Incentive to Invest?

How education affects economic growth

Gabriel Heller Sahlgren

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1 Introduction

Human capital is generally considered a key ingredient for improving countries' economic trajectories. Education, in turn, is viewed as a way to increase the overall level of human capital in the workforce. For example, in 2011, speaking to the Education World Forum, former Education Secretary Michael Gove (2011) claimed that 'the single most effective way to generate economic growth is [to] invest in human and intellectual capital – to build a better education system'. Education might be a way to personal fulfilment, but it can also be an instrument for a healthy economy. Reforming the education system could thus be a key part of any long-term growth strategy.

There are, however, many ways in which education could impact growth. The previous Labour government, for example, increased spending significantly, while gradually raising the compulsory education age from 16 to 18 following the Education and Skills Act of 2008. But will merely expanding the average number of years spent in education be sufficient to improve growth? Or is raising education quality more important than how much education one receives (i.e. 'education quantity')? And how can education policy secure the highest possible economic dividend in as resource efficient manner as possible? This paper aims to answer these questions.

1 Technical statistical terms are generally explained in the body of the text as they occur. These terms appear in bold in the first instance, which link to fuller explanation in the Glossary.

The paper begins by briefly noting the theoretical foundations underpinning the relationship between education and growth. It continues by reviewing the empirical evidence linking education to growth. Most research has focused on measures of education quantity, such as average years of schooling, and the evidence is rather mixed. Recent studies actually suggest that education quantity is unrelated to economic growth.

Yet education quantity is a poor proxy for the level of human capital in the labour force since skills are unlikely to increase linearly with, for example, the number of years that pupils have participated in formal education. New research instead suggests that education quality – measured by international test scores – is a considerably more important contributor to growth than education quantity. In fact, supporting the mixed findings of the overall research on the relationship between education quantity and growth, these studies tend to find that education quantity has either no or only a small impact on growth once education quality is taken into consideration. Estimates suggests that the UK's GDP per capita would have been about $8,751 higher today had it performed as well as Taiwan on average since the mid-twentieth century.

To add robustness to these findings, this report also provides new statistical evidence, analysing the growth impact of TIMSS test scores among pupils in the last year of upper-secondary school only. The results give further support to the argument that education quality, but not quantity, spurs growth. The preferred model suggests that a 10 per cent increase in test scores raises a country's average annual growth rate by 0.85 percentage points, which is remarkably similar to what previous research has found.

The estimated impact in this paper and previous studies is very large and suggests a strong case for education reform. It is important to note that much research utilise similar methodology, which might pick up other factors than just education quality to a certain extent. For example, there is a risk that stronger work ethic correlates with higher cognitive skills, and that it is the former that produces higher growth. Nevertheless, newer research utilise more sophisticated strategies to separate causation from correlation, and it finds very similar effects. But even if the true effect were just half of the estimated one, it would still be too economically important to ignore.

The results also display the important spill-over effects school choice and competition may have if these mechanisms successfully work to raise educational achievement. The strongest available research shows that independent school competition increases performance in international tests, while also decreasing educational costs. Calculations imply that an expansion of the share of pupils attending independently operated schools to the Netherlands' level would raise the annual average economic growth rate by 0.92 percentage points in the long term. This, in turn, implies that the UK's per-capita GDP would have been $10,165 higher in 2007 if it had had that long-term level of independent-school enrolment in 1960. This stands in contrast to costly universal input-based policies, which are rarely successful at raising achievement more than marginally.

The policy implication is clear: the government should encourage an increase in the enrolment shares of independently operated schools, for example by streamlining the requirements and process to establish new free schools. A voucher system with which pupils could attend the school of their choice, either public or independent, would be preferable. Such a system would sharpen competitive incentives in the education system significantly, thus increasing the potential for choice to produce an economic dividend.

2 Theory

Why is education presumed to affect economic growth? The main reason given is that it should improve the overall skill level, or human capital, of the labour force. How human capital, in turn, may be related to economic growth, is the subject of various theoretical accounts. In Solow's (1956) neo-classical growth model, per-capita growth is only determined by capital accumulation and technological change. In the growth model, only technological innovation can explain sustained, long-term growth because capital accumulation effects suffer from diminishing returns and eventually peter out. Technological change is thus the sole determinant of growth once an economy's new equilibrium/steady state (zero growth state) is reached. At the same time, the sources of technological change, such as human capital, are assumed to be 'exogenous', meaning that they are not included as an explanatory variable in the model. In other words, the model treats education as a residual rather than as integral part of the process of change in explaining an economy's per-capita growth rate. The neo-classical growth model, therefore, is not a very useful conceptual tool when analysing the impact of education.

Augmenting the neo-classical growth model, Mankiw, Romer, and Weil (1992) include human capital as an additional factor of production. In this version, human capital holds similar properties to physical capital – holding all other factors constant, an increase in the labour force's skill level shifts the economy's steady state. But since the human capital accumulation effect is also subject to diminishing returns, it no longer contributes to growth when the new steady state is reached. Again, it is only the exogenous process of technological change that drives growth once an economy has reached the equilibrium determined by its capital, labour, and education levels. The problem, of course, is that human capital also affects technological progress, meaning that the model is probably insufficient for predicting the total effect on economic growth. If technological progress is partly determined by the level of human capital, the latter can contribute to continuous growth despite diminishing returns as a direct factor of production.

Attempting to remedy such flaws, other researchers have developed 'endogenous' growth models, in which 'economic growth is an endogenous outcome of an economic system, not the result of forces that impinge from outside' (Romer 1994:3). In other words, technological progress is not treated as a residual, but rather as a result of the growth determinants included in the model. In endogenous growth theory, human capital is considered a contributor to ideas and innovations, meaning that it can generate *continuous* growth rather than merely shift the economy's steady state. Similarly, it can also facilitate technology diffusion. Simply put, 'educated people make good innovators, so that education speeds the process of technological diffusion' (Nelson and Phelps 1966:70). Thus, education can impact growth not only by affecting innovation directly, but also by aiding the adoption of existing technology. While the augmented neo-classical model assumes that the effect of education eventually peters out, endogenous growth models allow education, at any given level, to continue to impact growth through its effect on technological change and diffusion in the economy. In other words, endogenous growth theory gives human capital, and thus education, a more prominent role as a unit of analysis compared to neo-classical growth theory.

An important difference between neo-classical and endogenous growth theory is that the former indicates that *changes* in education over a given period affect the growth rate during that period, since education is treated as a regular factor of production, whereas the latter indicates that also the *initial level* of education affects the growth rate in the subsequent period (Breton 2011). This has implications for how the education variable should be included in statistical analyses, which has been a subject of debate.

3 The empirical literature

Having briefly discussed various pathways through which education may impact growth, this section reviews the existing empirical literature. Most research thus far has focused mostly on education quantity, such as the average number of years of schooling, although a burgeoning literature evaluates the impact of education quality.

3.1 Education quantity

Some older studies used school enrolment rates as a measure of education. For example, Barro (1991) finds that both primary and secondary school enrolment rates predict higher growth. Mankiw, Romer, and Weil's (1992) results imply that a 10% increase in the secondary school enrolment ratio raises growth by 2.2%. At the same time, Levine and Renelt (1992) find that neither primary nor secondary school enrolment rates' impacts are robust to using different growth periods, when measuring enrolment rates at the beginning of the periods rather than as an average over the period. Yet in more recent robustness tests, Sala-i-Martin, Doppelhofer, and Miller (2004), evaluating 67 variables, find that primary school enrolment rates are one of the most robust determinants of growth. Recent research also indicates that increasing enrolment rates are positive for economic growth in developing countries, although these findings are somewhat sensitive to the statistical model utilised (Baldacci et al. 2008).

However, enrolment figures are unlikely to be a good measure of the human capital stock, partly because 'children currently enrolled in schools are by definition not yet a part of the labour force' (Woessmann 2003:244). Another problem, of course, is that most developed countries have very high primary and secondary enrolment rates already, making it unclear what policy implications this research might have for the English context. Furthermore, most of the above studies utilise methods that make it difficult to separate causation from correlation. Higher growth is also likely to produce higher school enrolment rates, or there could be third variable that is not held constant which causes both, and the studies are generally not sophisticated enough to separate cause from effect. Unless all variables that affect both education and economic growth are included in the statistical model, the results cannot be interpreted as truly causal. Most of the above research is quite old and fails on these accounts.

While the growth impact of enrolment rates has been analysed, the most commonly used gauge of education quantity is the average number of years of schooling in the population. The evidence using this measure is mixed. As noted in Section 2, it is a topic of debate whether education should be included in the statistical model as changes over the growth period, which augmented neo-classical growth models would suggest, or as initial levels, as endogenous growth models would suggest. Benhabib and Spiegel (1994) do not find that changes in the average number of years of schooling are related to growth, but find that average levels generally are. The authors argue that this supports theories arguing that human capital can spur growth through technological innovation and diffusion rather than as a direct factor of production. Temple (1999), however, finds positive effects of changes in the average number of years of schooling when using a different estimation strategy. Meanwhile, Barro (1996) finds that the initial level of the average number of years of schooling among males aged 25 and over is positive: one extra year of schooling raises the per-capita growth rate by 1.2 percentage points. At the same time, he finds that average schooling among females does not have a positive impact. Yet Caselli, Esquivel, and Lefort (1996) find that changes in the average number of years of schooling for females are positively related to growth while for males they are negatively related.

Krueger and Lindahl (2001) argue that these inconsistencies may simply be due to the strong correlation between female and male schooling, indicating that one should be cautious about findings from the disaggregated measures. This inclines them to prefer the aggregated average number of years of schooling, and the authors find positive effects of both levels and changes using this measure, indicating that education is positive both as a factor of production and through technological innovation and diffusion. But these findings are sensitive to model specification: including physical capital, both its growth and initial level, renders education irrelevant for growth, which the authors argue is likely to be partly due to poor data. Pritchett (2001) also finds that education – both in terms of initial levels and changes in the average number of years of schooling – is unrelated to growth when changes in physical capital are included.

However, de la Fuente and Doménech (2006) as well as Cohen and Soto (2007) introduce new and (they argue) better data, finding robust positive effects of changes in the average number of years of schooling on growth also when holding constant physical capital. Meanwhile, Glaeser et al. (2004) find that the average number of years of schooling is a better predictor of growth over the long term than political institutions, which is supported by Bhattacharyya's (2009) study. Meanwhile, Mamood and Murshed (2009) find that political institutions and average years of schooling have positive interaction effects, meaning that they reinforce each other, indicating that institutions and human capital may be complementary in promoting growth. In a recent study, Gennaioli et al. (2013) also find support for the idea that average years of schooling has a positive impact on growth.

Yet, again, the problem with the above studies is that it is difficult to assess the robustness of the results. It is crucial to note the problem involved in unveiling the causal impact. Different models include different variables, making it possible that positive results reflect specific model specification rather than a true causal relationship between the average number of years of schooling and growth. In a recent study, Delgado, Henderson, and Parmeter (2013) use five different databases of average years of schooling, and conduct a rigorous test of the education–growth relationship. Using a very parsimonious model specification, the authors find little evidence that average years of schooling matters at all. Castelló-Climent and Hidalgo-Cabrillana (2012) further show that the relationship between education quantity and growth is not as clear-cut as commonly thought. They do find a positive effect in developing countries, but no impact at all in developed countries. However, the results are based solely on rather rudimentary statistical analyses and they should consequently be interpreted with caution. Acemoglu, Gallego and Robinson (2014) analyse long-run development levels rather than growth and find that institutions are much more important than average years of schooling, although the latter also has a smaller positive effect.[2]

Overall, therefore, the research suggests that the relationship between education quantity and economic growth is shaky at best. Of course, education quantity may have other benefits, but the research does not suggest that it is a robust determinant of economic growth (at least in developed countries).

[2] It should be noted that the relevant statistical analyses that include both institutions and education quantity suffer from weak instruments (see Section 3.2 and the Glossary for more discussion about **instrumental-variable models**).

3.2 Education quality

Having showed that the relationship between education quantity and economic growth is not robust, let us turn to the impact of education quality on growth. A key assumption of studies analysing education quantity is that it affect skills similarly across countries. But this is clearly not the case. One additional year of schooling in South Africa is not likely to have the same impact on skills as one additional year of schooling in England. Even within developed countries, which spend similar amounts on education, there are large variations in performance (e.g. OECD 2013). In contrast, there are few differences between developed countries in terms of average years of schooling or other education quantity variables, leaving very little of the variation in growth to be explained. It thus clearly makes more conceptual sense to evaluate the impact of more direct proxies for skills when estimating the impact of education on growth (especially in developed countries).

A couple of old large-scale studies by Azariadis and Drazen (1990) and Romer (1990) used countries' adult literacy rates as proxies for education quality, finding that education contributes to growth either directly or indirectly through its positive impact on investment. However, as Woessmann (2003:243) argues, although literacy rates certainly reflect one component of human capital accumulation, '[a]ny educational investment which occurs on top of the acquisition of basic literacy – e.g., the acquisition of numeracy, of logical and analytical reasoning, and of scientific and technical knowledge – is neglected in this measure'. For this reason, literacy rates are unlikely to capture the entire effect of education on growth. This is especially true in developed countries, where the overwhelming majority of people are literate according to conventional metrics. Furthermore, the above studies are old and utilise methods that cannot separate causation from correlation.

Instead, scores on international tests, such as PISA and TIMSS, are a more promising proxy of education quality. Such test scores are a more fine-grained and direct measure of the average cognitive skill level in the labour force than literacy rates. Although a relatively new field, there are now several studies analysing the relationship between international test scores and economic growth. In the first contribution, Lee and Lee (1995) analyse 17 countries, finding that a one **standard deviation (SD)**[3] increase in test scores raises the average annual growth rate by 1.2 percentage points. In another contribution analysing 31 countries, but constructing

[3] See definition in the Glossary.

test scores for 80 countries based on predictions from other variables, Hanushek and Kimko (2000) still find large positive effects of average scores on international tests in mathematics and science carried out during the growth period 1960–1990. The effect is of similar magnitude compared to Lee and Lee's (1995) estimates. Meanwhile, the effect of average years of schooling declines significantly once test scores are included. It is then indeed dwarfed by the effect of education quality. Bosworth and Collins (2003) also find that education quality dominates education quantity in terms of explaining growth, but that the impact of education quality cannot be reliably distinguished from the impact of government institutions. Yet, increasing the sample size to 43 countries with actual test scores, Barro (2001) also finds that test scores have a positive impact on growth despite controlling for institutions. Again, the effect of average years of schooling decreases significantly when test scores are included. The author concludes that education quality is much more important for economic growth than education quantity.

More recent contributions in this field have included even more countries and longer time periods. Jamison, Jamison, and Hanushek (2007) analyse 43–54 countries in the 1960–2000 period, also finding positive effects of education quality. The estimates suggest that a one SD increase in test scores produces a 0.5–0.9 percentage point higher growth rate depending on the model, with the impact being larger in countries open to international trade. Furthermore, the effect of the average number of years of schooling is not as robust. The authors also provide evidence indicating that education quality most likely affects growth through its impact on technological advancements.

While the inclusion of education quality in the studies above appears to reduce the effect of education quantity, more recent papers have shown that education quantity has no impact at all once controlling for test scores. Hanushek and Woessmann (2008) extend the analysis to 50 countries and include the most updated test score information, finding strong evidence that education quality increases the average annual growth rate in the period 1960–2000: a one SD increase in test scores produces up to 2 percentage points' higher growth. Yet the average number of years of schooling does not have any impact at all once test scores are held constant, indicating that 'school attainment has no independent effect over and above its impact on cognitive skills' (Hanushek and Woessmann 2008:639).[4] Based on these find-

[4] Atherton, Appleton, and Bleaney (2013) carry out a robustness test of these findings and show that the effects are similar when only analysing the impact of test scores on subsequent growth – using different lags and both short and longer growth

ings, education quality is shown to be a key determinant of the differences in long-term growth rates among OECD countries (Hanushek and Woessmann 2011a). Hanushek (2013) also shows that the impact is just as large in non-OECD countries. However, Castelló-Climent and Hidalgo-Cabrillana (2012), using Hanushek and Kimko's (2000) data on education quality, find that the positive effects can only be detected for countries that have reached a specific threshold of quality. Nevertheless, all these studies confirm the importance of education quality for countries' economic growth rates.[5]

However, neither of the above studies attempts to deal with common concerns in econometric analyses. More specifically, they do not control for **endogeneity**. Economic growth might produce higher test scores rather than vice versa – a problem referred to as 'reverse causality'. Another concern is that other, 'unseen' variables that are excluded from the models cause both test scores and growth and thus produce a spurious correlation between the two. If this is the case, the results discussed above may very well fail to unveil the causal relationship between education quality and economic growth.

There are, to the author's knowledge, only a couple of studies on the relationship between education quality and economic growth, which attempt to control for endogeneity entirely. Hanushek and Woessmann (2009, 2012a, 2012b) display similar results when using so-called **instrumental-variable models**. An instrumental-variable model necessitates a third variable – an instrument – which in this case is related to economic growth only through its impact on test scores (after holding constant other relevant variables). If this is the case, it is possible to circumvent both reverse causality and the problem that occurs when variables affecting both test scores and growth are omitted from the statistical model.[6]

The authors utilise institutional features of countries' education systems – the pupil enrolment shares in independent schools, whether there are exit exams, and the degree of centralisation in decision-making – as instruments for test scores. Since

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periods – rather than scores on tests administered during the growth period.

5 Hanushek and Woessmann (2011b) also show that the positive effects of test scores are robust to accounting for sample selection in international test scores.

6 For a full discussion of endogeneity and instrumental-variable models, see the Glossary.

test scores are influenced by other factors than formal schooling only – such as families and ability – the rationale for using institutional features as instruments is that only the part of test scores affected by differences in education systems is used to analyse the impact on growth. Tests carried out by the authors indicate that there is no reason to believe that reverse causality or the problem of omitted variables drive the relationship between test scores and growth – the results with instruments are quantitatively similar to those obtained without instruments.[7]

At the same time, Hanushek and Woessmann (2012b) also find that within-country trends in test scores are related to trends in growth rates, but trends in the average years of schooling are not. While not sufficient to rid the results from bias, this at the very least holds constant time-constant country-specific variables, such as national cultures, that affect both growth and achievement – and thus further indicates the importance of educational performance for countries' growth trajectories. The authors also find that the trend in test scores *after* the growth period analysed has no separate relationship with growth. This can be considered a 'placebo' test – if test scores cause growth rather than vice versa, there should be no impact of changes in test scores after the growth period analysed, once controlling for changes in test scores during the growth period. Since the authors analyse trends in test scores, however, it is questionable whether the full effect of education quality is taken into account given that the initial level can also produce innovation and technological diffusion as indicated by endogenous growth models and discussed in Section 2.[8]

In another robustness test, the authors analyse micro-level earnings data within the US labour market, comparing immigrants educated in their home countries with immigrants from the same country but educated in America. This holds constant

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7 It should be noted, however, that these instruments turn out to be too weak predictors of test scores. Only when introducing average years of schooling as an additional instrument are they above the conventionally accepted threshold, and then only by a razor thin margin. The authors also use Catholic shares in 1900 and relative teacher salaries as instruments, but these are also too weak to be used without average years of schooling.

8 Using different methods, Altinok (2007) and Appleton, Atherton, and Bleaney (2008) also find evidence of positive effects of education quality when controlling for time-invariant unobserved differences between countries. Again, education quantity does not seem to matter.

any cultural and institutional factors that affect the economy. Assigning to each immigrant the average test score of their home country, the authors find that this measure has a strong positive effect on earnings among those educated in that country, but no impact among those educated in the US. While it is difficult to compare the earnings and economic growth estimates, since the former focus only on private returns while the latter also takes into account spill-over effects, this exercise provides further support for the argument that the positive impact of education quality on growth is causal.

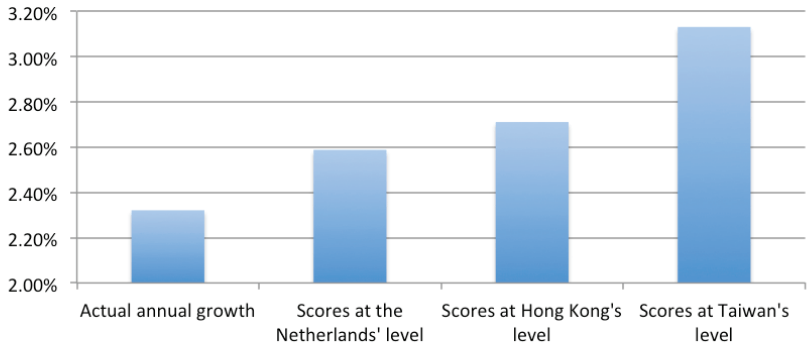
An important question is whether it is more important to promote high test scores among a small group of pupils or to promote a more egalitarian education system in which more pupils reach a relatively high achievement level. Hanushek and Woessmann (2012b) find that both the share of pupils reaching basic literacy levels and the share of top-performing pupils in the international tests are related to growth. Interestingly, the impact of top-performers is stronger: a 10 percentage point increase in the share of pupils reaching basic literacy would raise growth by 0.3 percentage points whereas the same increase in the share of top performers would raise growth by 1.3 percentage points. This gives some support for the idea that it might be more worthwhile to focus on a more elitist education system rather than egalitarian.

However, these figures do not take into account that it might be easier to raise the share of basic literates rather than the share of top performers. Indeed, the international variation of the share of basic literates is much larger than the variation of the share of top performers. In other words, increasing the share of basic literates by one standard deviation has a similar impact on growth as increasing the share of top performers by one standard deviation. Furthermore, there seem to be positive interaction effects between the two variables. As Hanushek and Woessmann (2012b: 299) argue, therefore, 'In terms of growth, our estimates suggest that developing basic skills and highly talented people reinforce each other.' Countries would thus be well-advised to improve the overall quality of their education systems, rather than merely focusing on reaching minimum levels or nurturing the development of more top performers.[9]

[9] The authors also find that their general results are robust to changes in model specification. Ramirez et al. (2006) find that the impact of education quality disappear when they analyse the period 1980–2000 and drop East Asian countries. But Hanushek and Woessmann (2012b) find positive effects despite restricting

How much, then, would the UK specifically gain from raising the quality of its education system? To calculate this, I use data obtained from Hanushek and Woessmann (2012b) on the average test scores over the growth period for different countries. Figure 1 displays the difference in the average growth rate in 1960–2007 at different average levels of performance in the international tests.[10] The average annual growth rate was 2.32%. Had the UK performed as well as the Netherlands (16.5 points higher), Hong Kong (24.5 points higher), and Taiwan (50.2 points higher) in international tests throughout the latter part of the 20th century, the average annual growth rate would have been 2.59%, 2.71%, and 3.13% respectively.[11]

Figure 1
Counterfactual average annual UK growth 1960–2007 with higher test scores



the sample in this way. A likely explanation for the differences is that Ramirez et al. (2006) use older data and analyse fewer countries.

10 Hanushek and Woessmann (2012b) find essentially exactly the same impact of education quality when analysing the period 1960–2007 instead of 1960–2000.

11 Calculations are based on Penn World Table (v.6.3) growth data, retrieved from Teorell et al. (2011).

Figure 2
Counterfactual real GDP per capita with higher education quality

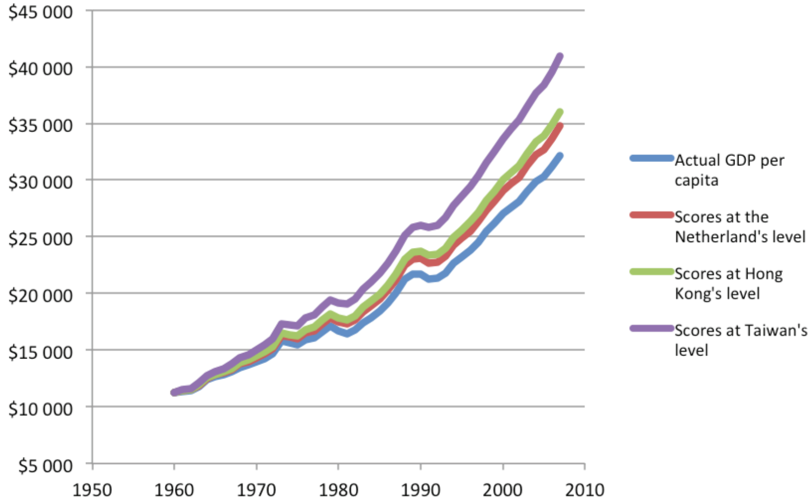


Figure 2, in turn, displays how the trajectory of the GPD per capita would differ at different levels of achievement. This exercise shows that 2007 GDP per capita would have been $2,620 higher if the UK had performed as well as the Netherlands in the international tests on average; $3,875 higher had the UK performed as well as Hong Kong; and $8,751 higher had the UK performed as well as Taiwan.[12] Of course, the exact magnitude of the effect should be interpreted with caution, but it does indicate the overall economic potential of improving performance in international tests.

Recently, Breton (2011), assuming that the augmented neo-classical growth model is correct, has questioned Hanushek and Woessmann's findings. Some of these questions are no longer relevant since the authors have dealt with them in later papers. One issue, however, is that international tests are administered during the growth period, which means that test scores are only representative of the average

[12] This is calculated by adding the difference between the counterfactual and the actual average annual growth rates over the period to the actual growth rate each year. The calculations are based Hanushek and Woessmann's (2012b) Table 1, which shows estimates implying that a one country-level standard deviation (61.1 points) increase in test scores generates a 0.76–1.21 percentage point increase in the average annual growth rate. I assume that the true effect is the average (0.98 percentage point).

labour force's human capital *after* the growth period. This is because it takes time before the pupils enter the workforce. Estimating a model explaining the level, rather than growth, of income – including test scores, average years of schooling and physical capital – the author shows that only education quantity matters.

In a more recent paper, however, Breton (2012a) comes to different conclusions. He continues to focus on the level rather than growth levels, and uses the share of Protestants in 1980 and latitude to control for reverse causality and the problem of 'unseen' variables. The author finds a positive impact of the share of workers that had scores above 400 in international surveys on the level of income in 2005. He finds that the average test score is less significant and that the share of workers scoring above 600 has no impact. In yet another contribution, Breton (2013a) uses religious population shares as instruments and finds that education quantity, education quality, and education expenditures have positive effects on growth in the period 1985–2005 and on the level of national income in 2005. The author thus argues that all three gauges are valid measures of human capital.

First, analysing static development levels is fundamentally different from analysing growth over a specific period. This is because much of the differences in income levels between countries in 2005 were established long before any of the test scores in question were obtained. Breton's analysis implicitly assumes that the human capital levels have not changed in the very long term, which is unlikely. Furthermore, it is questionable whether the author's strategy captures the causal impact of test scores. Geography, for example, may very well play a role in the long-run development of nations in other ways other than through the human capital channel (e.g. McCord and Sachs 2013). Furthermore, as noted in Section 2, the neo-classical assumption that the human capital growth effect is subject to diminishing returns ignores its impact on technological change and diffusion. Overall, therefore, it is questionable what Breton's findings can tell us about the total impact of education on economic growth.

Also focusing on education quality, although using a different approach, Coulombe and Tremblay (2006) analyse 14 OECD countries in a panel covering the period 1960–1995, using scores from IALS tests measuring prose, document and quantitative literacy. Analysing whether changes in test scores affect changes in growth, the authors find literacy scores to be related to growth. They also show that average years of schooling have no positive effects in this sample. The problem with the authors' approach, however, is that scores from 17–25 year olds from the 1990s are used to construct the panel data back to 1960, an approach assuming that individuals' test scores remain constant throughout their lives.

Finally, in a very different attempt to analyse the impact of education quality on income, Breton (2010a, 2010b) estimates the effect of cumulative investment per average years of schooling, finding that this measure is significantly positive in cross-national regressions on levels of income. In another paper he finds a positive impact of education investment solely on the level of income (Breton 2013b). Again, the author uses the population share of Protestants as instrument for education and education investment.

The problem with this approach is that the cumulative investment per average years of schooling and education investments more generally are not good proxies for education quality. First, as noted above, the average number of years of schooling measures quantity of education, not quality. Second, the problems with using development levels apply also to these papers. Third, investment in education is unlikely to be a good general proxy for quality, especially when not taking into consideration that spending might be caused by low quality (which induces reverse causality since governments may begin to spend more when performance is low). Investment can of course also target many different things, not necessarily the quality level in the system.

In general, furthermore, it is problematic to use inputs as a proxy for output. Overall, the effect of inputs on educational achievement is not clear (Chingos 2012; Gibbons and McNally 2013). Often, flawed incentive structures in schools have lessened or neutralised the impact of additional resources (Hanushek 2008). In England, for example, the impact of increased resources has been small on average (Holmlund, McNally, and Viarengo 2010), with only relatively sizeable effects in disadvantaged urban areas (Gibbons, McNally, and Viarengo 2012). The research on international test scores generally finds no or very little impact of input-based education policies (Hanushek and Woessmann 2011c). Thus, it is not straightforward to use the level of education investment as a general proxy for the overall level of education quality in an education system.

This, of course, does not mean that the level of investment can *never* be used as a proxy for the impact of education quality on economic growth. In the US, for example, Aghion et al. (2009) find positive economic growth effects of investment in four-year college education, but not in two-year college education. The results also suggest that innovation drives these findings, and since enrolment rates barely are affected by the investment, 'college quality, not the enrolment margin, seems most likely to be the productive one' (Aghion et al. 2009:35). This is in contrast to two-year college education, where enrolment rates increased as a result of increased investment. Although this further shows that investment cannot be used as a general quality proxy, since its often targets other things, the study does support the idea that education quality, not quantity, is likely to be related to economic growth.

Overall, the research suggests that education quality has positive effects on the long-term economic growth rate. International test scores are consistently statistically and economically significant in models explaining countries' growth rates. Nevertheless, most studies utilise parsimonious models, which exclude other important variables that may impact long-term economic growth. It is important to understand that while the evidence on education quality appears strong, it is still difficult to discern the causal effect merely from a correlation. While it is impossible to include all variables of importance, one could still provide more rigorous robustness tests. Using alternative strategies and data to estimate the impact of education quality and quantity on growth therefore remains important.

4 New evidence on the effect of upper-secondary education quality on growth

Having discussed available studies on the impact of education on economic growth, this section provides new quantitative evidence. Given the issues raised with the hitherto available studies, it is important to further enquire into this relationship and assess its robustness. All details regarding the technical nature of the methodology are provided in the Appendix.

This paper uses 1995 TIMSS Advanced average science and mathematics test scores from pupils in the final year of upper-secondary school in all 21 participating countries as a proxy for education quality (IEA 1998).[13] This is the first time, to the author's knowledge, that this gauge is used as the sole measure of education

[13] The participating countries are Austria, Australia, Canada, Czech Republic, Cyprus, Denmark, France, Germany, Hungary, Iceland, Italy, Lithuania, Netherlands, New Zealand, Norway, Russia, Slovenia, South Africa, Sweden, Switzerland, and the United States.

quality in statistical analyses explaining economic growth. The distinct advantage is that the effect of upper-secondary education quality can be directly analysed; prior studies mix these scores with scores from primary and lower-secondary school pupils. Test scores in the final year of upper-secondary school are also potentially better proxies for countries' human capital stocks since the tests are administered sooner before pupils enter the labour market. Using scores from pupils at the very end of upper-secondary school also takes into account that their performance may have changed during their schooling years.

The growth period analysed is the ten-year period 1995–2005.[14] Averaging annual growth rates over a ten-year period is supposed to take into account business-cycle fluctuations in order to estimate the impact of education quality in a more long-term perspective (see Barro 1996). As a measure of education quantity, the paper follows praxis and uses the average number of years of schooling among the share of the population aged 15 and over, using the most recent data retrieved from Barro and Lee (2010).[15] In order to assess the robustness of the analysis, it also includes many more control variables that might correlate with both education quality/quantity and economic growth, compared to previous research. These variables are included in the different model specifications below, and are discussed more in the Appendix.

The findings presented in Table 1 show that upper-secondary education quality impacts growth positively regardless of specification. The results for all variables are presented in the Appendix.[16] At the same time, education quantity is only significantly positive when education quality is excluded. Model 4, which is preferred

14 Results are robust to using the average annual growth rates up to and including 2007, but I refrain from going further because of the 2008 financial crisis that can bias estimates from thereon onwards. Clearly, the fall in growth rates caused by the financial crisis had very little to do with education and more to do with the structure of the financial system (see Hanushek and Woessmann 2012b).

15 In robustness analyses, the average years of schooling among the share of the population aged 25 and over were utilised instead, but the results were almost exactly the same.

16 Model 1 corresponds to Model 1 in Table 2, Model 2 corresponds to Model 2 in Table 2, Model 3 corresponds to Model 3 in Table 2, Model 4 corresponds to Model 5 in Table 2, and Model 5 corresponds to Model 1 in Table 3.

based on the analysis in the Appendix, suggests that a 10% increase in TIMSS Advanced test scores raises the average annual growth rate by 0.85 percentage points. However, while the point estimate of the average number of years of schooling is positive, the coefficient is insignificant. The variables included in Model 4 explain about 90% of the cross-national variation in growth, which is comparable to or higher than many growth equations in previous studies.[17]

TABLE 1. *The relationship between education and economic growth*

Dependent variable: average annual GDP per capita growth rate 1995–2005					
	Model 1	Model 2	Model 3	Model 4	Model 5 (IV)
Education quality (1995)	6.40**		5.43**	8.49***	8.62***
	(2.68)		(2.32)	(7.77)	(8.53)
Education quantity (1995)		3.02**	1.98	0.03	–0.03
		(2.22)	(1.61)	(0.03)	(–0.04)

Note: Unstandardised coefficients (t-statistics based on robust standard errors in parentheses). Significance levels: *p<0.10, **p<0.05, ***p<0.01.

What about potential reverse causality and 'unseen' variables that affect both education quality and economic growth? In order to provide a stronger robustness test of the causal impact of education quality on growth, it is important to investigate this further. Thus, the paper employs an instrumental-variable model with two instruments for test scores: (1) enrolment shares in independent secondary schools in 1995 (UNESCO 1998),[18] and (2) the percentage of Muslims in each country in 1980 retrieved from Teorell et al. (2011).[19] The Appendix discusses the rationale and justification for this strategy in more detail.

[17] This is according to the adjusted-R2 value, which measures the explanatory power of the model specification, as discussed more thoroughly in the Appendix.

[18] Due to a lack of data, 1998 independent enrolment shares for Sweden, Hungary and the US were obtained from the OECD database (OECD 2011).

[19] Using Muslim shares in 1990 generated almost exactly the same findings, which is expected since such variables change slowly over time, but this data are unreliable for two of the countries in the sample (Pew Research Centre 2009).

Model 5 displays that the main results are largely unchanged when employing the instrumental-variable model. Test specifications presented in the Appendix also indicate that there is no evidence of reverse causality or that 'unseen' variables bias the results, thus supporting previous research.

Figure 3 displays the relationship between upper-secondary education quality and growth, and Figure 4 displays the relationship between education quantity and growth, when controlling for all other variables in Model 4, which is the preferred model specification given the results presented in the Appendix.

Figure 3
The impact of upper-secondary education quality on growth

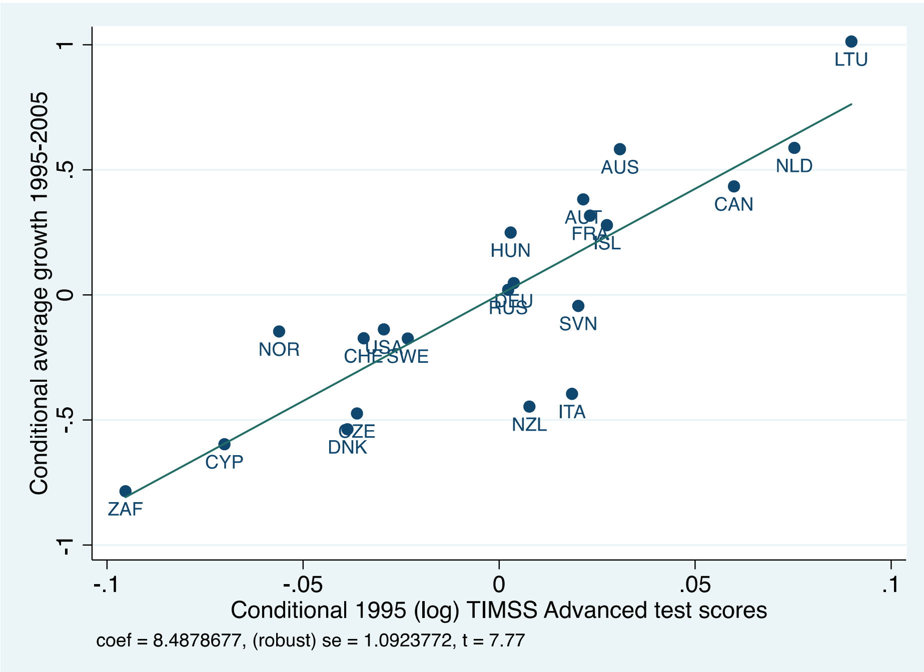
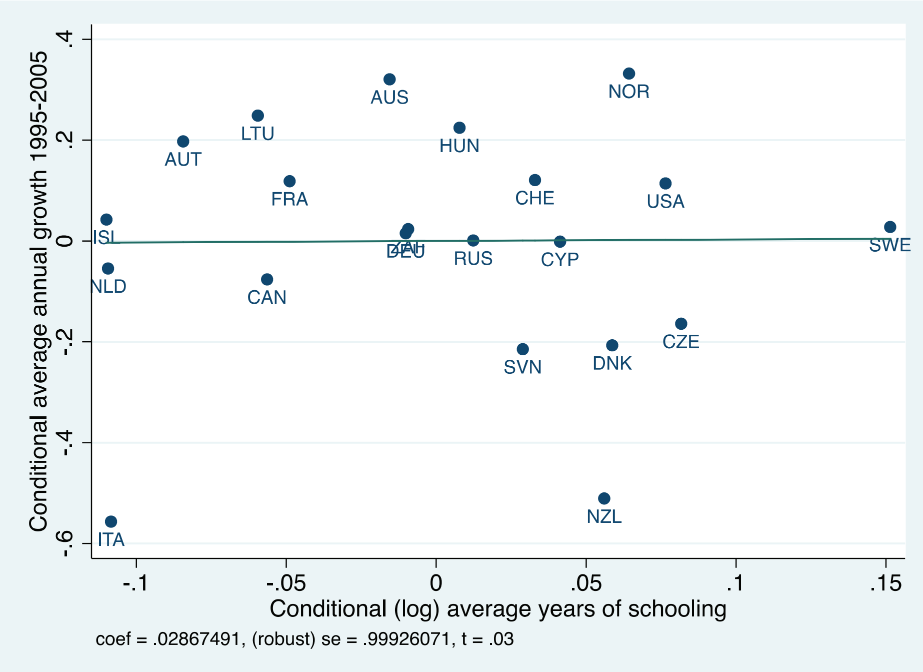


Figure 4
The impact of education quantity on growth



Overall, therefore, the results support Hanushek and Woessmann's argument that education quality, but not quantity, has the potential to raise countries' growth rates. The main differences in comparison with these authors' research, however, are that this paper: (1) uses test scores from pupils in the final year of upper-secondary school only; (2) provides a much more extensive set of control variables in the regressions as well as in unreported robustness analyses as noted in the Appendix; and (3) uses an alternative and stronger set of instruments. Additionally, it is worth pointing out that (4) this paper analyses a much shorter growth period. It is, therefore, interesting that the overall conclusion remains the same.

Quantitatively, the best estimate suggests that a 10% increase in TIMSS Advanced average mathematics and science test scores raises the average annual growth rate by 0.85 percentage points. At the same time, the effect of education quantity is insignificant. These results are remarkably similar to previous research, despite the differences in data, growth period, and methodology.

As noted in Appendix, it is of course important to note the uncertainty in the exact estimates as well as the methodological issues involved in causal interpretation. Without a natural experiment, it is impossible to completely rule out that reverse causality and 'unseen' variables bias the results. However, neither this paper nor previous research, despite a battery of sensitivity analyses and different methodologies, find evidence that these issues bias the results. Indeed, the consistency of results across studies, datasets, and methodologies does suggest that the relationship between education quality and growth is indeed causal.

For the purpose of increasing growth, therefore, the policy implication is that countries would be better off focusing on improving the overall quality of their education systems rather than merely increasing the number of pupils taking higher qualifications.

5 The indirect impact of independent education provision on growth

Having discussed the role of education quality, as measured by high international test scores, in spurring economic growth, it is important to discuss cost-effective ways to produce higher education quality. Research consistently shows that competition from independently operated schools generates higher scores in PISA and TIMSS – the two main international league tables (Hanushek and Woessmann 2011c). The strongest research finds that such competition raises PISA scores for pupils in both independently operated and state schools equally, while also driving down costs. The total productivity gains are substantial, and they arise regardless of whether the independently operated schools are publicly or privately funded (West and Woessmann 2010). The international research thus strongly suggests that competition from independently operated schools is an efficient way to increase economic growth indirectly via improved education quality.

How much could we expect that competition from private education providers would contribute to economic growth via its impact on international test scores? Combining estimates from West and Woessmann's (2010) research with estimates from the economic growth studies suggests that if countries increased the pupil enrolment share in independently operated schools among fifteen-year olds by 20 percentage points, their long-term annual growth rate would increase by 0.40 percentage points through the positive impact of private competition on achievement – a strong effect.[20]

[20] These calculations are based on the average effect of independent school enrolment

Using the estimates from the statistical analysis in this paper, and presuming that the impact of competition from independently operated schools also applies to upper-secondary education, one obtains similar results. Since the impact of TIMSS Advanced test scores in the analysis is expressed in terms of a percentage increase, the boost in growth rates depends on the initial achievement level of any given country. If we assume a country that performs at the international average of 500 points, a 20 percentage point increase in the independent school enrolment share would raise the country's long-term economic growth rate by 0.33 percentage points, again a sizable impact.

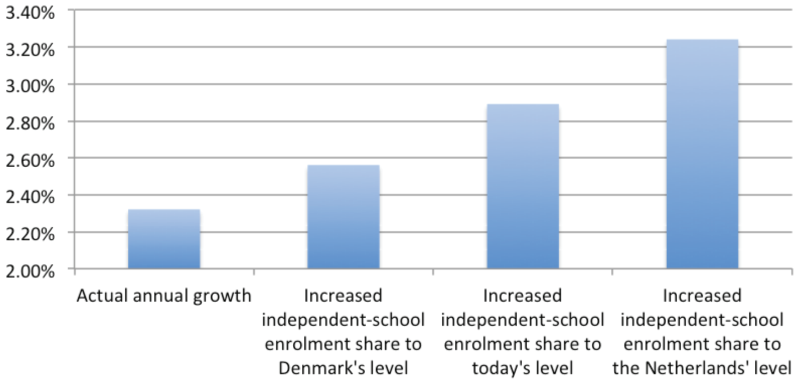
To give a better overview of the potential economic dividend, Figure 5 displays the difference between the UK's actual average annual growth rate in the period 1960–2007 (2.32%) and what it would have been at different levels of independent school enrolment share.[21] About 8% of fifteen-year old pupils attended independently operated schools, publicly and privately funded, in the UK in 2006/2009 (Falck and Woessmann 2011; OECD 2010). This had been the case for a long time, and did not change significantly until the 2010 Academies Act, which increased the number of pupils attending government funded but independently operated schools significantly. If the figure had been at Denmark's level as in 2012 (23%) continuously throughout these decades, the UK's average annual growth could have been 2.56%. If it had been at the UK's level in 2012 (44%), the growth rate could have been 2.89%, and if it had been at the Netherlands' level in 2012 (66%), growth could have reached 3.24%.[22]

shares on individual pupils' average PISA 2003 scores in mathematics and science, calculated from West and Woessmann (2010), which imply that a 20 percentage point increase in independent school enrolment would raise achievement by 19.7 points, and Hanushek and Woessmann's (2012b) estimates showing that a one standard deviation increase in the test scores in these subjects generates a 0.76-1.21 percentage point increase in the average annual growth rate. Again, I presume the true effect is 0.98 percentage points, which is the average of the figures.

21 The calculations are (again) based on the presumption that a one country-level standard deviation increase in test scores generates a 0.98 percentage increase in growth.

22 The enrolment figures for 2012 are obtained from OECD (2013).

Figure 5
Counterfactual average annual UK growth 1960–2007 with higher independent-school competition

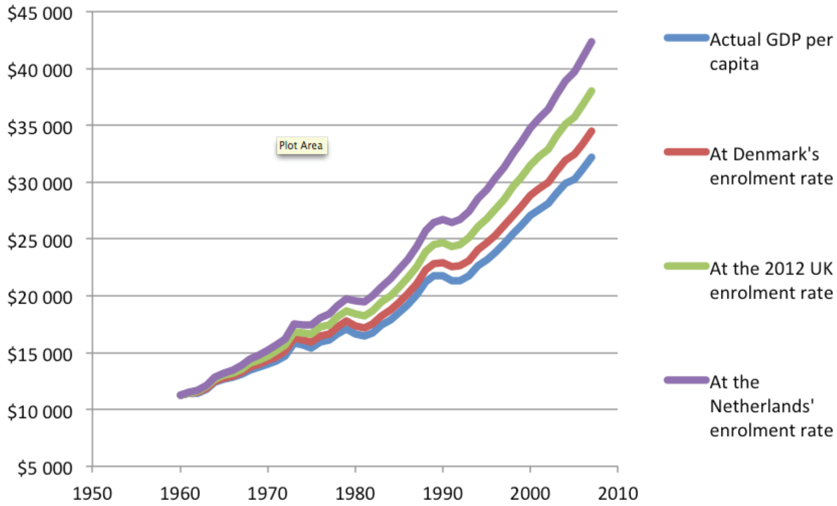


What does this mean in real GDP per capita terms? Figure 6 displays that the UK's real GDP per capita in 2007 would have been $2,316 higher with an enrolment rate in independently operated schools at Denmark's level; $5,868 higher with an enrolment rate at the UK's level in 2012; and $10,165 higher with an enrolment rate at the Netherlands' level.[23]

The calculations presume that the improvements due to competition from independently operated schools occur directly. This is not realistic, but the point is to show the potential growth rate at different *long-term* levels of independent school competition. So the estimates are best interpreted as the growth effects induced by an overnight switch to higher historical levels of independent school enrolment rates in 1960. Of course, the calculations should be interpreted with caution, as they are only suggestive, but they clearly indicate the overall potential for independent education providers in a coherent long-term growth strategy.

[23] Again, this is calculated by adding the difference between the counterfactual and the actual average annual growth rates over the period to the actual growth rate each year.

Figure 6
Counterfactual UK real GDP per capita at different independent-school enrolment levels



5.1 What about input?

Again, one should note that private competition appears to be cost-effective since it raises achievement and economic growth while depressing educational costs. In contrast, the research on international tests such as PISA and TIMSS does not generally find any positive impact of input-based policies (Hanushek and Woessmann 2011c). Since such policies by definition also increase educational expenditures, they cannot compete with choice-based policies in terms of increasing economic growth via higher cognitive achievement.

It is true that methodologically strong research *sometimes* – but far from always – finds positive effects of input-based policies on domestic achievement measures, but it is still questionable how big the impact is and whether it is cost-effective (see Chingos 2012; Gibbons and McNally 2013; Heller Sahlgren forthcoming). The key problem with much research, however, is that it is not policy relevant, regardless of whether or not it finds cost-effective positive effects of inputs. Indeed, research shows that universal increases in resources over time, such as decreases in class size, seem to have modest effects at best (Heller Sahlgren forthcoming). One reason for this is that results from many experiments and quasi-experiments cannot be extrapolated to reforms. While the academic question of whether resources improve results ‘everything else equal’ is clearly important, it is also crucial to understand that reforms make sure that ‘everything else is not equal’ – widespread changes in resource-based policies also have other effects. For example, even if smaller classes are better than larger classes on average, one must hire more teachers who may very well not be of the same quality. Is that the case, the impact of smaller classes may be reduced or disappear, which research analysing experiments and most quasi-experiments does not take into account.[24]

Another example of changes that make much research policy irrelevant is that schools, teachers, parents, and pupils may also adapt to changes in resources over time by adjusting their efforts to counter lower resources, thus ‘crowding out’ the impact (Gibbons and McNally 2013). This is especially true when actors know about the resource change (Das et al. 2013). If actors adjust their behaviour to accommodate for decreasing/increasing resources over time, it may be a waste of money to increase educational spending in the first place. This does not only concern small changes in resources over time, which is probably easier to accommodate with changes in behaviour. For example, Thompson (2012) analyses the impact on Wyoming schools of a 20.7% resource increase from 2006–07 onwards because of an increase in the price of natural gas, but despite this generous funding increase, there was no general improvement in results after four years. The policy implications from experimental and quasi-experimental studies finding positive effects of resources on achievement are thus far from clear.

Either way, increasing competition and pursuing input-oriented policies are not mutually exclusive for the purpose of raising achievement. In fact, one way to produce lower classes cheaply is to increase the number of schools – and perhaps the only way to do so cost-effectively is to increase the number of independently operated schools.

Of course, there might be other channels through which market reforms in education affect economic growth. For example, research suggests that school choice and competition spur entrepreneurship and entrepreneurial intentions (Falck and

24 However, recent research suggests only a small part of the lack of class size reduction reform effects can be explained by reduced teacher quality (Dieterle 2013).

Woessmann 2011; Sobel and King 2008). Although the Appendix presents evidence that there is no direct relationship between independent school enrolment shares and growth once accounting for test scores, there is a large literature linking entrepreneurship to growth (Carree and Thurik 2010). The effect calculated here could thus in fact underestimate the indirect contribution of school competition to growth in the long run.

Regardless, overall, it seems clear that expanding private provision in education could have an important positive role in promoting countries' economic well-being. Unlike expensive input-based education policies, promoting private provision could save money *and* raise achievement and growth. This is clearly a win-win situation of which the government should not hesitate to take advantage.

6 Conclusion

This paper has discussed the potential impact of education and private education provision on economic growth. Theoretically, education, via its impact on human capital, could impact growth both as a direct factor of production and as a catalyst for technological innovation and diffusion. Much previous empirical research has focused on the effect of education quantity, measured by variables such as average years of schooling, with the more recent research questioning whether it actually matters for growth at all. There is currently no robust support for the idea that education quantity increases countries' economic well-being, at least in developed countries.

On the other hand, recent studies have found that international test scores – a more direct measure of cognitive skills and thus probably a better proxy for the labour force's human capital – are strongly related to growth. The same studies also find that education quantity is less important or irrelevant for growth, apart from its impact on education quality. Estimates suggests that the UK's GDP per capita would have been about $8,751 higher today had it performed as well as Taiwan on average since the mid-twentieth century.

In order to investigate the relationship between education quality and growth further, the paper also provided new quantitative evidence using 1995 TIMSS Advanced test scores. The preferred model indicates that a 10% increase in test scores generates a 0.85 percentage point increase in the average annual growth rate. At the same time, education quantity is a significant predictor of growth only when excluding test scores in the analysis. This finding is remarkably robust to the inclusion of a vast range of relevant control variables as well as controlling for potential reverse causation, which does not seem to be a problem. The finding is also quantitatively similar to what previous research has found.

It is certainly important to highlight the limitations of the research in determining the exact effect of education quality on economic growth. Due to data limitations, it is difficult to utilise the most up-to-date econometric tools in order to conclusively establish a causal link, although the newest research does a good job to deflect such concerns in plenty of robustness tests. In fact, international test scores appear to be a strongly robust predictor of economic growth in almost all research, regardless of specific model specifications, lending further support to the idea that education quality is causally related to growth. And even if we assume that education quality picks up other variables too, and that the impact of education quality on growth is merely half of the one highlighted here, it is still sizeable. The results thus indicate that countries may be better off focusing on raising the overall quality in their education systems rather than merely increasing the number of pupils taking higher qualifications.

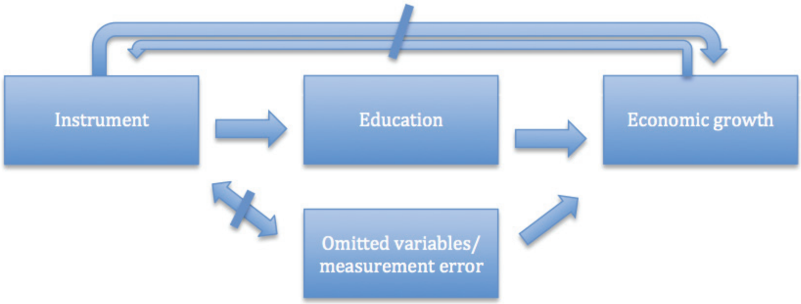
The paper also displays the potential economic benefits of private education provision. The strongest available research suggests that increasing the enrolment rate in independently operated schools both raises international test scores while keeping costs down. The evidence suggests that the UK would have had a 0.92 percentage point higher average annual growth rate in the period 1960–2007 with an independent school enrolment rate at the level of the Netherlands, which means that GDP per capita would have been $10,165 higher in 2007. Again, these effects are very large, but even if the true effect is only half of the estimated one, the indirect impact on growth still appears sizeable. Increasing choice and competition thus appears to be a cost-effective way for the government to increase growth rates. This stands in contrast to costly input-based policies.

The policy implication is that the government should encourage more private provision and competition in education. Of course, there are various ways to expand school competition, and this is discussed extensively elsewhere (Heller Sahlgren 2013). A clear-cut policy implication, however, is to streamline the bureaucratic requirements and process for establishing and running free schools. This could be combined with vouchers on which all schools would be dependent. Pupils could then use their vouchers to attend the school of their choice, which would further raise the enrolment share in privately operated schools and promote strong competition in the system. Not only is this likely to raise achievement in international tests, but the economic dividend could be large indeed.

Glossary

Endogeneity means that the predictor in question, in this case education, is in itself either (1) a product of economic growth; (2) a product of other variables that are important determinants of economic growth, but which are not included in the statistical model; or (3) suffers from measurement error, the difference between the measured value of an independent variable and its actual value. The former case means that there is a reverse causality problem (e.g. that growth causes more/better education rather than vice versa), and the latter case means that there are 'unseen' variables that cause omitted variable bias or selection bias**.** For example, regarding (1), policies that increase education quality/quantity could be a reaction to low growth. That is, low growth spurs changes in the education system. If this is not accounted for, one might erroneously conclude that education is negative for growth. In regard to (2), when analysing the effects of education on growth, countries with better education systems may differ significantly from other countries in other respects. They might, for example, have a stronger work ethic on average, which is difficult to control for. Finally, (3) if the predictor of interest, such as education quality, is not measured correctly, it suffers from measurement error. This tends to bias its effect in regressions towards zero.

Instrumental variable (IV) model. An econometric tool that can potentially solve endogeneity bias as defined above. To do this one must find a specific variable, an instrument, which causes the variable of interest, for example education quality, but is unrelated to economic growth directly. In this case, it is possible to isolate the part of education quality/quantity, via the instrument, that is not shaped by economic growth directly. This solves the problem of reverse causality. If the instrument is also unrelated to any other variable that is not included in the model that affects growth, for example the average work ethic, the problem of omitted variable bias is solved too. Finally, by finding an instrument that is correlated with the measured value of a variable, but uncorrelated with the portion in this variable that is due to measurement error, the latter problem can be solved too. In practice, however, it is very difficult to find instruments that satisfy these criteria, especially the second one. If the instrument affects growth directly, or is related to any other variable that also affects growth but that is not included in the statistical model, it is not an 'exogenous' (valid) instrument. The assumptions of an instrumental variable are displayed in the figure below.



Standard deviation (SD) is a measure of the variation from the arithmetic mean in data. The standard deviation in test scores, or whatever measure of education that is analysed, displays how varied the results are between countries. The standard deviation is often used as a reference point for the effect size of an independent variable.

Appendix

This Appendix provides more detail of the methodological approach and the results provided in the paper. Following previous research, a simple growth equation combining elements of endogenous and augmented neo-classical growth theory is estimated (see Hanushek and Woessmann 2012b):

$$\Delta GDPcapita_i = \alpha + \beta_1 EdQuality_i + \beta_2 EdQuantity_i + + \beta_3 X_i + \varepsilon_i \qquad (1)$$

The outcome variable $\Delta GDPcapita_i$ represents the annual growth rate averaged over the ten-year period 1995–2005. The main independent variable of interest, $EdQuality_i$, which denotes the quality of education, is represented by 1995 TIMSS Advanced average science and mathematics test scores. $EdQuality_i$ represents the average number of years of schooling among the share of the population aged 15 and over in 1995. Both education measures are logged to account for potential diminishing returns, but all results are robust to using unlogged measures. The variable X_i denotes a vector of control variables of potential importance for growth, which are described below.

The baseline model includes the logarithm of initial GDP/capita.[25] Additional models add: (1) the level of democracy as measured by average Freedom House (2010) and Polity scores (Marshall and Jaggers 2009), (2) the log of the number of international non-governmental organisation (INGO) memberships, retrieved from the *Yearbook of International Organizations* (Union of International Associations 1995–2005), which, following Paxton (2002), is used as a measure of social capital; (3) the log of population; (4) the level of religious fractionalisation, retrieved from Alesina et al. (2003); (5) the log of inflation; (6) the log of trade openness; and (7) the log of investment/GDP. All control variables, apart from initial GDP per capita and religious fractionalisation, are averaged over the same period as the dependent variable.

In unreported robustness regressions, a vast number of additional control variables were added one at a time: changes in education quantity (in line with neo-classical growth models); initial physical capital per worker; gross capital formation (levels and changes; corruption; press and economic freedom; population growth; social trust; inequality; the government share of GDP; the industry share of GDP; foreign direct investment; life expectancy; the number of internet users and phone lines; fertility and mortality rates; energy use; electric power consumption; and oil and metal indicators. However, none of these was significant or altered the overall findings regarding education.[26] This holds true despite these analyses reducing the number of observations by up to 19%.[27]

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[25] The overall results are robust to using the non-logged initial GDP per capita level too.

[26] The oil indicator, retrieved from Teorell (2010), was significantly positive only when including two extreme outliers (Norway and Lithuania), but the general conclusion regarding the impact of education merely grew stronger when including it.

[27] Growth rates, GDP per capita (PPP), population levels, investment/GDP and trade openness were retrieved from the Penn World Table (PWT), version 6.3, as reported in Teorell et al. (2011), from which the control variables included in the robustness tests were also retrieved. In general, PWT versions <7.0 are preferable because of substantial changes in the methodology that rendered the data more unreliable thereafter (Breton 2012b). However, to ensure that results were not strongly dependent on one specific dataset, I also cross-checked the results with per-capita growth data from the World Bank's World Development Indicators (WDI) – also

One would expect the initial level of GDP per capita to be negative due to conditional convergence as predicted by neo-classical growth theory. Democracy, through different mechanisms, may be positive or negative for growth (see Barro 1996) so there are no strong theoretical predictions either way. Similarly, the effect of INGOs is not clear-cut. While Putnam (1994) argues that a vibrant civil society is good for economic development, Olson (1982) predicts that dense civil societies spur interest-group activity, undermining states' power to undertake reforms and dividing political life – which could reduce growth. At the same time, endogenous growth models predict positive impacts of overall country size since larger populations may benefit from more innovations and gains from specialisation (Ruffin 2009). Social fractionalisation, however, is expected to be negative. Prior analyses tend to find that ethnic and linguistic fractionalisations are more important than religious (Montalvo and Reynal-Querol 2005). Thus, all three types were investigated, but the former two were insignificant when controlling for religious fractionalisation. Finally, inflation is expected to be negative, while trade openness and the investment share are expected to be positive for growth (e.g. Barro 2001).

Table 2 presents the results. Models 1–3 are the baseline estimations. These show that both test scores and years of schooling have a positive relationship with growth, but once both are included in the same model only test scores remain significant. Model 4 adds democracy, which enters positively but does little to alter the relationship between education quality and growth. Model 5 adds the log of INGO memberships, population size and inflation, as well as religious fractionalisation. The INGO variable enters significantly negative, supporting Olson's hypothesis over Putnam's, while both population and religious fractionalisation enter with the expected signs. Inflation, however, is significant with the 'wrong' sign. The effect of education quality increases in effect size and statistical significance: a 10% increase in test scores generates a 0.85 percentage point higher growth rate. The adjusted-R2 value increases radically, suggesting that the model explains 93% of the cross-national variation in growth. Model 6 and Model 7 add trade openness and the investment

obtained from Teorell et al. (2011) – from which the inflation rate also was retrieved. I also double-checked the results when using the most recently revised growth data from PWT 8.0. In both cases, the overall results were similar. In fact, the point estimates for education quality were actually higher when using the alternative data, although they became less precise (while remaining significant). Education quantity remained insignificant. This is important since growth estimates often are sensitive to different GDP datasets and revisions of datasets. (Ciccone and Jarociński 2010; Johnson et al. 2013).

share separately, but none is significant, while test scores remain strongly significant. The adjusted-R2 value always drops in comparison to Model 5. The same findings remained when including both trade openness and the investment share. Model 5, therefore, is so far the preferred specification.

TABLE 2. *The relationship between education and economic growth*

Dependent variable: average annual growth rate between 1995 and 2005							
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
	OLS	OLS	OLS	OLS	OLS	OLS	OLS
TIMSS Advanced score 1995 (log)	6.40**		5.43**	6.13**	8.49***	8.55***	9.02***
	(2.68)		(2.32)	(2.50)	(7.77)	(6.71)	(8.26)
Average years of schooling 1995 (log)		3.02**	1.98	1.87	0.03	0.01	–0.02
		(2.22)	(1.61)	(1.35)	(0.03)	(0.01)	(–0.03)
Initial GDP/capita (log)	–2.70***	–1.48**	–2.15***	–2.70***	–1.34***	–1.37***	–1.21***
	(3.37)	(–2.57)	(–3.33)	(–4.72)	(–4.28)	(–3.30)	(–3.97)
Democracy				0.45***	0.91***	0.91***	0.94***
				(3.66)	(6.26)	(6.02)	(7.10)
INGOs (log)					–2.20***	–2.17***	–2.28***
					(–7.05)	(–6.05)	(–6.86)
Population (log)					0.52***	0.51***	0.52***
					(4.38)	(3.41)	(4.63)
Religious fractionalisation					–1.49***	–1.49***	–1.50***
					(–3.54)	(–3.28)	(–3.35)
Inflation (log)					0.50**	0.50**	0.53***
					(2.88)	(2.79)	(3.23)
Trade openness (log)						–0.06	
						(–0.17)	
Investment/GDP (log)							–0.35
							(–0.86)
Adjusted R2	0.51	0.47	0.60	0.62	0.93	0.92	0.92
Observations	21	21	21	21	21	21	21

Note: Unstandardised coefficients (t–statistics based on robust standard errors in parentheses). Significance levels: *p<0.10, **p<0.05, ***p<0.01.

What about endogeneity? As noted in Section 4, the paper uses enrolment shares in independent secondary schools and the percentage of Muslims as instruments. The first instrument has been used by Hanushek and Woessmann (2009) and is supposed to take into account that independent school choice can spur achievement. At the same time, the authors argue, little suggests that growth produces larger independent school enrolment shares, which mostly depend on long-standing education policies rooted in law. On the other hand, the authors fail to recognise that independent school competition may spur growth in other indirect ways, such as by increasing entrepreneurship (Falck and Woessmann 2011; Sobel and King 2008), which means that it is important to make sure that the variable is not related to growth once controlling for education quality. Previous analyses have not investigated this.

The religious variable is justified by recent studies suggesting that immigrants from Islamic countries to Western OECD nations perform significantly lower in PISA tests than native pupils and other immigrants from outside the West (de Heus and Dronkers 2010; Dronkers and van der Velden 2010; Dronkers, Velden, and Dunne 2011). Other evidence also suggests that second-generation Muslim male immigrants in Europe generally have lower educational attainment compared to natives and other second-generation immigrants, and that it is the individual's religion, not the dominant religion in the country of origin, that explains this divergence (Fleischmann and Dronkers 2010). The authors of these studies suggest that the effect could be due to, for example, discrimination against Muslims in traditionally Christian societies or negative influences of Islamic values on educational achievement in modern schooling. The former is especially relevant given that all countries in this sample are traditionally Christian. The percentage of Muslims in each country should therefore be negatively related to test scores. Given the debate about cultures' impact on economic development, dating back to Weber (2003), the religious variable may not be exogenous to growth. This, however, can be tested statistically provided that the independent school instrument is exogenous.[28]

Thus, I estimate the following instrumental-variable estimation with the control variables in Model 5:

[28] It should be noted that there was no evidence that the share of Protestants was positive for achievement. Similarly, countries' latitude was not positive either. This further raises questions regarding Breton's (2012a) findings, although he uses a larger sample of countries.

$$EdQuantity_i = \alpha + \beta_1 Z_i + \beta_2 EdQuantity_i + + \beta_3 X_i + \varepsilon_i \tag{2}$$

$$\Delta GDPcapita_i = \alpha + \beta_1 EdQuality_i + \beta_2 EdQuantity_i + + \beta_3 X_i + \varepsilon_i \tag{3}$$

where is a vector including the instruments discussed above. This means that I only analyse the growth impact of the variation in test scores that can be explained by independent school enrolment and the share of Muslims. Model 1 in Table 3 displays the results from the IV model. The first stage analysis shows that both instruments are significantly related to test scores with the excepted signs. The F-test of weak instruments displays a value of 15.11, which is above the conventional threshold of 10. Most important, test scores remain significant at the 1% level with almost exactly the same point estimate as Model 5 in Table 2. Meanwhile, education quantity remains insignificant.[29]

But are the instruments exogenous? First, it is noteworthy that the over-identification test does not reject the null hypothesis that the instruments are valid. This means that both instruments are exogenous provided that at least one instrument is exogenous. As argued earlier, it is unlikely that independent school competition is produced by economic growth since the former mostly depends on long-standing education policies rooted in law and not economic performance. This would also mean that both the share of pupils in independent schools and the share of Muslims are valid instruments to rule out basic concerns of reverse causality running from growth to test scores. It is, however, conceivable that both school competition and the share of Muslims are related to growth in other indirect ways. For example, as noted above, independent school competition can spur entrepreneurship that in turn produces growth.

[29] The control variables are all significant also in this model.

TABLE 3. *The relationship between education and economic growth*			
Dependent variable: average annual growth rate between 1995 and 2005			
	Model 1	Model 2	Model 3
	IV	OLS	OLS
TIMSS Advanced test score 1995 (log)	8.62*** (8.53)		8.33*** (4.26)
Average years of schooling 1995 (log)	–0.03 (–0.04)	3.74** (3.25)	0.04 (0.04)
Instruments	*Instruments*	*Growth regressions*	
Independent enrolment shares 1995	0.002*** (3.74)	0.02** (2.75)	0.00 (0.15)
Share of Muslims	–0.01*** (–5.48)	–0.07** (–3.06)	–0.00 (–0.06)
First stage *F*–statistic	15.11		
Hausman test (p–value)	0.90		
Over-identification test (p–value)	0.81		
Adjusted R2	0.955	0.816	0.910
Observations	21	21	21

Note: Unstandardised coefficients (t–statistics based on robust standard errors in parentheses). Significance levels: *p<0.10, **p<0.05, ***p<0.01. All control variables in Model 5 in Table 2 are included.

To explore this further, Model 2 in Table 3 includes the instruments as predictors in the growth regression, while excluding test scores. And, actually, the independent school share is significantly positive, and the share of Muslims is significantly negative, for growth. Notably, average years of schooling also turn significantly positive again. Yet Model 3 includes test scores again – and average years of schooling, the independent school share, and the share of Muslims all turn insignificant while the adjusted-R2 increases significantly. This indicates that the two instruments impact growth through their effect on test scores only over the period analysed, although this assumption can never be tested conclusively. Finally, the Hausman test fails to reject the null hypothesis of no endogeneity, suggesting that TIMSS Advanced test scores are not endogenous to growth. This supports Hanushek and Woessmann's (2012b) findings regarding other test scores, despite using a different set of instruments.

Overall, therefore, Model 5 in Table 2 remains the preferred specification in terms of the impact of education on economic growth. The results from this model are therefore presented in Table 1 (as Model 4) and Figures 3 and 4 in Section 4.[30]

Although indicative of the impact of education on economic growth, it is of course important to point out that the lack of better data prevents our being able to draw strong conclusions from the analysis. For example, only eight of the 21 countries satisfied all guidelines for sample participation rates and classroom sampling procedures, although Hanushek and Woessmann (2011b) have shown that these issues do not seem to affect the impact of test scores on growth. At the same time, the cross-sectional nature of the data is a problem. Since it is difficult to find valid instruments, and because there is no conclusive way to determine whether instruments are valid, the impact of education quality on economic growth may be susceptible to omitted variable bias. However, neither prior studies nor this paper find any evidence that basic reverse causation biases estimates. Because of that and the battery of reported and unreported robustness regressions, it appears to be the case that education quality is indeed causally related to economic growth.

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[30] In addition to these results, I also included interaction terms between dummies indicating high-quality systems and education quality as well as interaction terms between a dummy indicating that initial income is lower than $15,000 and education quantity. In contrast to Castelló-Climent and Hidalgo-Cabrillana (2012), I could not find evidence for any interaction effects. In all regressions, education quality remained highly significant and the effect size even increased.

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