important for the economy in recent periods.

Third, even if reverse causality is not an issue, one cannot be sure that the important international differences in test scores reflect school policies. After all, differences in achievement may arise because of health and nutrition differences in the population or simply because of cultural differences regarding learning and testing. This concern can be addressed by focusing attention just on the variations in achievement that arise directly from institutional characteristics of each country's school system (exit examinations, autonomy, relative teacher salaries and private schooling).[17] When the analysis is limited in this way, the estimation of the growth relationship yields essentially the same results as previously presented. The similarity of the results supports the causal interpretation of the effect of cognitive skills as well as the conclusion that schooling policies can have direct economic returns.

Fourth, a possible alternative to the conclusion that high achievement drives economic growth not eliminated by the prior analysis is that countries with good economies also have good school systems. In this case, achievement is simply a reflection of other important aspects of the economy and not the driving force in growth.

One simple way to test this possibility is to consider the implications of differences in measured skills within a single economy, thus eliminating institutional or cultural factors that may make the economies of different countries grow faster. This can readily be done by comparing immigrants to the United States who have been educated in their home countries with immigrants educated just in the United States. Since the two groups are within the single labour market of the United States, any differences in labour market returns associated with cognitive skills cannot arise from differences in the economy or culture of their home country.

This comparison finds that the cognitive skills seen in the immigrant's home country lead to higher incomes, but only if the immigrant was in fact educated in the home country. Immigrants from the same home country who are schooled in the United States see no economic return to home-country test scores – a finding that pinpoints the value of better schools. These results hold when Mexicans (the largest U.S. immigrant group) are excluded and when only immigrants from English-speaking countries are included. While not free from problems, this comparative analysis rules out the possibility that test scores simply reflect cultural factors or economic institutions of the home country.[18] It also lends further support to the potential role of schools in changing the cognitive skills of citizens in economically meaningful ways.

CHANGES OVER TIME

Perhaps the toughest test of causality is relating changes in test scores over time to changes in growth rates. If test-score improvements actually lead to an increase in growth rates, it should show up in such a relationship. For those countries that have participated in testing at different points over the past half century, one can observe whether students seem to be getting better or worse over time. (For more recent periods, the report examines changes over time in detail in Chapter 7). This approach implicitly eliminates country-specific economic and cultural factors because it looks at what happens over time within each country.

For 12 OECD countries, the magnitude of trends in education performance can be related to the magnitude of trends in growth rates over time.[19] This investigation provides more evidence of the causal influence of cognitive skills, although the small number of countries is obviously problematic. The gains in test scores over time are very closely related to the gains in growth rates over time.[20] Like the other approaches, this analysis must presume that the pattern of achievement changes has been occurring over a long time, because it is not the achievement of school children but the skills of workers that count. Nonetheless, the consistency of the patterns is striking.

Again, each approach to determining causation is subject to its own uncertainty. Nonetheless, the combined evidence consistently points to the conclusion that differences in cognitive skills lead to significant differences in economic growth. Moreover, even if issues related to omitted factors or reverse causation remain, it seems very unlikely that these cause all of the estimated effects.[21]

Since the causality tests concentrate on the impact of schools, the evidence suggests that school policy, if effective in raising cognitive skills, can be an important force in economic development. While other factors – culture, health, and so forth – may affect the level of cognitive skills in an economy, schools clearly contribute to the development of human capital. More years of schooling in a system that is not well designed to enhance learning, however, will have little effect.

NOTES

1. See the reviews in Hanushek and Woessmann (2008), and OECD, Hanuskek and Woessmann (2010).

2. A major difference of perspective in modeling economic growth rests on whether education should be thought of as an input to overall production, affecting the level of income in a country but not the growth rate in the long run (augmented neoclassical models, as in Mankiw, Romer and Weil [1992]) or whether education directly affects the long-run growth rate (endogenous growth models as, importantly, in Lucas [1988], Romer [1990], and Aghion and Howitt [1998]). See Acemoglu (2009), Aghion and Howitt (2009), Barro and Sala-i-Martin (2004), and Jones and Vollrath (2013) for textbook introductions. In terms of these major theoretical distinctions, the formulation here combines key elements of both competing models. Because the model directly relates the rate of technological change and productivity improvement to the stock of a nation's human capital, it can be seen as an endogenous growth model. At the same time, by including the initial level of income among the control variables, the model does allow for conditional convergence, a leading feature of the augmented neoclassical approach. These alternatives in the projections of economic outcomes are examined in Chapter 5.

3. To give an idea of the robustness of this association, an extensive empirical analysis by Sala-i-Martin, Doppelhofer and Miller (2004) of 67 explanatory variables in growth regressions on a sample of 88 countries found that primary schooling was the most robust influence factor (after an East Asian dummy) on growth in per capita GDP in 1960-96.

4. Various analyses suggest that a difference in test scores of one-quarter to one-third of a standard deviation is equivalent to one year of school attainment. Thus, one way to characterise the differences in schooling between Korea and Brazil is to translate the approximately 1.5 standard deviation difference in PISA scores into differences in effective years of schooling for the 15-year-olds taking the PISA test: some 5-6 years difference in quality-equivalent years of schooling.

5. See Hanushek (1986, 2002) for reviews.

6. See Hanushek and Woessmann (2011) for a review. Note that there have been five major international assessments since 2003. Emphasis is placed on the early assessments because they fit into the analysis of long-run growth. The analysis of economic impacts for countries relies on the subsequent testing.

7. By transforming the means and variances of the original country scores (partly based on external longitudinal test score information available for the United States), each is placed into a common distribution of outcomes. Each age group and subject is normalised to the PISA standard of mean 500 and individual standard deviation of 100 across OECD countries, and then all available test scores are averaged at the country level.

8. The correlation between the measure based on student achievement tests between 1964 and 2003 and the recent adult numeracy achievement test of the Programme for the International Assessment of Adult Competencies (PIAAC), conducted in 2011/12, is 0.448 (statistically significant at the 6% level) among the 18 countries available in both data sets. Without three significant outliers (Korea doing better on the student tests, and Cyprus [see notes at the end of this Annex] and Norway doing better at the adult test), the correlation is 0.793 (significant at the 1% level).

9. For the 50 countries in the growth analysis, 73% of the variance in scores lies between countries (Hanushek and Woessmann [2012]). The remaining 27% includes both true score changes and any measurement error in the tests. Any measurement error in this case will tend to bias downward the estimates of the impact of cognitive skills on growth, so that the estimates of economic implications will be conservative.

10. For data on per capita GDP and its growth, the analyses used the Penn World Tables (Heston, Summers and Aten [2002]). Data on quantitative educational attainment are an extended version of the Cohen and Soto (2007) data. Results are very similar when using the latest Barro and Lee (2013) data on educational attainment; see Hanushek and Woessmann (2015), Appendix 3A.

11. See Hanushek and Woessmann (2012, 2015) for a more complete description of both the data and the estimation, which extends previous work by Hanushek and Kimko (2000).

12. To avoid the 2008 global recession, its aftermath, and any potential bubbles building up beforehand, the growth analysis stops in 2000, but results are very similar when extending the growth period to 2007 or 2009; see Hanushek and Woessmann (2015), Appendix 3A.

13. This section summarises the detailed analysis found in Hanushek and Woessmann (2015), Chapter 4.

14. See, for example, Bils and Klenow (2000).

15. See the review in Hanushek and Woessmann (2011).

16. See the extended discussion in Hanushek and Woessmann (2015), Chapter 4.

17. The formal approach is called "instrumental variables." In order for this to be a valid approach, it must be the case that the institutions are not themselves related to differences in growth beyond their relation with test scores. For a fuller discussion, see Hanushek and Woessmann (2012).

18. The formal approach is often called "difference-in-differences." Three potential problems arise in this analysis. First, it looks at the labour market returns just for the individual and not at the aggregate impact on the economy of achievement differences. Second, those who migrate at a young enough age to be educated in the United States might differ from those who migrate at later ages. Third, employers may treat people with a foreign education differently from those with a U.S. education. The second two potential problems, however, can affect the results only in complicated ways, because the identification of the impact of cognitive skills is based on a comparison across the home countries. As long as the impact of these is similar for the different origin countries, the results would remain. Any problems would come from different patterns of these factors that are correlated with test scores across countries.

19. Only 12 OECD countries have participated in international tests over a long enough period to provide the possibility of looking at trends in test performance over more than 30 years. The analysis simply considers a bivariate regression of test scores on time for countries with multiple observations. The trends in growth rates are determined in a similar manner: annual growth rates are regressed on a time trend. The analysis relates the slopes in the test regression to the slopes in the growth rate regression. Hanushek and Woessmann (2012) consider more complicated statistical relationships, but the overall results hold. They also hold when the sample of countries is expanded to include the non-OECD countries.

20. It is very unlikely that the changes in growth rates suffer the same reverse causality concerns suggested previously, because a change in growth rate can occur at varying income levels and varying rates of growth.

21. Another way to circumvent potential bias in cross-country regression estimates is to employ a development accounting framework that assumes a particular macroeconomic production function and takes parameter values from microeconometric earnings regressions. In such analyses, cognitive skills and years of schooling together play a major role in accounting for cross-country differences in current levels of per capita GDP (Hanushek and Woessmann, 2015, section 4.4). Such estimation is of course highly dependent on the choice of production function parameters. The development accounting in Hanushek and Woessmann (2015) relies on estimates for school attainment and cognitive skills from the International Adult Literacy Survey. Caselli (2014) employs much smaller estimates of the returns to cognitive skills and reaches different conclusions. His returns to skills come from a specific set of coefficient estimates in one Mexican study that uses a shortened-version of the Raven ability test to measure cognitive skills (Vogl, 2014), leading to questions of generalisability.

Notes regarding Cyprus

Readers should note the following information provided by Turkey and by the European Union Member States of the OECD and the European Union regarding the status of Cyprus:

Note by Turkey

The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus issue".

Note by all the European Union member States of the OECD and the European Union

The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

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