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Quality-adjusted Human Capital and Productivity Growth

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Abstract

Both the quality and quantity of human capital are important for growth. Although the quality aspects of human capital may have greater potential in explaining growth, given that the quantity effects of human capital have been found to be ambiguous, they have long been ignored in empirical growth literature. This paper empirically tests the joint effects of both the quantity and quality of human capital in stimulating productivity growth for a panel of 89 countries over the period 1970-2007. Based on different measures of human capital quantity and quality, the results show that the growth effects of educational attainment can be significantly enhanced when the quality of schooling is improved. The joint effect of human capital quality and quantity is found to be stronger in developing countries.

JEL Classifications: I20, O30, O40

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1. Introduction

The question of whether the quality of human capital is more important than its quantity for improving long-run economic growth has recently become the subject of an important policy debate among academics and policymakers.[2] The proponents of educational quality often argue that the most widely accepted quantity measure of human capital (i.e., the average years of schooling) does not adequately explain the relationship between education and the stock of human capital for at least three reasons: first, it assumes that workers with a given level of education are perfect substitutes for workers of all other levels, and that the elasticity of substitution across workers of different educational categories is always constant; second, it assumes that the productivity differentials among workers with different educational attainment levels are proportional to their schooling years; and third, one year of schooling is assumed to generate the same productivity increase regardless of the fields of study and quality of the educational institutes or systems (Mulligan and Sala-i-Martin, 2000; Woessmann, 2003). However, school attainment has been widely used as a measure of human capital quantity for at least four reasons: first, it is readily available across individuals over time; second, its economic returns (benefits and costs) are easy to calculate; third, schooling quality data are scarce; and fourth, there may be uncertainty in changing educational quality and supporting expenditures. Despite these limitations schooling quality may provide significant rewards to society (Hanushek, 2004).

Therefore, empirical growth literature has recently turned its focus on quality of human capital measured by educational inputs (pupil-teacher ratio, expenditure per pupil, teacher salary and so on) and outputs (dropout rates, repetition rates, scores on standardized international tests in mathematics, science and reading and so on) though the later particularly, test performance has been consistently receiving more attention (Hanushek and Kimko, 2000; Lee and Barro, 2001; Barro, 2001). However, theoretical foundations as well as empirical evidence explaining educational quality are somewhat limited. The significant effect of educational quality even disappears after controlling for the quality of government institutions (Bosworth and Collins, 2003), or per capita scientific and technical journal articles, or R&D researchers (Chen and Luoh, 2010). Again, quality of education may influence growth by increasing quantity of school attainment (Castello-Climent and Hidalgo-

[2] Education makes significant contribution to human capital formation by increasing future labour productivity and income that lead higher level of output and hence this paper considers 'formal schooling' as the synonym of human capital.

Cabrillana, 2009). Therefore, instead of competing between quantity and quality, one should focus on 'quality adjusted quantity' and hence the interaction between quantity and quality of human capital in enhancing cross-country productivity growth deserves more attention.

Although theoretical growth models predict that human capital is one of the most important sources of economic growth, macro-level empirical evidence is at best mixed.[3] Most of the studies so far concentrate on quantity of human capital and hence the mixed outcome may be due to measurement error as well as large variations in the quality of human capital. Therefore, a growing number of recent empirical studies have consistently focused on the quality of human capital and its impact on economic growth. Using science and mathematics scores on internationally comparable tests to measure human capital quality, Hanushek and Kimko (2000) and Barro (2001) argue that both educational quality and quantity affect growth positively, but quality becomes more important because quantity lacks significance once quality is controlled for. Their results imply that the quality of human capital may contain more information than that of quantity to predict subsequent growth across nations. Despite the importance of educational quality, Hanushek and Kimko admit that their estimates may overstate the quality impact of human capital but the precise cause and magnitude of that overstatement are not clear (Engelbrecht, 2003).

Quality of human capital seems very difficult to measure. Lee and Barro (2001) argue that family characteristics such as, income and education of parents, and educational inputs such as, teacher-pupil ratio have significant positive effects on quality of human capital measured by educational outputs, such as scores in cognitive skills tests, dropout and repetition rates. The significance of educational inputs is in sharp contrast to the micro-level empirical findings. After replicating Lee and Barro's estimated results by incorporating more meaningful input variables, such as teachers' salaries as well as educational expenditure per pupil as a ratio of GDP, Sequeira and Robalo (2008) find that the significance of educational inputs disappears. The only exception they observe is that the teacher-pupil ratio shows a consistent positive relationship with schooling output and hence smaller classes may be important. However, these resource based educational inputs do not have any significant

[3]A series of empirical studies obtain either significant positive (Barro, 1991; Mankiw *et al.,* 1992; Gemmell, 1996; Engelbrecht, 2002) or, significant negative (Caselli *et al.,* 1996) or, insignificant (Knowles and Owen, 1995; Pritchett, 2001) or, even non-linear (Kalaitzidakis *et al.*, 2001) association between human capital and growth. In some studies, growth rate of human capital significantly affects output growth (Krueger, 1968; Barro, 1991; Mankiw *et al.,* 1992) whereas, some other studies cast doubt on this channel and propose that the stock of human capital can better explain variations in output growth (Romer, 1990; Benhabib and Spiegel, 1994; Hall and Jones, 1999).

impact on cognitive test performance and hence they may turn out to be a poor proxy for educational quality (Hanushek, 2003).

Educational output measures such as repetition and dropout rates largely depend on school and educational policy and hence they may not capture sufficient schooling quality (Lee and Barro, 2001). Again, cognitive skills measured by science and mathematics test scores at primary and secondary level may not adequately represent the quality of human capital because the test performances may be significantly affected by the outside of school factors such as, individual, families, and cultural factors (Liu *et al.*, 2006). They may also reflect appropriate skills in preparing for those tests. For instance, students from top performing countries such as, Singapore, Korea, Hong Kong, Taiwan, and Japan face entrance examinations in their secondary (8^{th} grade) level of education. Again, Japanese students are consistently achieving higher scores in those tests but their economy has experienced booms and recessions during the last couple of decades and hence test scores could not adequately predict Japanese growth rate over time (Chen and Luoh, 2010). However, returns from investment in human capital become higher as educational quality increases and thus countries with high quality educational systems may have superior school attainment (Castello-Climent and Hidalgo-Cabrillana, 2009).

Most of the recent empirical growth studies have focused just on the additive effects of quantity and quality of human capital, but their effects may be complementary. The complementarity theory states that quantity or quality alone cannot improve overall human capital, rather both are important. To the best of our knowledge, only Hanushek and Kimko (2000) do some experimentation, using a linear interaction term of their human capital quantity and quality variables, but obtain implausible results. They do not explain the reason behind such unexpected outcomes. Apparently the complementarity issue regarding human capital has not yet received much attention, which does not necessarily mean that it is unimportant. Countries with high quality but a low quantity of human capital may fall short of highly educated competent labour force whereas, countries with low quality but a high quantity of human capital may become overburdened with a less capable highly educated work force. An efficient human capital formation requires quantity as well as quality of education and hence both must exist together for overall human capital to grow.

Very few studies, if any, have considered quality adjusted human capital to explain cross-country variations in productivity growth. Therefore, this study contributes to existing literature on human capital and growth by investigating the interaction effect of human capital quantity and quality on productivity growth for a panel of 89 developed and developing countries over the period 1970 to 2007. It uses almost all of the relevant macro level data (panel and cross-sectional) on quantity and quality of human capital in order to test the robustness of its empirical findings.

The paper is structured as follows. Section 2 explains alternative measures of the quantity and quality of human capital. Section 3 discusses recent empirical studies on educational quantity and quality. Section 4 focuses on hypothesis development. Section 5 illustrates research design. Section 6 presents empirical findings and section 7 concludes.

2. Alternative Measures of Human Capital Quantity and Quality

A large number of alternative measures of quantity of human capital have been extensively used in the existing literature on human capital and the growth nexus. Most of the studies investigate the effect of human capital quantity measured by either 'literacy rates' (Azariadis and Drazen, 1990; Benhabib and Spiegel, 1994), or 'school enrolment rates' (Barro, 1991; Mankiw *et al.*, 1992), or 'average years of schooling among the adult population' (Barro and Sala-i-Martin, 1995; Islam, 1995; Barro 1997; Temple, 1999; Wolff, 2000; Krueger and Lindahl, 2001). Being a stock variable, average years of schooling has been widely used as a standard measure of the quantity of human capital in the empirical literature. An extensive discussion on human capital quantity measures has been provided by Le *et al.* (2005).[4]

Many researchers argue that the quality of schooling is more important than the quantity measured by average years of schooling and hence they propose different proxies to measure educational quality, for example, repetition and dropout rates (UNESCO, 1993); scores on internationally comparable cognitive skills tests in mathematics, science, and reading (Hanushek and Kimko, 2000; Barro, 2001; Altinok, 2007; and Hanushek and Woessmann, 2008); IQ test scores (Jones and Schneider, 2006); family background and socioeconomic factors (Hanushek, 1986); school resources and intensity of education including pupil-teacher ratios, expenditure per pupil, teacher salaries, availability of teaching materials, and length of the school year (Card and Krueger, 1992; Psacharopoulos, 1994; Krueger, 1999; Lee and Barro, 2001). However, quality of schooling varies substantially

[4] Le *et al.* (2003), Woessmann (2003), Oxley *et al.* (2008) and Folloni &Vittadini (2010) provide comprehensive discussions on different measures of human capital quantity particularly, and quality.

across countries and thus it may be very difficult to measure quality of education for a large number of countries over time. Therefore, macro data on human capital quality are rather scarce.

To the best of our knowledge, Hanushek and Kimko (2000) took the first initiative to develop educational quality indexes for about 39 countries based on the performance of internationally comparable tests in science and mathematics averaged over 1965 to 1991. They also combine performance in both the tests to construct a single measure for labour force quality. Following Romer (1990), they argue that the emphasis on mathematics and science is well connected to the theoretical importance of R&D activities on growth. Students with good understanding in those two subjects may find themselves in the pool of future scientists and engineers. There are six voluntary international tests of student achievements in mathematics and science administered over the past three decades, four were conducted by the International Association for the Evaluation of Educational Achievement (IEA) and two by the International Assessment of Educational Progress (IAEP). Since its inception in 1959, IEA has been consistently carrying out comparative research on individual learning achievement in primary as well as secondary education. The IAEP was established in 1988 based on the statistical procedures and techniques followed by the United States for the National Assessment of Educational Progress (NAEP) since 1969. The IEA focuses on international performance whereas, the IAEP emphasizes national performance in cognitive tests in the US.[5] Later Bosworth and Collins (2003) extend Hanushek and Kimko's educational quality measures to 84 countries averaged over 1960 to 2000 with updated 2002 World Development Indicators (WDI) data dealing with and without institutional quality variables.

Cross-sectional measures of educational quality cannot exploit the temporal dimension of the data to capture country specific effects and to mitigate endogeneity problems and hence an extensive initiative was taken by Lee and Barro (2001) to construct broad-based human capital quality data for a large number of countries over the period from 1964 to 1991. They compile data on both schooling input and output to measure educational quality. Their educational input measures include indicators of educational intensity and school resources, such as pupil-teachers ratios, real public educational expenditure per student, estimated real salaries of teachers and length of the school year. Their educational

[5] For detailed construction of the cognitive skills data, see Hanushek and Kim (1995).

outcome measures include test scores on internationally comparable examinations in science, mathematics and reading for students, rates of grade repetition and dropping out. The data are available for primary as well as secondary levels of education. However, only a very few developing countries took part in those international cognitive skills tests over the last two decades and thus the total number of sample countries becomes very small when test scores are taken into consideration.

Following a different methodology than that used by Hanushek and Kimko (2000) and Lee and Barro (2001), Altinok and Murseli (2007) compile two macro databases relative to educational quality: the first one is a cross-country database of the qualitative indicators of human capital (QIHC) for approximately 105 countries for most recent years, and the second one is a panel database on educational input and output over the period 1964 to 2005. In fact, they extend Lee and Barro's panel database of educational inputs and outputs for a larger number of countries (mostly with low or middle income levels) to the latest time period (1990-1999). Their data re-adjustment is based on eight international surveys on student learning achievements at primary as well as secondary education levels.[6] All surveys are adjusted to a 0-100 scale and the mean and variance of all tests between 1964 and 2005 are assumed to vary over time. Therefore, without standardization the highest possible test score may become 100. In cross-sectional analysis, they construct a general index of the qualitative indicators of human capital (QIHC-G) by taking arithmetic averages of the qualitative indicators of human capital in mathematics (QIHC-M), science (QIHC-S), and reading (QIHC-R).

It has been repeatedly argued that educational inputs are not strongly associated with the performance in cognitive skill tests and hence they may appear as poor proxy for human capital quality (Hanushek, 1996, 2003; Altinok and Bennaghmouch, 2008). Again, the scores on those internationally comparable exams are available for a large number of countries only for recent time periods. Therefore, cross-sectional analysis can be undertaken by considering the most recent tests scores. Hanushek and Woessmann (2009b) develop new measures of

[6] The surveys are: IAEP (International Assessment of Educational Progress), IEA-TIMSS (International Association of the Evaluation of Educational Achievement-Third International Mathematics and Science Study), IEA-PIRLS (Progress in International Reading Literacy Study), OECD-PISA (Organization for Economic Co-operation and Development -Programme for International Student Assessment), UNESCO-LABORATORIO (United Nations Educational, Scientific and Cultural Organization-Latin American Laboratory for Assessment of the Quality of Education), CONFEMEN-PASEC (Conference of Francophone Education Ministers-Programme on Analysis of Education Systems), UNESCO-SACMEQ (Southern and Eastern Africa Consortium for Monitoring Educational Quality), and UNESCO-MLA (Monitoring Learning Achievement). For detailed analysis of data construction on quality of learning achievement (1965-07), see Altinok (2008).

international differences of cognitive skills. Using twelve different international tests of math, science, or reading, conducted voluntarily between 1964 and 2003, they measure cognitive skills by taking simple averages of all observed test scores in math and science from primary through to the end of secondary education (cognitive) as well as only for lower secondary (lowsec). They scale their data to PISA scale divided by 100. Chen and Luoh (2010) use science and math test scores in 2003 in the TIMSS and PISA. TIMSS test focuses on knowledge and skills acquired by the students from the national schools' curriculum in mathematics and science. Therefore, PISA test scores are better than TIMSS scores because it measures students' ability to apply their acquired knowledge in science and mathematics to the real world.

'Competitiveness' can be defined as a set of institutions, policies, and factors that determine the level of productivity of a country. The World Economic Forum has published '*The Global Competitiveness Report'* annually since 1979. Its competitiveness analysis, based on the Global Competitiveness Index (GCI), is a highly comprehensive index for measuring national competitiveness, which captures both the microeconomic and macroeconomic foundations of national competitiveness. The recent GCI is based on twelve pillars, namely, institutions, infrastructure, macroeconomic stability, health and primary education, higher education and training, goods market efficiency, labour market efficiency, financial market sophistication, technological readiness, market size, business sophistication, and innovation. In recent years, especially from 2000 onwards, it has been regularly reporting various human capital quality indicators, for instance, quality of primary education, quality of public schools, quality of educational system, quality of math and science education and quality of management schools for a large number of countries. The top score on these quality indices is 7, the lowest is 1.

University ranking may be a good proxy for quality of human capital. There are more than 40 countries that have their own national university ranking, and the global rankings have mushroomed.The Shanghai Jiao Tong University published the first Academic Ranking of World Universities (*ARWU*) in 2003, which was followed by the Times Higher Education (*THE*)-*QS* World University Ranking and Webometrics in 2004 and the Taiwan Performance Ranking of Scientific Papers for Research Universities in 2007. The EU has recently announced its intention to develop a 'new multi-dimensional university-ranking system with global outreach' to be piloted in 2010. ARWU considers academic or research performance to rank institutions. Its ranking indicators include alumni and staff wining Nobel Prizes and

Field Medals, highly cited researchers, articles published in Nature and Science, articles indexed in major citation indices, for example, Science Citation Index-Expanded (SCIE) and Social Science Citation Index (SSCI), and the per capita academic performance of an institution. The highest scoring university is assigned a score of 100 and the other universities are calculated as a percentage of the top score. In total, more than 1000 universities are actually ranked and the best 500 are published on the web. On the other hand, *THE-QS* balances research looks at peer reviews, student/staff ratios and internationalisation and employer feedback and publishes the best 200 universities on the web. Since ARWU reports the top 500 universities, it includes universities from both developed and developing countries and hence this study concentrates only on ARWU.

Intelligence and knowledge are directly related to the performance of cognitive skill tests and thus IQ test performance can be considered as an important measure of the quality of the national labour force (Jones and Schneider, 2006). Lynn and Vanhanen (2002, 2006) provide a new database of IQ tests for a large number of countries. They also construct the quality of human capital conditions (QHC) index from five important variables, for instance, PPP gross national income per capita, adult literacy rate, gross tertiary enrolment ratio, life expectancy at birth, and the level of democratization.

3. Literature Review

Investment in education or human capital is believed to be an important source of economic growth over long time periods. Over the last couple of decades, output and labour productivity have grown about 3.5% and 2.4% a year, respectively. The contribution of human capital to labour productivity growth is estimated in different studies as between 13% and 30% of the total change. The contribution of human capital has become even more important for the knowledge based economy to grow more in the future (Dickens *et al.*, 2006). Despite human capital's significance, macro-level empirical evidence on its relationship with growth is at best mixed.

Krueger and Lindhal (2001) observe that education is statistically significant and positively associated with growth only for those countries with the lowest level of education. Pritchett (2001) observes insignificant effects of the growth of schooling on output growth. He remarks that the quality of education may be so low that it is not capable of producing a skilled labour force to enhance growth. However, Rogers (2008) argues that human capital does not automatically translate into higher growth. The weak association between schooling and growth is expected if one includes heterogeneous sample countries that vary significantly in their capacity to use schooling productively. Using data on corruption, black market premia and brain drain to the US as indicators of productive use of schooling for a panel of 76 developing countries over 1960 to 2000, he finds that the effect of schooling on growth is significantly higher for countries that use schooling more productively. An extensive literature review on human capital quantity and growth has been provided by Schutt (2003).

In addition to quantity, quality of schooling is an important ingredient of human capital. Amongst very few researchers, Hanushek and his co-authors in particular, have been regularly investigating the macroeconomic effect of human capital quality on economic growth.[7] Employing a cross-section dataset on cognitive achievement test scores for 39 countries over the period 1960 to 1990, Hanushek and Kimko (2000) observe that labour quality measured by comparative tests of mathematics and scientific skills has a consistent, stable and strong positive significant relationship with economic growth. After controlling for the quality of human capital in their growth regressions, they obtain insignificant effect of the quantity of human capital measured by the average years of schooling. Again, using 31 observations in cross-country regressions they find that conventional measures of school resources, such as educational expenditure and teacher-pupil ratios do not have strong effects on test performances. By investigating the channel through which their educational quality measures affect immigrants' earnings in the US, they obtain clear evidence that performance in cognitive skills tests are positively related to productivity differences. However, these productivity differences appear related to schooling differences and not cultural factors, such as family support and attitude.

Using unbalanced panel data for a large number of countries over 1964 to 1991, Lee and Barro (2001) investigate the relationship between various measures of school outcomes (internationally comparable test scores for examinations in science, mathematics and reading for students, rates of grade repetition and dropping out) and various measures of school inputs (family characteristics, school resources and intensity of education, including pupil-teacher ratio, real public educational expenditure per student, estimated real salaries of teachers and length of the school year). Family background measured by the income and education of parents is found to be very important for student performance. More school resources and lower pupil-teacher ratios are found to be strongly significant, whereas higher

[7] Hanushek and Woessmann (2007a, b) provide extensive reviews on quality of human capital and growth.

average teacher salaries and the length of the school year (days per year and hours per day) are found weakly significant. Therefore, inputs from schools, families and communities are found to be important in improving schooling quality. GDP per capita is found to have an insignificant relationship with mathematics and science test scores but a strong positive relationship with reading scores. Finally, length of school term is positively related to mathematics and science scores but negatively related to reading performances.

Applying panel data for a pool of around 100 countries from 1965 to 1995, Barro (2001) examines the role of quantity of education (measured by years of schooling) and quality of education (measured by scores on internationally comparable examinations) in determining long-run economic growth. School attainment measured by adult males at the secondary and higher level is found to have a positive and statistically significant relationship with growth. An additional schooling year raises the growth rate by 0.44 percent per year. The estimate also implies that the social return to male secondary and higher schooling is around 7 percent per year. Female educational attainment at the secondary and higher level as well as male primary schooling is found to be statistically insignificant. Female primary schooling has a significant positive effect on growth when the estimation does not hold the fertility rate fixed, i.e. primary education for female promotes growth indirectly by lowering fertility. Turning to the quality of human capital, students' scores on internationally comparable examinations in science are found to have a strong positive and statistically significant effect on growth. Mathematics scores are found to be positive but less significant than science scores. While including both science and mathematics scores in the same regression, science scores are found to be more predictive of growth. Reading scores are found to be insignificant in all specifications. Although the effect of schooling quality is more important than that of quantity, average years of school attainment of adult males at secondary and higher level still have positive and significant effects on subsequent growth at a given level of educational quality measured by the overall test scores.

After re-estimating and extending Hanushek and Kimko's (2000) measure of educational quality to 84 countries over the period from 1960 to 2000, Bosworth and Collins (2003) find that the quality of education is statistically significant at the cost of a reduced role of educational quantity measured by the average years of schooling. However, the effect of quality education on growth is not robust to control for additional conditioning variables. Specifically, the coefficient of educational quality becomes insignificant after controlling for the quality of government institutions. Therefore, they conclude that the difficulties in measuring accurate cross-country variations in quantity and quality of education may be responsible for a weak correlation between aggregate measures of educational attainment and economic growth. Therefore, an optimistic valuation of the return to education may lead to only small variations in growth rates across countries.

Expenditure and resource differences across schools are known to be poor measures of the differences of quality schooling (Hanushek, 2002a). The aggregate feature is consistent with other studies indicating that resources alone do not yield any systematic returns in terms of student performance (Hanushek, 1996, 2003). A large number of empirical studies suggest that the quality of human capital measured by the test scores on cognitive skills has significant positive effects on individual earnings, productivity, and economic growth. The relationship between labour force quality and economic growth is perhaps more important than the impact of schooling quality on individual earnings and productivity. A large amount of empirical evidence suggests that schools do not have significant impact on student outcomes. Higher achievements in internationally comparable math and science tests are associated with increased individual productivity and earnings and with faster economic growth across nations (Hanushek, 2002b).

By extending and replicating Hanushek and Kimko's (2000) analysis from 31 countries to 45 countries over the period 1960 to 2000, Jamison *et al.* (2007) re-confirm the strong link between educational quality and economic outcomes. Mathematics scores on the international student achievement tests are significantly important for growth which cannot be captured by the quantity of human capital measured by the average years of schooling. Quantitatively, a one standard deviation increase in test scores raises the annual growth rate of per capita income by 0.5-0.9 percent. While investigating the potential channel through which test scores affect economic outcome, they find strong support for the changes in the rate of technological progress. They also observe a strong relationship between educational quality and the infant mortality rate. Finally, they notice that the effect of the quality of education depends significantly on the openness of an economy. In other words, higher cognitive skills are associated with higher rates of technical progress only in open economies. Therefore, they conclude that the economic and health effects of appropriate investments in human capital quality can well exceed those from increasing the average years of educational attainment.

In a more comprehensive investigation, Hanushek and Woessmann (2008) obtain strong evidence that the quality of education has significant effects on individual earnings and income distribution as well as economic growth. Schooling that does not improve cognitive skills measured by scores on internationally comparable mathematics, science and reading tests, has limited effects on economic development. Using simple averages of the mathematics and science scores on comparable international tests as a measure of cognitive skills for 50 countries over the period from 1960 to 2000, they find that the quantity of human capital measured by average years of school attainment does not have significant independent effects over and above its impact on cognitive skills. The results remain the same while using initial (1960) instead of average (1960-2000) years of schooling. The results also hold after including regional dummies. The significant positive effect of cognitive skills is found to be robust after controlling for institution (trade openness and property rights), fertility and geography. A number of robustness tests also confirm the significant relationship between cognitive skills and growth. In addition, they investigate the quality effect through individual scores on different subjects (mathematics, science and reading) separately. Their empirical evidence shows that scores on mathematics and science tests may have significant independent effects on economic growth, while the scores on reading tests may have significant effects on growth when other subjects are not taken into consideration. Finally, cognitive skills and trade openness are found not only to have positive significant independent effects on growth but also their interaction effect is positive and significant.

Despite relatively high initial levels of schooling, the poor growth performance of Latin American countries remains a puzzle. In an attempt to resolve this 'puzzle' Hanushek and Woessmann (2009a) find that the disappointing performance can be attributed to the difference between the quantity and quality of education. Despite showing significant improvements in school attainment, the average scores of Latin American students on international tests are considerably lower than those of East Asian and Middle Eastern and North African students. Education is relevant to economic growth only in so far as it actually improves cognitive skill. School attainment does not even produce any significant growth effects once cognitive skills are taken into consideration. This is consistent with the findings of Hanushek *et al.* (2006) who observe that lower cognitive skills at primary level lead to higher dropout rates in Egyptian primary school. Therefore, educational policy should focus on quality rather than quantity and hence policymakers should improve the actual learning of their students.

In the presence of endogeneity and reverse causality, the strong cross-country empirical association between cognitive skills and economic growth may produce biased results and hence may not provide any significant real policy guidelines. Endogeneity of cognitive skills may arise because countries with higher economic growth may produce higher test performances. This relationship arises due to different factors such as, institutional development, social and cultural factors, health status which might induce higher performance in cognitive tests. Similarly, reverse causality may arise because higher expected growth may induce higher investment in schooling that facilitates higher cognitive skills. To address these important issues of endogeneity and reverse causality, Hanushek and Woessmann (2009b) investigate the causal relationship between cognitive skills and growth for a panel of 50 countries from 1960 to 2000. They use institutional characteristics of the schooling systems in individual countries as instruments for cognitive test scores. Using different approaches and sets of models, they find consistent and strong support for a causal interpretation of the effect of cognitive skills on growth. Even if the cognitive skill-growth relationship is causal, one needs to understand that cognitive skills are likely to depend not only on formal schooling but also on non-schooling factors such as, culture, ability, peers, family and health. Hence, estimated results are only relevant for a schooling policy that facilitates growth.

Castello-Climent and Hidalgo-Cabrillana (2009) develop an analytical model to study how the quality of the educational system affects the composition of human capital and its relationship with growth. In addition to the single measure of labour force quality constructed by Hanushek and Kimko (2000) and updated by Bosworth and Collins (2003), they use scores on internationally comparable science, mathematics and reading tests compiled by Lee and Barro (2001) as proxies for the quality of human capital. To measure human capital quantity they use Barro and Lee’s (2001) share of population aged 25 years and above having primary and secondary education and average years of school attainment. Also they use enrolment rates in primary and secondary education updated with UNESCO data. They consider 5-year or 10-year lagged values of human capital quantity and quality to reduce endogenetiy problem. Using dynamic panel data over 1960 to 1990 for a large number of countries, they find that educational quality and its effect on the accumulation of human capital are important factors for development. As the quality of educational systems increases, the return from investment in higher education becomes larger and hence more people will have an incentive to invest in higher education. On the other hand, people will get stuck in primary education if educational quality deteriorates. Therefore, countries with a higher quality of educational system may have greater school attainment at secondary level.

Primary education is compulsory and publicly provided in most of the countries and hence greater educational quality may not have any impact on the level of school attainment as well as enrolment rates at primary level.

Liu *et al.* (2006) investigates whether and to what extent the outside of school considerations such as, individual, families, and cultural factors are associated with the students' TIMSS mathematics achievement for the US and five top performing Asian nations such as, Korea, Taiwan, Japan, Singapore, and Hong Kong. Using scores on TIMSS 2003 grade-8 mathematics tests as the dependent variable, they examine the impact of eight (8) outside of school factors (parent educational level, educational aspiration, students' self confidence in learning mathematics, students' valuing mathematics, time students spend doing math homework, extra lessons or tutoring, availability of computer and number of books at home) and fifteen (15) school-associated factors (*Student-Principal:* school size, good school and class attendance, school climate, low social economic status, high social economic status, grouping instructions, grouping students; *Student-Teacher:* perception of no or few limitations on instructions due to students, emphasis on homework, class size, covering overall math topics, teaching time, interaction with colleagues, professional development and content related activities) on mathematics achievement. Their results show that outside of school factors are significantly related to students' mathematics achievement for Korea, Japan, Taiwan, and the US, but less related for Singapore and Hong Kong. It also reveals that none of the school associated factors are related to students' mathematics achievement for Japan however, some of them are related for other countries. Finally, they conclude that the educational system of a country is not isolated from society and thus the mathematics achievement in their sample countries are related to many (if not all) of these outside of school factors.

Chen and Luoh (2010) cast doubt on the existing measures of the quality of human capital. They argue that the scores on internationally comparable mathematics and science tests may not be a good proxy for human capital quality because of their indirect nature. The performance in cognitive skill tests may only reflect superior skill for examination preparation rather than aggregate educational quality. Using test scores data from 2003 PISA & TIMSS for 43 countries, they find that the strong association between mathematics and science test scores and cross-country income differences becomes insignificant once they control for more direct measures of labour force quality such as, scientific and technical journal articles per capita, or R&D researchers per capita. Finally, they conclude that the more effective way to enhance labour productivity for sustained growth is to attract and recruit more international R&D researchers.

With the increasing use of international student achievements data as a proxy for human capital quality, a common criticism that arises is whether the estimated results are affected by the sampling issues that compromise data comparability across different nations. However, Hanushek and Woessmann (2010) argue that school enrolment, sample exclusions and non-response rates are likely to be positively related to cross-country average scores on international achievement tests, but these measures do not affect the estimated results of the effect of schooling quality on growth. Nevertheless, it should be noted that cognitive skills not only depend on schooling quality but also on other non-schooling factors such as, family background, social context, innate abilities and so on. Learning may be affected by externalities and hence it does not depend solely on personal abilities, rather it may be influenced by peer groups in the same school. Again, benefits and losses of schooling may perpetuate over generations, but data on parents' education, qualifications, occupation and income are rarely available. Therefore, multidimensional analysis of human capital includes not only formal schooling and training, but also family background, cultural and social context and non-cognitive skills (Folloni and Vittadini, 2010).

4. Hypothesis Development

4.1 Theories Related to Hypothesis Development

The modelling of the relationship between human capital and economic growth is not unanimous (Engelbrecht, 2003). There are two major approaches to human capital modelling in endogenous growth literature. The first approach is the Lucas (1988) human capital accumulation model, which assumes that the rate of human capital accumulation is the major driving force behind economic growth. Considering human capital as a production input, he argues that the differences in growth rates across countries are primarily due to differences in the human capital accumulation rates. In other words, the rate of growth is proportional to the rate of human capital accumulation. The second approach is the Nelson and Phelps (1966) catch up model for technology diffusion, which relates growth to the stock of human capital through two major channels such as, innovation of new technology and diffusion of existing technology developed elsewhere. The domestic knowledge creation process through innovation is the direct effect, whereas, adoption of the foreign technology is the indirect effect of the stock of human capital.

In Nelson and Phelps (1966) model, the growth rate in total factor productivity (*A*) depends on the distance to the technology frontier and the stock of human capital measured by the level of educational attainment (*sch*) as follows:

$$\frac{\dot{A}_t}{A_t} = \phi(sch)\left[\frac{T_t - A_t}{A_t}\right] = \phi(sch)\left[\frac{A_t^{\max} - A_t}{A_t}\right], \qquad \phi(0) = 0, \qquad \phi'(sch) > 0 \qquad \text{(a)}$$

Therefore, TFP growth is an increasing function of educational attainment and proportional to the technology gap measured by the relative distance between the best practice levels of technology (A^{max}) and technology in practice (*A*). Therefore, it stands in contrast to the Lucas (1988) model where, stock of human capital (*sch*) is assumed to be a factor of production.

However, the stock of human capital does not only affect TFP growth directly by discovering new ideas but also affects it indirectly through speeding up adoption and diffusion of technology developed elsewhere. Therefore, as an extension of the Nelson and Phelps (1966) catch-up hypothesis, Benhabib and Spiegel (1994) consider the direct effect of the level of human capital as follows:

$$\frac{\dot{A}_t}{A_t} = \delta(sch) + \phi(sch)\left[\frac{A_t^{\max} - A_t}{A_t}\right] \qquad \text{(b)}$$

Therefore, equation (b) states that the stock of human capital does not only enhance the ability of a country to develop its own technological innovation, but also improves its ability to catch-up the technological leader by adapting and applying technologies developed elsewhere. However, this study examines only the interaction effect of quantity and quality of human capital on productivity growth.

4.2 Testable Hypothesis

The following hypothesis will be tested in this study for a panel of 89 sample counties over the period 1970 to 2007.

Hypothesis: *The interaction between quantity and quality of human capital has significant positive effects on TFP growth.* Educational quantity measures how much time a person has spent in school, whereas educational quality measures how much the person has actually learned in school. Hence both schooling quantity and quality are likely to affect a person's productivity and income and thus both of them should be taken into account when considering improvements in overall human capital that lead to higher productivity growth.

To illustrate this hypothesis one can set up an ideas production function in which the number of ideas produced depends on quantity ($HK^{Quantity}$) and quality ($HK^{Quality}$) of human capital as follows:

$$\dot{A} = \lambda\left(HK^{Quantity} \times HK^{Quality}\right)^{\sigma} A^{\phi} \qquad 0 < \sigma \leq 1,\ \phi \leq 1 \qquad \text{(h1)}$$

where $\dot{A}$ is new ideas; λ is a research productivity parameter; σ is a duplication parameter, which is zero if all innovations are duplications and 1 if there are no duplicating innovations; A is domestic knowledge stock; ϕ is returns to scale in knowledge. Therefore, one may argue that a large $HK^{Quantity}$ may be unimportant for ideas production if $HK^{Quality}$ is low and vice versa.

5. Research Design

5.1 Model Specification

This study tests for the interaction effect of human capital quantity and quality on productivity growth using the following baseline empirical specification:

$$\Delta \ln A_{it} = \alpha_i + \beta_1 (\ln HK_{it}^{Quantity} \times \ln HK_{it}^{Quality}) + \beta_2 \ln(A^{US} / A_i)_{t-1} + \lambda' X_{it} + \varepsilon_{it} \qquad (1)$$

where, the dependent variable is total factor productivity (TFP) growth ($\Delta \ln A_{it}$)measured by the first difference of the log of TFP (A). $HK_{it}^{Quantity}$ denotes the quantity of human capital measured by the average years of schooling and $HK_{it}^{Quality}$ indicates the quality of human capital measured by schooling inputs and outputs as discussed above. 'ln' stands for natural logarithm. $\ln(A^{US} / A_i)_{i,t-1}$ is the distance to technological frontier measured by the logarithm of the relative TFP gap between the US and the sample countries. The US technology is assumed here as the world technology frontier and it has been supported by the relevant TFP data over the sample period. X_{it} stands for the vector of control variables as mentioned above. ε_{it} is the random error term. The subscript 'i' denotes a particular country, whereas, subscript 't' indicates a particular time period.

5.2 Data and Measurement Issues

This study has estimated growth regression (equation 1) on unbalanced panel data for a sample of 89 countries consisting of 26 developed and 63 developing nations over the period 1970-2007.[8] It estimates panel regression in 5-year differences in order to filter out the business cycle effects. Since TFP growth and level of human capital may be pro-cyclical, a positive correlation between the variables may be driven by business cycle, instead of true structural relationship between them. Therefore, human capital and relevant control variables are measured as the average within the period that is covered by the differences. Distance to frontier is measured in a 5-year lag to allow sufficient time for technology to be accommodated by the economy. Penn World Tables 6.3 (PWT63) compiled by Heston, Summers and Aten (2009) is used to calculate the growth rates of Total Factor Productivity (TFP). Human capital quantity data are collected from four alternative datasets provided by Barro and Lee (2001), Baier *et al.* (2005), Cohen and Soto (2007) and Lutz *et al.* (2007). Data on quality of human capital (schooling input and output) are collected from Altinok and Murseli (2007) that have extended Lee and Barro's (2001) schooling quality data from 1990 to 1999. The most recent quality indicators such as ranking of the top 500 universities in the world has been collected from Shanghai Jiao Tong University's 'Academic Ranking of World Universities (ARWU)' and competitiveness data are compiled from the World Economic Forum's '*Global Competitiveness Report*'.The World Development Indicators (WDI) 2010 online database of the World Bank is used for the rest of the macroeconomic control variables.

TFP Growth ($\Delta \ln A_{it}$): In order to calculate total factor productivity (TFP) growth, this study at first estimates TFP (A) from the aggregate production function, $Y = AK^{\alpha}L^{1-\alpha}$, where, Y is the real GDP, K is the real physical capital stock, and L is the total labour force. Therefore, TFP is measured by $A = TFP = y/k^{\alpha}$, where y is the output-worker ratio (Y/L) and k is the capital-worker ratio (K/L) .Capital's income share (α) is set to 0.30 following Gollin (2002). K is constructed using the perpetual inventory method, $K_{it} = I_{it} + (1-\delta)K_{i,t-1}$, where, I is the amount of investment, δ is the depreciation rate, assumed as 5% as used by Bosworth and Collins (2003). The initial capital stock is

[8] A complete definition of the variables and their sources are listed in the Appendix Table A1. A detailed list of the sample countries along with their country codes is supplied in the Appendix Table A2

estimated as, $K_{i0} = \dfrac{I_{i0}}{g_{ss} + \delta}$, where I_{i0} is the initial real investment, g_{ss} indicates the steady state rate of investment growth, measured by the simple average of the real investment growth rate over the period from 1970 to 2007.

Finally, TFP growth rate is calculated from the first difference of log of TFP (A): $g_{A_{it}} = \dfrac{\dot{A}_{it}}{A_{it}} = \Delta \ln A_{it} = \ln A_{it} - \ln A_{i,t-1}$

Data from Penn World Table 6.3 is used to estimate TFP using the similar process followed by Caselli (2005).

Quantity and Quality of Human Capital (*$HK^{Quantity}$ & $HK^{Quality}$*) : To identify whether the contribution of human capital to productivity growth depends on the complementarity effect of human capital quantity and quality, this study uses average years of schooling for the population aged 25 years and over as the measure of educational quantity, whereas the quality of human capital is measured by schooling inputs (teacher-pupil ratio, expenditure per pupil/GDP per capita, teachers' salary/GDP per capita) and outputs [retention rates (1-dropout rates), non-repetition rates (1-repetition rates), cognitive test scores in science, mathematics and reading]. For cross-sectional analysis it has also used most recent (2000-2007) proxies for quality of human capital including university ranking, IQ scores, competitive quality of educational system and schooling and so on.

Distance to the Technological Frontier [*$ln(A^{US}/A_i)_{t-1}$*] : The potential for distance to technological frontier is measured by the logarithm of the relative TFP gap between the US and the sample countries. As the US is the technology leader as well as the major trading partner of most of the developing countries, US technology is assumed here as the technological frontier. The underlying feature of including this variable is that, other things remain unchanged, countries that lie further behind the technological frontier will experience faster TFP growth by leapfrogging the early stages of the leading technology.

Control Variables: Levine and Renelt (1992) show that the initial real GDP per capita, initial secondary school enrolment ratio and the ratio of domestic investment to GDP are robust control variables across different specifications. Later Sala-i-Martin (1997) departs from Levine and Renelt's (1992) 'extreme bound test' and uses the normality of distribution of the coefficients of the control variables and finally argues that a substantial number of control variables can be found to be strongly related to growth. Using initial GDP per capita for convergence effect is not a usual practice in productivity studies. Instead, distance to technological frontier deals with the convergence issue in endogenous growth models. In most studies current US technology is used to proxy this technological frontier (Aghion *et al.*, 2009).

This study has incorporated five important control variables, namely, trade openness measured by the ratio of the sum of exports and imports to GDP (*OP*), the ratio of foreign direct investment inflow to GDP (*FDI*), the inflation rate (*INF*) measured by the growth rate of consumer price index, the ratio of private credit to GDP (*PC*), and a dummy for tropical countries (*TROP*). *OP*, *FDI*, *INF* and *PC* control for macroeconomic policy issues whereas *TROP* controls for geographical variations across countries. In standard empirical literature, higher *OP*, *FDI*, and *PC* are found (to be) growth improving, whereas higher *INF* and *TROP* are found to cause growth disaster.

5.3 Estimation Techniques

Panel data analysis allows one to exploit the time-series variation as well as cross-sectional heterogeneity of the variables in interest. Hence this study uses 5-year differences unbalanced panel data consisting of a large panel of developed and developing countries spanning the period from 1970 to 2007. The data are averaged over 5-year periods (except 7-year average for the last period, 2000-2007) so that there could be 7 observations per country from 1970 to 2007, which is commonly used in macro-level panel study to reduce business cycle effects. The nature of this panel is unbalanced since data are not available for all the sample countries for all the seven time periods. This study estimates its empirical model for the entire sample at first and then divides the sample into developed and developing countries to gain some insights into the importance of complementarity effect of the quantity and quality of human capital on productivity growth in laggard economies relative to their advanced counterparts.

The baseline panel model in equation (1) shows a pooled ordinary least squares (OLS) relationship between the TFP growth and its potential determinants and thus one can argue that there could be unobserved country specific characteristics, such as institutional quality, schooling environment which might affect the TFP growth rate and are not captured by the pooled OLS model. Such unobserved country-specific effects would be a part of the error term, potentially leading to biased coefficient estimates. By using a fixed effects estimator one can control for time invariant unobserved country-specific fixed effects (f_i) and thereby reduce biases in the estimated coefficients. Again, by allowing the error term (ε_{it}) to include time dummies (t_t), one can easily capture common macroeconomic shocks that might have significant impact on TFP growth in the sample countries. Therefore, by incorporating fixed effects and time dummies into the baseline model (equation 1), this study can construct its baseline empirical panel model as follows:

$$\Delta \ln A_{it} = \alpha_i + \beta_1 (\ln HK_{it}^{Quantity} * \ln HK_{it}^{Quality}) + \beta_2 \ln(A^{US} / A_i)_{t-1} + \lambda' X_{it} + f_i + t_t + e_{it} \qquad (1a)$$

where, $\varepsilon_{it} = f_i + t_t + e_{it}$, and e_{it} is serially uncorrelated error.

However, there are three major concerns that remain after controlling time invariant country specific fixed effects. First, the error term (e_{it}) may contain time varying country specific factors that affect productivity growth and hence estimated coefficients may be biased. Second, most explanatory variables are likely to be jointly endogenous with economic growth and hence fixed effects estimator may produce biased results due to simultaneity or reverse causality. Third, it may exacerbate problems of measurement error if the reliability of time series variation in explanatory variables is poor.

The relationship between human capital and growth is more likely to be affected by endogeneity and reverse causality and hence generalized method of moments (GMM) estimator is widely used to mitigate those problems, where the endogenous explanatory variables are instrumented with their suitable lags so that the instruments are not correlated to the error term. Anderson and Hsiao (1982) suggest a first-differenced transformation to eliminate fixed effects as well as constant. Arellano and Bond (1991) argue that the Anderson-Hsiao estimator fails to take all orthogonality conditions and thus it is not an efficient estimator. Therefore, they propose difference GMM estimator as a system of equations allowing lagged values of the endogenous regressors as instruments. Arellano and Bover (1995) and Blundell and Bond (1998) demonstrate that the lagged level of the endogenous variables may be poor instruments for the first differenced variables and thus they suggest lagged difference as instruments which is popularly known as system GMM.

System GMM is superior to difference GMM because the latter has weak instrument problem and it generates inefficient estimates and according to Monte Carlo experiments it can yield inconsistent coefficients in small samples. System GMM in fact combines the regressions in differences and in levels in a system of equations using the lagged differences instruments for the level series, and the lagged levels of instruments for the differenced series. In Monte Carlo simulations Blundell and Bond (1998) observe that system GMM estimator produces efficiency gain when the number of time series observation is relatively small. Again, System GMM is the most efficient estimator to exploit stationary restrictions in empirical growth model (Bond *et al.*, 2001).

The reliability of the system GMM estimation procedure depends on the validity of the instruments. Hence this study considers the validity of the instruments by presenting the Hansen test on over-identifying restrictions. It is asymptotically distributed as $\chi 2$ and tests the null hypothesis of validity of the (over-identifying) instruments. The p-values report the probability of incorrectly rejecting the null hypothesis, so that a p-value above 0.05 implies that the probability of incorrectly rejecting the null is above 0.05. As a result, a higher p-value makes it more likely that the instruments are valid. The key identifying assumption in Hansen test is that the instruments used in the model are not correlated with the residuals. In addition, system GMM estimator needs to satisfy F-test for joint significance of the estimated coefficients and AR(1) & AR(2) tests for serial correlation in the error term. AR(1) test checks the first order serial correlation between the error and level equation, whereas AR(2) test examines the second order serial correlation between the error and first differenced equation. The null hypotheses in serial correlation tests are that the level regression shows no first order serial correlation and the first differenced regression exhibits no second order serial correlation.

5.4 Data Analysis

Table 1 presents descriptive statistics for the variables used in the empirical study for the entire sample of 26 high income developed and 63 low and middle income developing countries over the period 1970 to 2007. Average years of schooling for the population aged 25 years and above (*SCH*) is used as a proxy for human capital quantity and it has been compiled from four alternative sources, namely, Barro and Lee (2001) henceforth 'BL', Baier *et al.* (2005) henceforth 'BD', Lutz *et al.* (2007) at IIASA-VID henceforth 'IV' and Cohen and Soto (2007) henceforth 'CS'. These data are available till 2000 except CS who have provided projected school attainment data for 2010 and hence this study has considered their projected end date as 2007 to match with its own end date. For the other three sources, it has extrapolated data for the last period (2000-2007). CS and BD data are available in 10-year interval and hence those data are interpolated arithmetically to match with 5-year interval. Throughout these four different sources, average years of school attainment in developed countries (8-10 years) are almost double than those in developing countries (4-5 years).

A number of educational inputs (teacher-pupil ratio, salary of school teachers/GDP per capita, govt. educational expenditures per pupil/ GDP per capita) and outputs (retention rates, non-repetition rates, scores on internationally comparable tests in mathematics, science and reading) are used as alternative measures for the quality of human capital. Retention rate is the inverse of dropout rates. Non-repetition rates are just the opposite of grade repetition rates. These educational quality data are collected from Altinok and Murseli (2007) who have extended Lee and Barro's (2001) schooling quality data from 1990 to 1999. However, educational quality data are extrapolated for the last period (2000-2007). On average, educational quality measures are found to have higher average values for developed countries relative to their developing counterparts.

Although the latest Penn World Table 6.3 (PWT63) has available data from 1950 to 2007, this study has considered its empirical time frame from 1970 to 2007 because a large number of sample developing countries became independent during the 1970s and hence their observable data for all of the relevant variables are available only from 1970 onwards. Therefore, this study has found common sample of maximum 89 countries for the entire period for a few matching variables. Even if this study considers years of schooling data from four alternative sources, it concentrates on Cohen and Soto (CS) school attainment data for reporting its empirical results in the main body due to its availability till the end date of the sample period. However, the estimated results are found to be consistent irrespective of sources (not reported). Also, instead of 5-year averages, this study also uses 5-year lagged data on educational quantity and quality and obtains reasonably consistent results (not reported).

Winsor takes the non-missing values of a variable X and generates a new variable Y identical to X except that the highest and lowest values are replaced by the next value counting inwards from the extremes. Therefore, winsorizing at the 5% level might shrink extreme values to the 5% and 95% percentiles over the years. Omitting outliers may result in significant information loss and thereby winsorizing has become a popular technique to handle outliers and is extensively used in Finance & Accounting literature (Fama and French, 2006). The estimated results after winsorizing do not show any significant differences and are less likely to be affected by outliers. Hence this study has kept the original data (without winsorzing) to estimate its empirical models.

Table 1: Descriptive Statistics: 1970-2007

Variables	TFP Growth $[(\Delta lnA_{it}]$	Distance to Frontier $(A^{US}/ A_i)_{t-1}$	Average Years of Schooling (Cohen & Soto) [CSSCH]	Average Years of Schooling (Lutz *et al.*) [IVSCH]	Average Years of Schooling (Barro & Lee) [BLSCH]	Average Years of Schooling (Baier *et al.*) [BDSCH]	Teacher-Pupil Ratio (SEC) [TPSEC]	Salary of School Teacher (PRI)/ GDP Per Capita [SALPRI]	Govt. Educational Expenditure per pupil (SEC)/ GDP Per Capita [EXSEC]	Retention Rate (1-Dropout Rate) (PRI) [RRPRI]	Non-Repetition Rate (SEC) [NRSEC]	MATH Test Scores (SEC) [MSSEC]	SCIENCE Test Scores (SEC) [SCSEC]	READING Test Scores (SEC) [RSSEC]
Total Sample Countries (89)														
Obs.	618	618	623	560	560	616	618	593	591	592	568	277	277	203
Mean	3.27	331.21	5.79	6.23	5.57	6.16	5.70	338.58	26.25	76.19	90.85	52.71	48.51	50.16
Std. Dev.	14.79	237.46	3.46	3.24	2.97	3.03	2.37	277.92	29.26	22.17	8.23	10.16	7.60	6.31
Min.	-88.25	100.00	0.08	0.10	0.14	0.20	1.56	29.45	1.32	6.00	49.26	23.49	22.09	29.69
Max.	66.35	1614.77	13.35	13.10	12.32	13.35	16.39	2684.00	245.60	100.00	100.00	96.48	69.24	67.32
High Income Developed Countries (26)														
Obs.	182	182	182	175	182	182	182	182	182	165	172	175	175	156
Mean	7.33	147.76	9.72	9.46	8.57	9.18	7.74	218.19	21.62	95.75	92.30	57.07	52.40	51.95
Std. Dev.	9.66	41.23	2.11	2.44	1.99	1.93	2.49	85.41	6.98	7.23	7.80	8.22	4.95	5.19
Min.	-37.20	100.00	3.89	3.40	2.79	4.32	2.54	42.91	3.70	38.71	55.00	31.48	37.51	31.80
Max.	61.41	421.20	13.35	13.10	12.32	13.35	16.39	496.00	39.61	100.00	100.00	96.48	69.24	67.32
Low and Middle Income Developing Countries (63)														
Obs.	436	436	441	385	378	434	436	411	409	427	396	102	102	47
Mean	1.57	407.78	4.16	4.76	4.13	4.90	4.85	391.89	28.31	68.63	90.22	45.23	41.82	44.24
Std. Dev.	16.17	243.55	2.46	2.39	2.17	2.45	1.72	314.68	34.68	21.36	8.34	8.74	6.65	6.11
Min.	-88.25	107.15	0.08	0.10	0.14	0.20	1.56	29.45	1.32	6.00	49.26	23.49	22.09	29.69
Max.	66.35	1614.77	11.05	10.80	9.97	10.41	13.51	2684.00	245.60	100.00	100.00	78.31	57.55	64.25

Notes: ΔlnA_{it} specifies Total Factor Productivity (TFP) Growth for country 'i' over period't'. $(A^{US}/ A_i)_{t-1}$ is one period lagged distance to technology frontier measured by the relative TFP gap between the US and the sample country 'i'. Schooling years are measured for population aged 25 years and above. PRI and SEC stand for primary and secondary level of education, respectively. Estimation period is 1970-2007. The period 2000-2007 is used for the last observation while averaging data for 5 year. TFP growth (ΔlnA) is calculated in 5-year differences. Human capital quantity and quality and control variables (not reported), for example, inflation rate (INF_{it}), trade openness measured by the ratio of the sum of export and import to GDP (OP_{it}), the ratio of foreign direct investment inflow to GDP (FDI_{it}), and the ratio of private sector credit to GDP (PC_{it}), and dummy variable for tropical ($TROP_{it}$) countries are measured in 5-year averages in the interval over which the 5-year differences have been considered to estimate productivity growth. Total sample is divided into developed and developing countries based on the World Bank's country classification based on 2008 GNI per capita.

[Insert Table A3]

Table A3 presents the correlation matrix for the entire as well as split samples. The correlation coefficient between alternative sources of educational quantity measured by average years of schooling is found to be significantly higher (more than 0.90). However, there is no evidence of high pairwise correlation between alternative sources of schooling quality measured by educational inputs and outputs. The correlation coefficients between the level of school attainment (CSSCH) and alternative measures of schooling quality are found to be considerably lower (0.29-0.62). Overall, this study has found significant evidence that average years of schooling are positively correlated with measures of schooling quality.

6. Empirical Analysis

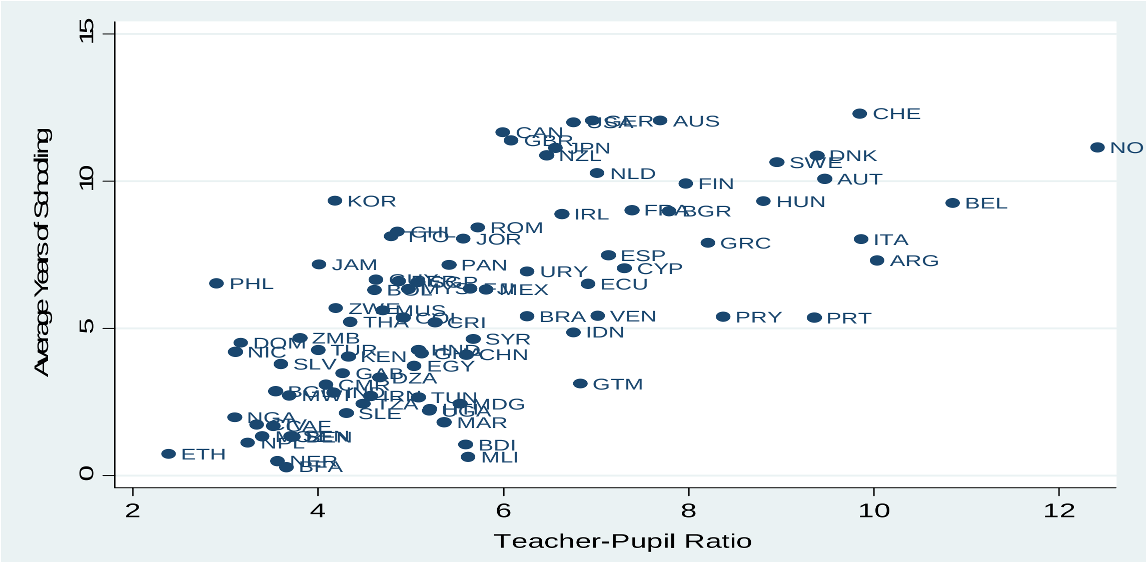
In order to test the interaction effect of quantity and quality of human capital on productivity growth from 1970-2007, this study at first estimates its empirical model for the entire sample (89 countries) and then divides it into 26 high income developed, and 63 low and middle income countries based on 2008 GNI per capita (World Bank 2008 classification).

6.1 Graphical Representation

Prior to running the formal TFP growth regression , this study can observe the following scatter diagram in Figure 1, which is a graphical representation of the relationship between average years of schooling and teacher-pupil ratio at secondary level over 1970 to 2007 for the entire sample.

Figure 1 clearly demonstrates a positive correlation between the educational quality, measured by the teacher-pupil ratio, taken from Lee and Barro (2001) extended by Altinok and Murseli (2007), and the educational quantity measured by the average years of schooling, taken from Cohen and Soto (2007). It shows that, on average, those countries with small class sizes are also those in which the average school attainment is higher. Countries in the upper right side of figure 1 with high quality and quantity of human capital are mostly the high income developed countries, whereas those in the lower left with low educational quality and quantity are low and middle income developing countries.

Figure 1: Quantity (average years of schooling) and Quality (teacher-pupil ratio) of human capital (1970-2007)



Hanushek (1996, 2003) argues that the educational inputs including teacher-pupil ratio, teacher education, teacher experience, teacher salary, government expenditure per pupil and so on, do not have strong and significant effects on student performance measured by scores in cognitive skill and thus these input based measures may turn up as a poor proxy for human capital quality.

Figure 2: Quantity (average years of schooling) and Quality (cognitive skills) of human capital (1970-2007)

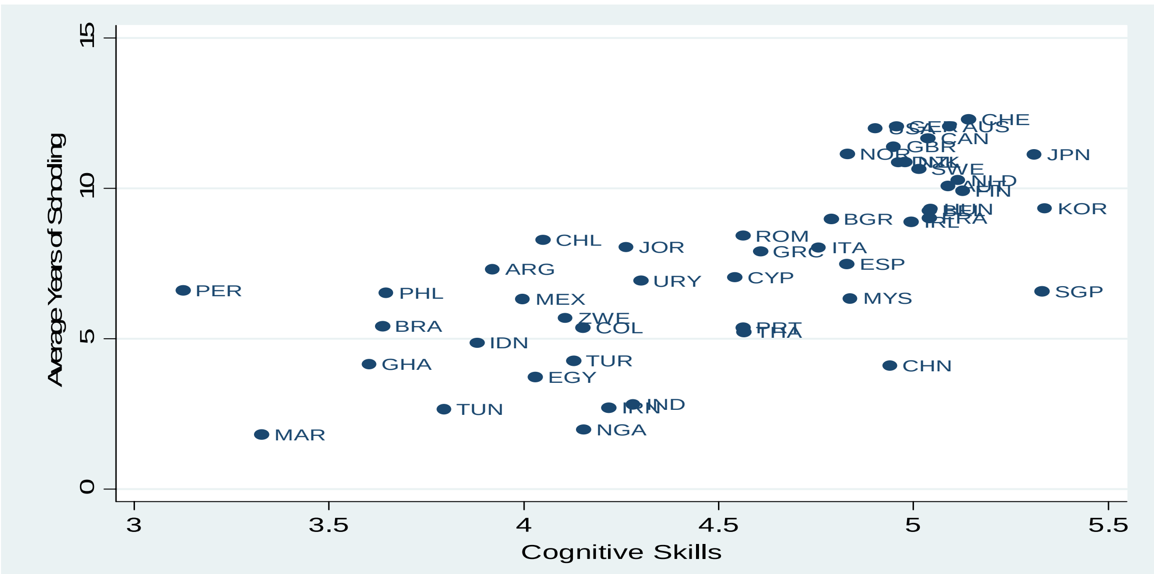
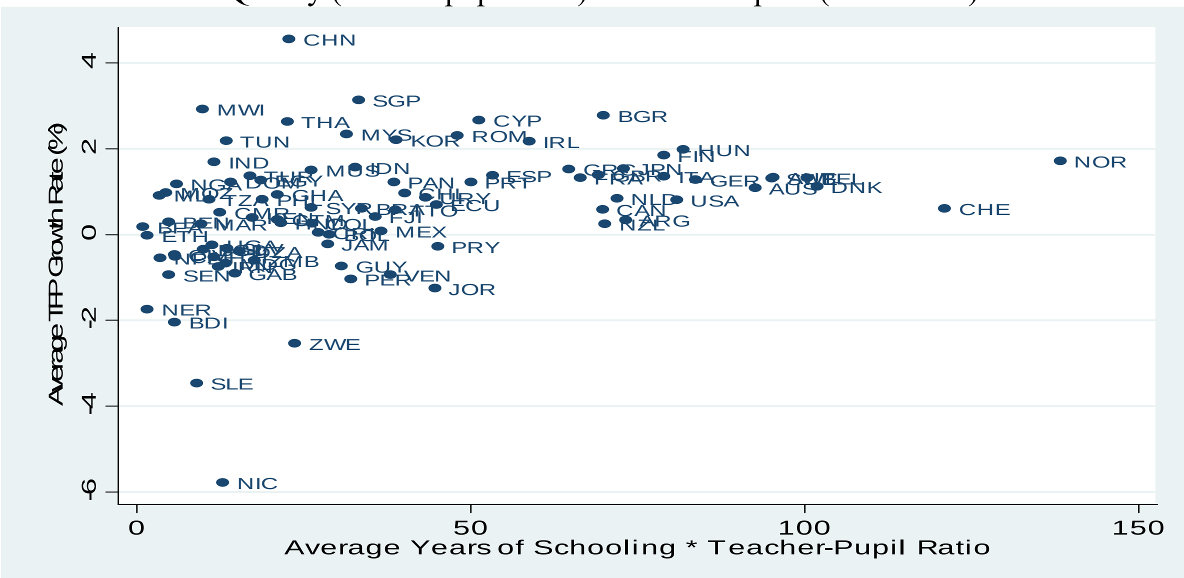


Figure 2 shows the graphical relationship between an alternative measure of educational quality (cognitive skills) and the average school years of attainment over the sample period. It clearly exhibits that there is a positive association between the cognitive skills measured by simple averaging of all observed test scores in math and science from primary through to the end of secondary education, taken from Hanushek and Woessmann (2009b), and the average years of school attainment. Developed countries are placed in the upper right corner of figure 2 with higher cognitive skills and school attainment, but the opposite happens to the developing countries that are placed in the lower left side.

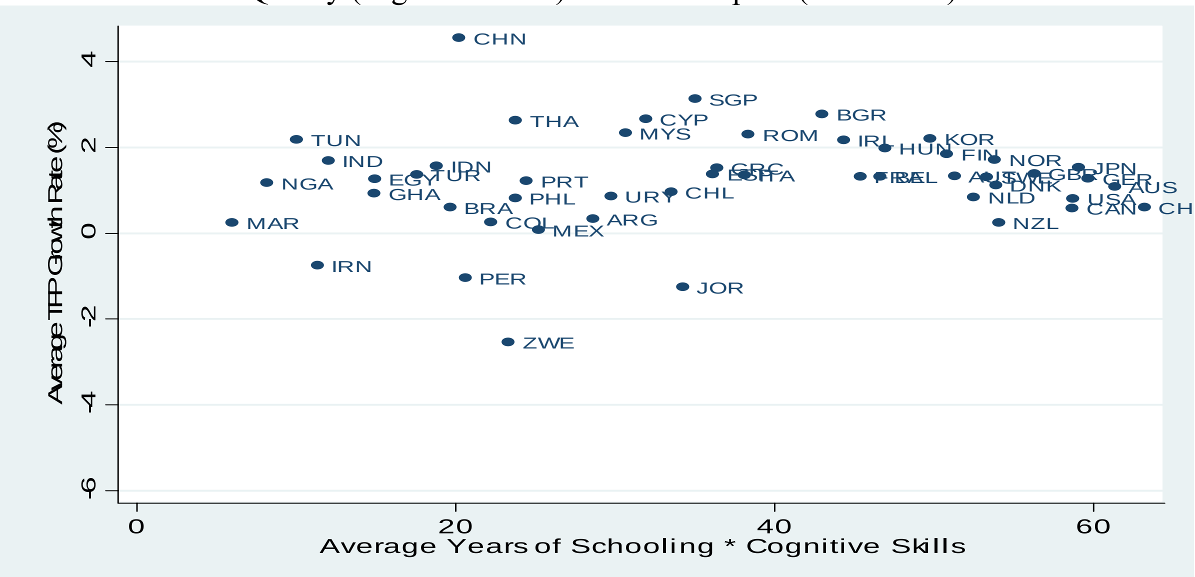
Figure 3: TFP growth and the interaction between Quantity (average years of schooling) and Quality (teacher-pupil ratio) of human capital (1970-2007)



An efficient human capital formation requires both quantitative and qualitative development of education and thus both of them must exist together for overall human capital to grow. In Figure 3 the average total factor productivity (TFP) growth for each country is plotted against the interaction between educational quantity (average years of schooling) and quality (teacher-pupil ratio). The scatter diagram does not exhibit any consistent interaction effect on growth for developed as well as developing countries.

By using cognitive skills as an alternative measure for educational quality Figure 4 exhibits a very similar graphical relationship between productivity growth and the interaction of quantity and quality of human capital across developing and developed countries, as shown in figure 3.

Figure 4: TFP growth and the interaction between Quantity (average years of schooling) and Quality (cognitive skills) of human capital (1970-2007)



Human capital quality data are available only for primary and secondary levels of education. Primary education is publicly provided and compulsory in most of the countries and hence greater educational quality may not have any impact on school attainment at primary level (Castello-Climent and Hidalgo-Cabrillana, 2009). Therefore, this study reports its empirical findings using secondary (SEC) level educational quality data in the text, while primary (PRI) level results are shown in the appendix.

6.2 Panel Estimated Results

Table 2 presents estimated results of TFP growth using the interaction between human capital quantity ($HK^{Quantity}$) measured by average years of schooling for population aged 25 years and above (Cohen and Soto) (CSSCH) and quality of human capital ($HK^{Quality}$) measured by six alternative educational input and output indicators. Estimated results are found consistent while using average years of schooling for population aged 15 years and above (not reported). The system GMM estimator satisfies all of the specification tests, for example, F-test for joint significance, Hansen's test for instrument validity, AR(1) and AR(2) tests for 1st order and 2nd order serial correlation, respectively. Colum (1) shows that the interaction between school attainment level and teacher-pupil ratio at secondary level (TPSEC) has a positive and significant (at 1% level) effect on the subsequent rate of productivity growth. The estimated coefficient implies that a one standard deviation increase in the average years of schooling, together with the teacher-pupil ratio raises the growth rate by 2.8 percentage points. Colum (2) considers the ratio of governmental educational expenditure per pupil at secondary level to GDP per capita (EXSEC) as a proxy for educational quality and shows that a one standard deviation increase in average school attainment level (CSSCH) combined with EXSEC is estimated to raise productivity growth by 1.5 percentage points at 1% level of significance. Both TPSEC and EXSEC are educational inputs and thus they may not adequately represent human capital quality (Hanushek, 1996, 2003).

Table 2: TFP Growth Estimates [Using Interaction between Quantity & Quality (Secondary) of Human Capital]

$HK_{it}^{Quantity}$:	Average Years of Schooling for Population aged 25 Years and Above (Cohen and Soto, 2007) (CSSCH)					
$HK_{it}^{Quality}$:	EDUCATIONAL INPUT		EDUCATIONAL OUTPUT			
[SEC]	[TPSEC]	[EXSEC]	[NRSEC]	[MSSEC]	[SSSEC]	[RSSEC]
Regression:	(1)	(2)	(3)	(4)	(5)	(6)
$(\ln HK^{Quantity} \times \ln HK^{Quality})_{it}$	0.028***	0.015***	0.009**	0.031**	0.029**	0.020**
	(3.066)	(3.106)	(2.044)	(2.428)	(2.080)	(2.667)
$\ln(A^{US}/A_i)_{t-1}$	0.118***	0.116**	0.122**	0.272*	0.330**	0.217***
	(2.660)	(2.619)	(2.385)	(1.913)	(2.372)	(2.974)
INF_{it}	-0.023***	-0.014**	-0.014**	-0.002	-0.003	-0.001
	(-3.285)	(-2.515)	(-2.177)	(-0.632)	(-0.745)	(-0.755)
$\ln OP_{it}$	-0.008	-0.008	0.007	-0.023	-0.003	-0.028
	(-0.431)	(-0.352)	(0.340)	(-0.624)	(-0.086)	(-0.805)
FDI_{it}	0.871**	0.825**	0.883**	0.629*	0.492	0.559
	(2.151)	(2.096)	(2.239)	(1.925)	(1.641)	(1.567)
$\ln PC_{it}$	0.030**	0.0294*	0.024*	0.046	0.059*	0.033
	(2.321)	(1.985)	(1.769)	(1.373)	(1.793)	(1.602)
$TROP_{it}$	-0.040*	-0.056**	-0.074***	-0.055	-0.087	-0.084**
	(-1.837)	(-2.251)	(-3.133)	(-1.043)	(-1.523)	(-2.347)
Constant	-0.196	-0.190	-0.234	-0.444	-0.582*	-0.238
	(-1.613)	(-1.375)	(-1.607)	(-1.498)	(-1.806)	(-1.203)
Hansen-test (p-val)	0.661	0.720	0.787	0.320	0.895	0.863
AR(2)-test (p-val)	0.309	0.368	0.357	0.934	0.934	0.421
No. of Countries	89	87	86	43	43	35
No. of Observation	524	502	486	239	239	176

Notes: See notes to Table 1. Dependent variable is the total factor productivity (TFP) growth for country 'i' over period't' ($\Delta \ln A_{it}$). Independent variables include human capital quantity ($HK_{it}^{Quantity}$), human capital quality ($HK_{it}^{Quality}$), distance to technological frontier [$(A^{US}/A_i)_{t-1}$] and a set of control variables. 'ln' stands for natural logarithm. SEC indicates secondary level of education. Figures in parentheses ( ) are t-values significant at 1% level (***), or 5% level (**), or 10% level (*). Robust Standard Errors are used. Hansen test measures the validity of the instruments where the null hypothesis is that the instruments are not correlated with the residuals. The null hypothesis in AR(2) test is that the error terms in the first difference regression exhibit no 2nd order serial correlation. All results satisfy the F-test for the joint significance of the estimated coefficients and the AR(1) test for 1st order serial correlation, however, they are not reported to conserve space. 2nd to 4th lags of the explanatory variables are taken as instruments for the differenced equation, whereas 1st difference of the explanatory variables is taken as instruments for the level equation in the System GMM. Time dummies are included but not reported for brevity.

Columns (3) to (6) show regression results that consider interaction effects between average years of schooling and alternative proxies for quality of human capital measured by educational outputs at secondary level. Column (3) shows that productivity growth is significantly (at the 5% level) positively related to the interaction between average years of schooling and non-repetition rate (1-repetition rate) (NRSEC). The estimated coefficient indicates that a one standard deviation increase in average schooling level coupled with NRSEC raises productivity growth by 0.9 percentage points. The interactions between average level of school attainment and scores on each of the three internationally comparable tests in mathematics (MSSEC) (column 4), science (SSSEC) (column 5), and reading (RSSEC) (column 6) have positive and statistically significant (at the 5% level) relationship with productivity growth. The estimated coefficients indicate that a one standard deviation increase in the average years of schooling combined with MSSEC raises productivity growth by 3.1 percentage points, with SSSEC, by 2.9 percentage points, and with RSSEC, by 2.0 percentage points. Therefore, the growth effect of an increase in schooling quantity measured by average level of school attainment depends positively on the improvement made in schooling quality measured by educational inputs and outputs. That is, more school attainment results in a larger increase in productivity growth when investment in human capital quality is stronger. On average, interactions between human capital quantity and quality measured by class size and performance in cognitive skill tests, particularly in mathematics and science have larger effects on productivity growth. The estimated results are consistent while using retention rate (1-dropout rate) (RRPRI) and other available educational quality indicators at primary level (see Appendix Table A4), and average years of schooling data from Lutz *et al.* (IVSCH), Barro and Lee (BLSCH) and Baier *et al.* (BDSCH) (not reported).

The estimated coefficients of one period lagged distance to technological frontier are consistently positive and statistically significant, implying the evidence of technology convergence independent of human capital among the sample countries. In other words, the further a country lies behind the technology frontier, the greater will be its potential to accelerate productivity growth. Foreign direct investment inflow (FDI_{it}) and private sector credit (PC_{it}) demonstrate positive and significant effects on TFP growth, whereas inflation rate (INF_{it}) and dummy for tropical countries ($TROP_{it}$) show negative and significant association with productivity growth as expected. Openness (OP_{it}) is found to be insignificant in all of the specifications.

One can argue that the interaction effect between quantity and quality of human capital may be influenced by their own independent effect. Table 3 reports estimated results that consider independent effect of quantity of human capital and its interaction with quality (Panel A), quality and its interaction with quantity (Panel B), and quantity, quality and interaction between them (Panel C). The growth effect of the interaction between quantity and quality is found to be positive and statistically significant though their independent effect remains insignificant in all of the cases. The estimated results are broadly consistent with the baseline findings reported in Table 2, though the level of significance of the interaction terms reduces in all of the specifications in panel C and some of the estimations in panel A and B.

Table 3: TFP Growth Estimates [Using Independent and Interaction between Quantity & Quality (Secondary) of Human Capital]

$HK_{it}^{Quantity}$:	Average Years of Schooling for Population aged 25 Years and Above (CSSCH)					
$HK_{it}^{Quality}$:	**EDUCATIONAL INPUT**		**EDUCATIONAL OUTPUT**			
[SEC]	TPSEC	EXSEC	NRSEC	MSSEC	SSSEC	RSSEC
Regression:	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Panel A: Human Capital Quantity and the interaction between Quantity and Quality						
$lnHK_{it}^{Quantity}$	-0.015	-0.044	-0.863	-0.135	-0.262	-0.185
	(-0.472)	(-1.074)	(-1.628)	(-1.091)	(-1.630)	(-1.319)
$(lnHK^{Quantity}$	0.040**	0.028**	0.020*	0.049*	0.092**	0.067*
$\times lnHK^{Quality})_{it}$	(2.514)	(2.311)	(1.715)	(1.751)	(2.281)	(1.772)
$ln(A^{US}/A_i)_{t-1}$	0.192***	0.096**	0.144*	0.158***	0.177*	0.219***
	(4.592)	(2.352)	(1.678)	(2.747)	(1.859)	(3.368)
Hansen-test (p-val)	0.990	0.991	0.543	0.990	0.990	0.993
AR(2)-test (p-val)	0.340	0.114	0.369	0.604	0.829	0.416
Panel B: Human Capital Quality and the interaction between Quantity and Quality						
$lnHK_{it}^{Quality}$	-0.029	0.020	-0.010	-0.0415	0.003	-0.033
	(-0.892)	(1.227)	(-0.062)	(-0.235)	(0.0270)	(-0.453)
$(lnHK^{Quantity}$	0.028**	0.015***	0.015**	0.039**	0.022*	0.018***
$\times lnHK^{Quality})_{it}$	(2.259)	(2.949)	(2.480)	(2.122)	(1.914)	(3.053)
$ln(A^{US}/A_i)_{t-1}$	0.110***	0.073**	0.162**	0.379**	0.245*	0.169***
	(2.877)	(2.063)	(2.293)	(2.314)	(2.000)	(2.863)
Hansen-test (p-val)	0.940	0.984	0.443	0.768	0.876	0.983
AR(2)-test (p-val)	0.380	0.274	0.416	0.949	0.722	0.246
Panel C: Human Capital Quantity, Quality and the interaction between Quantity and Quality						
$lnHK_{it}^{Quantity}$	-0.015	-0.042	-1.342	-1.554	-3.027	-2.727
	(-0.369)	(-0.609)	(-1.412)	(-1.652)	(-1.589)	(-1.671)
$lnHK_{it}^{Quality}$	-0.044	0.007	-0.238	-0.859	-1.741	-1.254
	(-0.857)	(0.237)	(-0.684)	(-1.652)	(-1.538)	(-1.518)
$(lnHK^{Quantity}$	0.049*	0.029*	0.318	0.444*	0.872*	0.730*
$\times lnHK^{Quality})_{it}$	(1.679)	(1.847)	(1.488)	(1.722)	(1.681)	(1.726)
$ln(A^{US}/A_i)_{t-1}$	0.193**	0.098**	0.226**	0.304**	0.868***	0.197***
	(2.451)	(2.050)	(2.583)	(2.085)	(4.144)	(3.391)
Hansen-test (p-val)	0.393	0.695	0.554	0.497	0.186	0.983
AR(2)-test (p-val)	0.622	0.146	0.401	0.932	0.486	0.857

Notes: See notes to Table 2. Constant and control variables such as, INF_{it}, OP_{it}, FDI_{it}, PC_{it}, and $TROP_{it}$ are included but not reported for brevity.

Multicollinearity may play an important role in growth regression to produce less significant estimates coefficients for interaction effects (Madsen, 2008). Since the correlation coefficients between the interaction terms and the independent human capital quantity (0.94-0.99) and quality (0.70-0.75) are relatively higher, there is a possibility that the reduction of significance in interaction effects may be driven by multicollinearity effect. The estimated results are consistent while using educational quality indicators at primary level (see Appendix Table A5).

Since this study has estimated growth regressions for a large number of sample countries with greater heterogeneity, the issue may arise as to whether the variables are measured in a consistent and reliable manner across different group of countries over time. Again, descriptive statistics in Table 1 clearly depict significant disparities between the developed and developing countries in terms of quantity and quality of human capital. International comparisons reveal even larger deficits in cognitive skills than school attainment in developing countries (Hanushek, 2007b). Therefore, this study has divided the entire sample into 26 high income developed and 63 low and middle income developing countries to gain some insights into the importance of complementarity effects of schooling quantity and quality on productivity growth in developing countries relative to their developed counterparts.

Table 4: TFP Growth Estimates (Using Interaction between Quantity & Quality (Secondary) of Human Capital) [*Developed versus Developing Countries*]

$HK_{it}^{Quantity}$:	Average Years of Schooling for Population aged 25 Years and Above (CSSCH)					
$HK_{it}^{Quality}$:	**EDUCATIONAL INPUT**		**EDUCATIONAL OUTPUT**			
[SEC]	TPSEC	EXSEC	NRSEC	MSSEC	SSSEC	RSSEC
Regression:	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Panel A: High Income Developed Countries (26)						
$(\ln HK^{Quantity}$	0.065*	0.038	0.061*	0.066*	0.076*	0.039*
$\times \ln HK^{Quality})_{it}$	(1.98)	(1.509)	(1.861)	(1.68)	(1.83)	(1.69)
$\ln(A^{US}/A_i)_{t-1}$	0.379*	0.708***	0.516***	0.494***	0.542***	0.452***
	(2.03)	(8.166)	(6.071)	(4.41)	(6.87)	(6.48)
Hansen-test (p-val)	0.993	0.896	0.983	0.944	0.967	0.990
AR(2)-test (p-val)	0.143	0.470	0.981	0.790	0.700	0.071
No. of Countries	26	26	25	25	25	24
No. of Observation	156	156	147	150	150	134
Panel B: Low and Middle Income Developing Countries (63)						
$(\ln HK^{Quantity}$	0.020**	0.012**	0.009**	0.023*	0.031*	0.032**
$\times \ln HK^{Quality})_{it}$	(2.25)	(2.63)	(2.36)	(1.811)	(2.061)	(3.01)
$\ln(A^{US}/A_i)_{t-1}$	0.098**	0.105**	0.104**	0.156**	0.244**	0.110**
	(2.11)	(2.04)	(2.37)	(2.507)	(2.299)	(2.45)
Hansen-test (p-val)	0.999	0.990	0.990	0.998	0.990	0.999
AR(2)-test (p-val)	0.169	0.190	0.184	0.500	0.232	0.271
No. of Countries	63	61	61	18	18	11
No. of Observation	368	346	339	89	89	42

Notes: See notes to Table 2.Constant and control variables, namely, INF_{it}, OP_{it}, FDI_{it}, PC_{it}, and $TROP_{it}$ are included but not reported for brevity. Total sample countries are divided into developed and developing according to the World Bank's country classification based on the 2008 GNI per capita.

Table 4 shows the interaction effects of educational quantity and quality on productivity growth for developed (Panel A) and developing countries (Panel B). Only a few developing countries participated in cognitive skills tests and hence this study had to compromise with small sample size for performance in mathematics, science and reading tests. The estimated results indicate that the growth effect of an increase in school attainment depends positively on the improvement in schooling quality for both groups of countries. In other words, educational quality enhances growth by increasing school attainment. The positive complementarity effects of quantity and quality of human capital are significantly stronger in developing countries than in developed countries. Estimated results are found to be consistent while using educational quality measures at primary level (see Appendix Table A6).

There is an ongoing debate whether the growth rate of output depends on the accumulation (growth rate), or stock (level) of human capital. As a production input, the growth rate of human capital may enhance output growth (Lucas, 1988; Mankiw *et al.,* 1992). On the other hand, human capital may facilitate technology transfer and discovery of new ideas through research & development and hence output growth depends on the level of human capital (Nelson and Phelps, 1966; Romer, 1990; Aghion and Howitt, 1992; Benhabib and Spiegel, 1994, 2005). However, Ciccone and Papaioannou (2006) point out that both human capital accumulation and level effects are important for growth.

Table 5 shows regression results estimating jointly the level and growth effects of human capital using the interaction between schooling quantity and quality. The interaction between level of educational quality and quantity is found to have significant positive effects on productivity growth. The estimated coefficients of the interaction term demonstrate that a one standard deviation increase in average years of schooling combined with improvement in different educational quality measures raises productivity growth by 0.9 to 4.2 percentage points per year and the magnitude of the effects is found to be higher for small class size and performance in cognitive skills tests, particularly in mathematics and science. However, none of the specifications produce significant interaction effect on the growth of quantity and quality of human capital. Therefore, this study argues that the level, not the growth, of overall human capital has significant positive effects on TFP growth. The estimated results are consistent while using educational quality measures at primary level (see Appendix Table A7).

Table 5: TFP Growth Estimates [Using Level and Growth of Interaction between Quantity & Quality (Secondary) of Human Capital]

$HK_{it}^{Quantity}$:	Average Years of Schooling for Population aged 25 Years and Above (CSSCH)					
$HK_{it}^{Quality}$:	**EDUCATIONAL INPUT**		**EDUCATIONAL OUTPUT**			
[SEC]	TPSEC	EXSEC	NRSEC	MSSEC	SSSEC	RSSEC
Regression:	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
$(\ln HK^{Quantity} \times \ln HK^{Quality})_{it}$	0.035***	0.016***	0.009**	0.029**	0.042**	0.021**
	(3.542)	(2.983)	(2.115)	(2.26)	(2.511)	(2.38)
$(\Delta \ln HK^{Quantity} \times \Delta \ln HK^{Quality})_{it}$	-0.001	-0.003	0.0008	0.336	-2.535	-1.536
	(-1.595)	(-0.014)	(0.059)	(0.27)	(-1.542)	(-0.31)
$\ln(A^{US}/A_i)_{t-1}$	0.116***	0.126***	0.114**	0.242*	0.544***	0.205***
	(2.752)	(3.066)	(2.191)	(1.85)	(5.563)	(3.14)
INF_{it}	-0.022***	-0.010*	-0.015**	-0.005	-0.006	-0.0005
	(-3.640)	(-1.696)	(-2.390)	(-0.81)	(-0.577)	(-0.15)
$\ln OP_{it}$	-0.027	-0.008	-0.008	-0.012	0.016	-0.014
	(-1.199)	(-0.358)	(-0.364)	(-0.42)	(0.278)	(-0.58)
FDI_{it}	0.934**	0.738*	0.830**	0.645**	0.259	0.341
	(2.211)	(1.946)	(2.122)	(2.14)	(0.640)	(1.61)
$\ln PC_{it}$	0.025*	0.027*	0.029**	0.013	0.081*	0.002
	(1.736)	(1.908)	(2.077)	(0.45)	(1.966)	(0.14)
$TROP_{it}$	-0.027	-0.061**	-0.060***	-0.058	-0.166*	-0.112*
	(-1.192)	(-2.545)	(-2.677)	(-1.18)	(-1.847)	(-1.88)
Constant	-0.129	-0.197	-0.180	-0.313	-0.972***	-0.153
	(-0.892)	(-1.492)	(-1.269)	(-1.13)	(-2.969)	(-1.11)
Hansen-test (p-val)	0.933	0.980	0.960	0.827	0.537	0.992
AR(2)-test (p-val)	0.255	0.475	0.317	0.781	0.998	0.316
No. of Countries	89	86	85	41	41	30
No. of Observation	516	498	477	234	234	168

Notes: See notes to Table 2.

By using average years of schooling as a proxy for schooling quantity, this study has estimated growth regressions assuming that the schooling quality has the same effect at any educational level (primary, secondary and tertiary). Since primary education is compulsory and publicly funded in most of the countries, quality improvement in secondary education may be more relevant than in primary level to increase school attainment in secondary level. Although educational quantity data are available for all those three levels, schooling quality data are only available for primary and secondary level. Therefore, this study only considers quantity and quality of primary and secondary schooling.

Table 6 demonstrates the estimated results that consider interaction between the composition of quantity and quality of human capital. Data on the ratio of salary of school teachers to GDP per capita (SAL) and the retention rate (1-dropout rate) (RR) are only available for primary education and hence column (2) & (4) show the interaction effect only at primary level. The estimated coefficients of the interaction effects at secondary level are found to be positive and statistically significant in all of the specifications. None of the complementarity effects of schooling quantity and quality at primary level is found to be significant. Therefore, higher school attainment at secondary level results in a larger increase in productivity growth when the educational quality at secondary level is improved.

Table 6: TFP Growth Estimates (Using Interaction between Quantity & Quality of Human Capital) [*Primary and Secondary Level*]

$HK_{it}^{Quantity}$:	Fraction of population aged 25 years and above having primary (PRI) and secondary (SEC) education (Cohen and Soto, 2007)							
$HK_{it}^{Quality}$:	**EDUCATIONAL INPUT**			**EDUCATIONAL OUTPUT**				
[PRI+SEC]	TP	SAL	EX	RR	NR	MS	SS	RS
Regression:	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
$(\ln HK^{Quantity}_{PRI}$	0.003	0.003	0.001	0.004	0.002	0.005	0.004	0.0021
$\times \ln HK^{Quality}_{PRI})_{it}$	(0.660)	(1.406)	(0.398)	(1.453)	(0.308)	(0.379)	(0.718)	(0.311)
$(\ln HK^{Quantity}_{SEC}$	0.012**		0.006*		0.018*	0.021**	0.016**	0.015**
$\times \ln HK^{Quality}_{SEC})_{it}$	(2.094)		(1.719)		(1.932)	(2.308)	(2.507)	(2.072)
$\ln(A^{US}/A_i)_{t-1}$	0.086**	0.088***	0.075**	0.084***	0.216**	0.528***	0.379***	0.232**
	(2.378)	(3.393)	(2.422)	(3.118)	(2.467)	(3.118)	(3.545)	(2.589)
INF_{it}	-0.023***	-0.015**	-0.020***	-0.013*	-0.015**	-0.021	-0.683**	0.003
	(-3.267)	(-2.549)	(-4.009)	(-1.938)	(-2.010)	(-1.402)	(-2.280)	(0.966)
$\ln OP_{it}$	-0.025	-0.013	-0.018	-0.004	0.073	-0.078	0.014	0.113***
	(-1.401)	(-0.599)	(-1.037)	(-0.199)	(1.190)	(-1.075)	(0.364)	(3.113)
FDI_{it}	0.811**	1.090**	0.709*	0.778*	1.056	0.890*	0.570	-0.693
	(2.222)	(2.426)	(1.920)	(1.934)	(1.470)	(1.966)	(1.680)	(-1.314)
$\ln PC_{it}$	0.019	0.034**	0.028*	0.033**	0.042	0.232**	0.101**	0.038
	(1.368)	(2.156)	(1.931)	(2.118)	(1.364)	(2.567)	(2.378)	(1.061)
$TROP_{it}$	-0.023	-0.062***	-0.026	-0.057***	-0.050	-0.046	-0.148	-0.037
	(-1.064)	(-2.904)	(-1.339)	(-2.865)	(-0.495)	(-0.457)	(-1.390)	(-0.876)
Constant	-0.032	-0.111	-0.088	-0.148	-0.849***	-1.213***	-0.822***	-0.835***
	(-0.273)	(-0.877)	(-0.788)	(-1.212)	(-2.718)	(-3.467)	(-2.812)	(-4.337)
Hansen-test (p-val)	0.927	0.844	0.995	0.813	0.442	0.987	0.990	0.980
AR(2)-test (p-val)	0.495	0.363	0.413	0.307	0.184	0.448	0.446	0.396
No. of Countries	88	86	85	86	84	30	27	26
No. of Observation	511	486	490	496	469	128	143	92

Notes: See notes to Table 2.

6.2.1 Panel Robustness Checks

Higher expected growth may induce more investment in overall human capital. Hence the relationship between human capital and growth is likely to be affected by endogeneity and reverse causality (Bils and Klenow, 2000; Hanushek and Woessmann, 2009b). Although system GMM estimator may capture unobserved heterogeneity and possible endogeneity in the model using internal instruments, there could still be endogeneity bias and thus a robustness check is desirable. **S**ystem GMM estimator is primarily designed for internal instruments (lagged differences and lagged levels of the explanatory variables), but it does also allow external instruments to deal with endogeneity problem (Roodman, 2009).

In addition to internal instrument, this study has used *life expectancy* and *the ratio of public educational expenditure to GDP* as external instruments for schooling quantity, whereas *effectiveness of legislature* and *the number of scientific and technical journal articles* *per thousand labourers* are used as external instruments for schooling quality.[9] Higher life expectancy may induce people to investment more in education over a longer period of time to realize higher expected returns in future. As life expectancy increases, the number of years in school will also increase and thus human capital investment may go up. Government educational expenditure may increase school attainment and thus Vandenbussche *et al.* (2006) consider public expenditure on different levels of education as instruments for different levels of school attainment. Bosworth and Collins (2003) observe that the significant effect of quality of education disappears once we control for the quality of government institutions. Hence, effectiveness of legislature as a proxy for political institution may be important for schooling quality. Effectiveness of legislature is highly correlated (0.70 or more) with standard institutional variables such as, Freedom House's political rights, or civil liberties and PRS group's ICRG composite index, or law and order, or corruption. Results are found consistent while using alternative institutional indices. Chen and Luoh (2010) find that the schooling quality lacks significance once it controls for per capita scientific and technical journal articles. Cognitive skills, especially knowledge in science and mathematics, can facilitate one to in publishing more journal articles.

Table 7 reports estimated results considering robustness checks with respect to internal as well as external instruments for quantity and quality of human capital. The estimated coefficients on the interaction between schooling quantity and quality remain of the same sign, statistical significance, and virtually the same magnitude as reported in the baseline Table 2. Hence empirical results are less likely to be affected by endogeneity and reverse causality. The results are consistent while using educational quality measures at primary level (see Appendix Table A8).

[9] Data on life expectancy, ratio of public educational expenditure to GDP and number of scientific and technical journal articles are collected from WDI 2010 online database. Effectiveness of legislature is compiled from Databanks International (Banks, 2007) and has four different categories coded on a scale from 0 to 3. Countries that have no legislature, largely ineffective, partly effective, and effective legislature receive a score of 0, 1, 2 and 3, respectively.

Table 7: TFP Growth Estimates (Using Interaction between Quantity & Quality (Secondary) of Human Capital) [*With Internal as well as External Instruments*]

$HK_{it}^{Quantity}$:	Average Years of Schooling for Population aged 25 Years and Above (CSSCH)					
$HK_{it}^{Quality}$:	**EDUCATIONAL INPUT**		**EDUCATIONAL OUTPUT**			
[SEC]	TPSEC	EXSEC	NRSEC	MSSEC	SSSEC	RSSEC
Regression:	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
$(\ln HK^{Quantity} \times \ln HK^{Quality})_{it}$	0.0276**	0.0146***	0.00870**	0.0307**	0.0282**	0.0222***
	(2.633)	(2.936)	(2.044)	(2.432)	(2.066)	(3.196)
$\ln(A^{US}/A_i)_{t-1}$	0.138***	0.118***	0.113***	0.233**	0.215**	0.222***
	(3.514)	(3.280)	(2.962)	(2.358)	(2.274)	(3.116)
INF_{it}	-0.0206***	-0.0132**	-0.0135**	-0.00265	-0.00298	-0.00162
	(-3.065)	(-2.401)	(-2.027)	(-0.744)	(-0.716)	(-0.592)
$\ln OP_{it}$	-0.00362	-0.00911	0.00331	-0.0261	0.0205	-0.0233
	(-0.174)	(-0.363)	(0.146)	(-0.654)	(0.515)	(-0.723)
FDI_{it}	0.836**	0.781**	0.853**	0.675*	0.449	0.532
	(2.168)	(2.032)	(2.234)	(1.960)	(1.585)	(1.634)
$\ln PC_{it}$	0.0231	0.0285*	0.0223	0.0409	0.0280	0.0328
	(1.552)	(1.758)	(1.515)	(1.337)	(1.074)	(1.623)
$TROP_{it}$	-0.0606***	-0.0586***	-0.0726***	-0.0407	-0.0521	-0.0842**
	(-3.060)	(-3.073)	(-3.570)	(-1.116)	(-1.564)	(-2.464)
Constant	-0.197	-0.177	-0.184	-0.385	-0.480*	-0.274
	(-1.497)	(-1.302)	(-1.274)	(-1.541)	(-1.888)	(-1.538)
Hansen-test (p-val)	0.836	0.950	0.918	0.329	0.921	0.978
AR(2)-test (p-val)	0.405	0.458	0.399	0.914	0.765	0.424
No. of Countries	87	85	84	43	43	35
No. of Observation	511	490	473	239	239	176

Notes: See notes to Table 2. External instruments for quantity of human capital are 'life expectancy' and 'the ratio of public educational expenditure to GDP', whereas external instruments for quality of human capital are 'effectiveness of legislature' and 'the number of scientific and technical journal articles per thousand labourers'.

A common criticism of average years of schooling as a proxy for human capital quantity is that the differences in labour productivity are assumed to be proportional to schooling years because it gives the same weight to any year of schooling. In reality, returns from schooling may vary across nations as well as different levels of education. In a micro-economic earning function, Mincer (1974) estimates the rate of return to education by regressing labour wages on years of schooling. He finds that each additional year of schooling raised annual labour earnings by 5 to 10 percentage points in the 1950s and 1960s. Hence a number of empirical studies propose that the relationship between human capital and schooling at macro level should consider the Mincerian way to incorporate schooling return (Klenow and Rodriguez-Clare, 1997; Hall and Jones, 1999; Bils and Klenow, 2000). Therefore, as a robustness check, the quantity of human capital (MSCH) is adjusted with the the Mincerian approach, as $MSCH = (1+r)^{CSSCH}$; where, r is the average return to schooling which is set at 0.07 following the standard practice in the literature (Jones, 2002).

Table 8: TFP Growth Estimates (Using Interaction between Quantity & Quality (Secondary) of Human Capital) [*With Mincerian 7% Return on School Attainment*]

$HK_{it}^{Quantity}$:	Mincerian specification for human capital quantity (MSCH) using 7% return and Average Years of Schooling for Population aged 25 Years and Above (Cohen and Soto, 2007) (CSSCH)					
$HK_{it}^{Quality}$:	**EDUCATIONAL INPUT**		**EDUCATIONAL OUTPUT**			
[SEC]	TPSEC	EXSEC	NRSEC	MSSEC	SSSEC	RSSEC
Regression:	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
$(\ln HK^{Quantity}$	0.102**	0.083**	0.060**	0.115**	0.116**	0.079**
$\times \ln HK^{Quality})_{it}$	(2.42)	(2.11)	(2.45)	(2.07)	(2.32)	(2.06)
$\ln(A^{US}/A_i)_{t-1}$	0.120***	0.127**	0.098**	0.319**	0.334**	0.334***
	(2.79)	(2.37)	(2.17)	(2.11)	(2.26)	(4.82)
INF_{it}	-0.023***	-0.013**	-0.016***	-0.001	-0.0006	0.007
	(-3.22)	(-2.32)	(-3.21)	(-0.28)	(-0.14)	(1.15)
$\ln OP_{it}$	-0.009	-0.016	-0.031	-0.033	0.005	-0.027
	(-0.47)	(-0.76)	(-1.09)	(-0.76)	(0.13)	(-0.68)
FDI_{it}	0.755*	0.719*	0.772*	0.615*	0.415	1.282
	(1.94)	(1.78)	(1.91)	(1.96)	(1.63)	(1.48)
$\ln PC_{it}$	0.029**	0.023	0.020	0.055	0.053	-0.006
	(2.15)	(1.57)	(0.85)	(1.59)	(1.63)	(-0.26)
$TROP_{it}$	-0.033	-0.038	-0.016	-0.025	-0.044	-0.148***
	(-1.48)	(-1.42)	(-0.62)	(-0.40)	(-0.67)	(-2.92)
Constant	-0.188	-0.194	-0.102	-0.498	-0.641**	-0.167
	(-1.50)	(-1.31)	(-0.55)	(-1.56)	(-2.15)	(-0.81)
Hansen-test (p-val)	0.688	0.750	0.340	0.702	0.875	0.784
AR(2)-test (p-val)	0.321	0.398	0.373	0.848	0.761	0.781
No. of Countries	89	87	86	43	43	35
No. of Observation	524	502	486	239	239	176

Notes: See notes to Table 2.

Table 8 shows the regression results that consider interaction effects between the Mincerian specification of educational attainment and the quality of human capital. The results are consistent with the baseline outcome reported in Table 2. Interestingly, the magnitude of the effect of complementarity between educational quantity and quality on productivity growth has significantly increased while considering the Mincerian return on school attainment. The estimated coefficients imply that a one standard deviation increase in the school attainment, coupled with the quality improvement in schooling, measured by alternative indicators, raises productivity growth by 6.0 to 11.6 percentage points per year and small class size and performance in mathematics and science tests dominate the interaction effect. The estimated results are consistent while using educational quality measures at primary level (see Appendix Table A9).

For further robustness check, this study also re-estimates TFP growth by incorporating three alternative control variables, such as financial development proxied by the ratio of liquid liabilities to GDP (*M3*), inflation rate measured by the growth rate of GDP deflator (*INFG*), and geographical location measured by landlockness (*LOCK*). The estimated results (not reported) remain consistent to baseline findings reported in Table 2. Till now this study has used data averaged or differenced over 5-year interval to filter out business cycle effects. However, longer interval may reduce such business cycles and transitional dynamics effects and hence this study re-estimates growth regressions over the full sample period from 1970 to 2007. The estimated results presented in Appendix Table A10 are found to be very consistent with the baseline outcome reported in Table 2. However, the magnitude of the interaction effect is found to be reduced in all of the specifications, perhaps due to the small number of sample observations over the longer period of time.

6.3 Most Recent Cross-Sectional Results

Although panel data has been extensively used in empirical studies on human capital and growth, it is predominantly limited to human capital quantity rather than quality. Data on quality of human capital are scarce and hence most of the studies conduct cross-sectional analysis while focusing on educational quality. Panel data may exploit temporal dimension as well as country specific effects, but they require shortening of growth periods to 5 to 10 years to mitigate business cycle effects and hence they may be inadequate to study the growth effect of human capital, because it may take longer time periods to translate human capital into higher productivity growth. Again, the problems of measurement error may be more severe in panel estimations (Pritchett, 2000; Krueger and Lindahl, 2000; Durlauf *et al*., 2005). Hence, the dominant methodology for testing the effect of schooling on growth is cross-sectional growth regressions (Rogers, 2008). Therefore, as a part of the cross-sectional analysis, this study uses the most recent (2000-2007) human capital quality indicators to test the interaction effect of educational quantity and quality on productivity growth over the total sample period (1970-2007), assuming that the schooling quality is reasonably constant over time.

Table 9 reports estimated cross-sectional results of growth regressions when quantity of human capital is interacted with some 'very' recent indicators of schooling quality that are not used in previous analysis. It relates the quantity and especially quality of human capital measured since 2000 to the productivity growth measured for 1970 to 2007. GMM estimator satisfies specification tests, for example, Hansen test for instrument validity and C (Difference-in-Sargan) test for instrument exogeneity. Estimated cross-sectional results are qualitatively similar to the panel results reported in the baseline Table 2. Columns(1) to (5) present regression results using alternative educational quality indicators compiled from 'The Global Competitiveness Reports' (2000 to 2007) published by World Economic Forum

(WEF). While interacted with school attainment level (CSSCH), all of those five alternative quality indicators, namely, quality of education system (QED), quality of math and science education (QMT), quality of management schools (QMS), quality of primary education (QPS), and quality of public schools (QPUB) produce strong and significant positive effects on productivity growth. The estimated coefficients imply that a one standard deviation increase in educational attainment together with alternative competitiveness of schooling qualities raises productivity growth by 0.5 to 0.7 percentage points. On an average, these specifications can explain 58% of the variations in productivity growth.

Table 9: Recent Cross-Sectional TFP Growth Estimates (Using Interaction between Quantity & Quality of Human Capital)

$HK_{it}^{Quantity}$:	Average Years of Schooling for Population aged 25 Years and Above(CSSCH)						
$HK_{it}^{Quality}$:	QED	QMT	QMS	QPS	QPUB	URANK	IQ
Regression:	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
$(\ln HK^{Quantity}$	0.006**	0.007***	0.006***	0.006**	0.005**	0.001**	0.001***
$\times \ln HK^{Quality})_i$	(2.646)	(2.790)	(2.876)	(2.407)	(2.466)	(2.667)	(3.51)
$\ln(A^{US}/A_i)_{1970}$	0.016***	0.016***	0.018***	0.015***	0.015***	0.019***	0.017***
	(6.207)	(6.456)	(6.504)	(5.299)	(6.191)	(12.55)	(10.8)
INF_i	-0.0002**	-0.0003**	-0.0003***	-0.0002**	-0.0002**	-0.0002	-0.0002***
	(-2.041)	(-2.534)	(-3.545)	(-2.020)	(-2.165)	(-0.244)	(-3.98)
$\ln OP_i$	-0.001	-0.001	-0.0007	-0.002	-0.002	0.002	-0.001
	(-0.649)	(-0.672)	(-0.288)	(-0.813)	(-0.932)	(1.283)	(-0.79)
FDI_i	0.0691	0.055	0.078	0.086	0.093	0.022	0.174**
	(0.708)	(0.582)	(0.816)	(0.907)	(1.048)	(0.529)	(2.61)
$\ln PC_i$	0.003**	0.003**	0.003**	0.003*	0.004**	0.002*	0.005***
	(2.049)	(2.203)	(2.272)	(1.727)	(2.643)	(1.726)	(4.55)
$TROP_i$	-0.001	-0.0006	-0.003*	-0.001	-0.001	-0.001	-0.004**
	(-0.743)	(-0.226)	(-1.675)	(-0.576)	(-0.382)	(-0.553)	(-2.35)
Constant	-0.027**	-0.030***	-0.035***	-0.023**	-0.025**	-0.022**	-0.034***
	(-2.420)	(-2.711)	(-3.002)	(-2.133)	(-2.471)	(-2.316)	(-3.65)
R-Squared	0.569	0.571	0.594	0.569	0.603	0.832	0.640
Hansen-test (p-val)	0.429	0.878	0.981	0.360	0.329	0.189	0.143
C-test (p-val)	0.361	0.664	0.909	0.399	0.223	0.465	0.539
No. of Countries	80	80	79	78	78	32	85

Notes: See notes to Table 2. Quality measures of human capital include: Quality of Education System (QED), Quality of Math and Science Education (QMT), Quality of Management Schools (QMS), Quality of Primary Education (QPS), Quality of Public Schools (QPUB), Number of universities listed in the top 500 ranking (ARWU) per million labour (URANK), and IQ test scores (IQ). GMM instruments for quantity of human capital are 'life expectancy' and 'the ratio of public educational expenditure to GDP', whereas instruments for quality of human capital are 'effectiveness of legislature' and 'the number of scientific and technical journal articles per thousand labours'. Hansen-test measures the validity of the instruments where the null hypothesis is that the instruments are not correlated with the residuals. C-test (also known as Difference-in-Sargan test) measures the exogeneity of one or more instruments where the null hypothesis is that the instruments are exogenous.

Since all of the existing educational quality indicators concentrate only on primary and secondary level of education, university ranking may adequately represent schooling quality at tertiary level. However, university ranking may be influenced by their originator's objective: Shanghai Jiao Tong University's the Academic Ranking for World Universities (ARWU) may be intended to encourage more state funding for Chinese universities, whereas the European rankings may be aimed at providing greater status to for its member countries.

Again, university ranking may be manipulated by university authorities through influencing students' pass marks and by students through providing spuriously flattering assessments of their own universities. Flawed or not, university rankings have significant impact on their measured universities. They at least provide the impression of students' choice of their investment in higher education (The Economist, 2010). ARWU was first administered in 2003 covering only 35 countries, which had universities ranked in the top 500. In 2007, this number increased to 40. The distribution of top universities by region in 2007 is 38.63% for North and Latin America, 40.78% for Europe, 19.61% for Asia/Pacific, and 0.98% for Africa. Therefore, the number of European universities in the top 500 ranking is slightly greater than that of the North and Latin American universities. The distribution of top universities among countries is also interesting. In 2007, the United States has consistent dominance with 32.50% followed by the United Kingdom with 8.20%, Germany with 8.00%, and Japan with 6.50%. The distribution of top ranked universities in developing countries in 2007 is 2.70% in China, 1.00% in Brazil, and 0.40% in India. Therefore, it is worth noting that most of the top ranked universities are in developed countries and hence this study compromises with small sample size. Using data on university ranking over 2003 to 2007, the estimated results in Column (6) show that the productivity growth is significantly positively related to the interaction between schooling years and the number of top 500 ranked universities per million labour force (URANK). Interestingly, this specification can explain 83.2% of the variations in the TFP growth, which is the highest among all of the specifications.

Column (7) shows the regression result that considers Lynn and Vanhanen's (2006) IQ test scores (IQ) in 2006 as a quality indicator of human capital. The estimated result demonstrates that the growth effect of an increase in school attainment depends positively on IQ test performance. Estimated coefficient specifies that a one standard deviation increase in schooling years together with IQ performance increases productivity growth by 0.10 percentage points at the 1% level of significance.

Most of the existing studies on human capital quality are based on the mathematics and science tests results in the Trends in International Mathematics and Science Study (TIMSS) or the Programme for International Student Assessment (PISA). Test scores data from PISA is a better choice than labour force quality since PISA test measures the ability of students to apply their acquired knowledge (science and mathematics) in the real world, whereas TIMSS test measures the knowledge that (science and mathematics) students acquire in their home countries (Chen and Luoh, 2010). TIMSS was first administered in

1995 and it assesses mathematics and science knowledge of 4th (primary) and 8th (secondary) grade students in every 4 years thereafter (1999, 2003 and 2007). PISA was first administered in 2000 and repeated every 3 years with special focus on mathematics (2000), science (2003) and reading knowledge (2006) of 15-year old students (secondary). Therefore, this study considers both PISA and TIMSS test results in mathematics and science at secondary level in 2003 for robustness check. The estimated results show that both the test scores produce significant positive interaction effect with school attainment on productivity growth, though PISA math score is marginally significant. The estimated cross-sectional results over longer period(s) of time are also consistent while using scores in cognitive skills tests constructed by Hanushek and Kimko (2000), Bosworth and Collins (2003), Altinok and Murseli (2007) and Hanushek and Woessmann (2009b) as alternative measures for quality of human capital (see Appendix Table A11).

7. Concluding Remarks

Quality aspects of human capital have long been overlooked in empirical growth studies and hence the effect of quantity of human capital measured by average years of school attainment on economic growth has been found to be inconclusive. Both educational quantity as well as quality is essential to enhance overall human capital. Therefore, this paper empirically examines possible interaction between the quantity and quality of human capital in improving productivity growth for a panel of 89 sample countries, consisting of 26 developed and 63 developing nations, over the period 1970 to 2007. It uses educational quantity (school attainment) data from four alternative sources, namely, BL (2001), BD (2005), CS (2007) and IV (2007), though it has placed more emphasis on CS data due to its longer availability. In the case of human capital quality, it explores almost all of the available macro level data (panel and cross-section) on schooling quality. It applies three different estimators, for instance, pooled OLS, fixed effects and system GMM, though the system GMM estimator has been preferred for its superiority for dealing with endogeneity. The estimated results are found to be consistent and robust to changes in specifications, econometric methods and alternative measures of quantity and quality of human capital.

The empirical results in this study suggest that the quantity of human capital measured by average years of schooling has significant positive effects on productivity growth when the complementarities between educational quantity and quality are taken into consideration. This has been done by incorporating an interaction term of human capital quantity and quality into regression models. The coefficients of the interaction term are found to be positive and statistically significant in almost all of the specifications. In other words, growth effects of an increase in schooling quantity depends positively and significantly on the progress of schooling quality, whatever the quality measure is taken into account. However, the magnitude of the effect is found to be dominated by small class size and the performance of cognitive skills tests in mathematics and science. The effect of secondary education is found to be more important than primary schooling for enhancing growth. The results are consistent in both cross-sectional and panel analysis. In most recent cross-sectional analysis, IQ, schooling competitiveness and world university ranking are also found to be important educational quality measures that have significant positive interaction effects on growth.

A number of empirical studies have reported that the quality of human capital outperforms the quantity (Hanushek and Kimko, 2000; Barro, 2001). They mainly focus on the additive effect by including both schooling quantity and quality simultaneously in their regression models and found that the quantity measure always becomes statistically insignificant, though quantity effect is found to be significant when quality effect is not controlled for. However, when they take into account the individual effect of quantity and quality on growth in the same model, it is possible that one more year of schooling with no changes of its quality may have smaller effects on growth. Hence a more convincing proxy for overall human capital is warranted. Therefore, this study multiplies schooling quantity and quality to get a suitable measure for overall human capital that can adequately explain differences in productivity growth across nations.

Developing countries are lagging far behind developed countries in both educational quantity and quality. They have even larger deficits in educational quality than quantity. Thus there may be an opportunity for those developing nations to grow more by improving their schooling quality. Hence, this study has divided its sample into developed and developing countries and found that the interaction effect of schooling quantity and quality on productivity growth is more significant in low and middle income developing countries than in their high income developed counterparts. Therefore, more school attainment results in a larger increase in productivity growth in those developing countries once they increase their investment in educational quality. However, quality has multidimensional aspects and hence instead of focusing only on a single component, quality improvement should be implemented as a package of interrelated factors that affect schooling quality, tailored to the specific needs of the countries concerned.

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Appendix

Table A1: Variable Sources and Definitions

Variable	*Source and Definition*
$\Delta \ln A$	Total Factor Productivity (TFP) Growth is calculated from the 6.3 version of the Penn World Table (PWT6.3-Heston, Summers and Aten ,2009) available at, http://pwt.econ.upenn.edu/php_site/pwt_index.php
$\ln(A_i / A^{US})$	Distance to technological frontier is measured by the logarithm of relative productivity (TFP) gap between the US and the sample countries and, calculated from productivity growth ($\Delta \ln A$) derivation as stated above. The US being the technology leader as well as the major trading partner of most of the countries, US technology is assumed here as the world technological frontier (A^{US}).
$HK^{Quantity}$	Quantity of human capital is measured by average years of schooling for population aged 25 years and above, taken from (i) Cohen and Soto (2007) henceforth 'CS' available at http://soto.iae-csic.org/Data.htm , (ii) Lutz et al. (2007) at International Institute for Applied Systems Analysis and Vienna Institute of Demography (2007) (IIASA-VID) henceforth 'IV' available at http://www.iiasa.ac.at/Research/POP/edu07/index.html?sb=11, (iii) Barro and Lee (2001) henceforth 'BL' available at http://www.cid.harvard.edu/ciddata/ciddata.html, and (iv) Baier, Dwyer and Tamura (2005) henceforth 'BD' available at http://www.jerrydwyer.com/growth.
$HK^{Quality}$	Quality of human capital is measured by schooling inputs and outputs, taken from (i) Hanushek and Kimko (2000), extended by Bosworth and Collins (2003), (ii) Lee and Barro (2001), extended by Altinok and Murseli (2007), (iii) Lynn and Vanhanen (2002, 2006), (iv) Hanushek and Woessmann (2009b), (v) Chen and Luoh (2010), (vi) The World Economic Forum's 'The Global Competitiveness Report' (2000-2007) at http://www.weforum.org, (vii) The Shanghai Jiao Tong University's 'Academic Ranking of World Universities (ARWU)' (2003-2007) at http://www.arwu.org/.
INF	Inflation Rate is measured by the growth rate of consumer price index, taken from World Development Indicators (WDI) 2010 online database.
OP	Trade Openness is measured by the ratio of the sum of total exports and imports to GDP, taken from the World Development Indicators (WDI) 2010 online database.
FDI	Inflow of Foreign Direct Investment (FDI) is measured by the ratio of foreign direct investment (FDI) inflow to GDP, taken from World Development Indicators (WDI) 2010 online database.
PC	Private Sector Credit is measured by the ratio of financial resources provided to the private sector to GDP, taken from World Development Indicators (WDI) 2010 online database.
TROP	Geographical location is measured by dummy for tropical countries if absolute value of latitude is less than or equal to 23, taken from Global Development Network Growth Database of the World Bank.
External Instruments	Life expectancy, Ratio of public educational expenditure to GDP, and Number of scientific and technical journal articles are collected from WDI 2010 online database. Effectiveness of legislature is compiled from Databanks International (Banks, 2007)

Table A2: List of the 89 Sample Countries with Country Codes (World Bank Classification)

High Income Developed Countries (26) 2008 GNI Per Capita (US$11,906 or More)		Middle and Low Income Developing Countries (63) 2008 GNI Per Capita (US$11,905 or Less)					
23-OECD Countries		**20-Upper-Middle Countries** (US$3,856 to US$11,905)		**22-Lower-Middle Countries** (US$976 to US$3,855)		**21-Low Income Countries** (US$975 or Less)	
Name	**Code**	**Name**	**Code**	**Name**	**Code**	**Name**	**Code**
Australia	AUS	Algeria	DZA	Cameroon	CMR	Bangladesh	BGD
Austria	AUT	Argentina	ARG	China	CHN	Benin	BEN
Belgium	BEL	Brazil	BRA	Cote d`Ivoire	CIV	Burkina Faso	BFA
Canada	CAN	Bulgaria	BGR	Ecuador	ECU	Burundi	BDI
Denmark	DNK	Chile	CHL	Egypt	EGY	Central African Republic	CAF
Finland	FIN	Colombia	COL	El Salvador	SLV	Ethiopia	ETH
France	FRA	Costa Rica	CRI	Guatemala	GTM	Ghana	GHA
Germany	GER	Dominican Republic	DOM	Guyana	GUY	Haiti	HTI
Greece	GRC	Fiji	FJI	Honduras	HND	Kenya	KEN
Hungary	HUN	Gabon	GAB	India	IND	Madagascar	MDG
Ireland	IRL	Jamaica	JAM	Indonesia	IDN	Malawi	MWI
Italy	ITA	Malaysia	MYS	Iran	IRN	Mali	MLI
Japan	JPN	Mauritius	MUS	Jordan	JOR	Mozambique	MOZ
Korea, Republic of	KOR	Mexico	MEX	Morocco	MAR	Nepal	NPL
Netherlands	NLD	Panama	PAN	Nicaragua	NIC	Niger	NER
New Zealand	NZL	Peru	PER	Nigeria	NGA	Senegal	SEN
Norway	NOR	Romania	ROM	Paraguay	PRY	Sierra Leone	SLE
Portugal	PRT	Turkey	TUR	Philippines	PHL	Tanzania	TZA
Spain	ESP	Uruguay	URY	Syria	SYR	Uganda	UGA
Sweden	SWE	Venezuela	VEN	Thailand	THA	Zambia	ZMB
Switzerland	CHE			Tunisia	TUN	Zimbabwe	ZWE
United Kingdom	GBR						
United States	USA						
3-Non-OECD Countries							
Cyprus	CYP						
Singapore	SGP						
Trinidad and Tobago	TTO						

Table A3: Correlation Matrix: 1970-2007

	TFP Growth [($\Delta \ln A_{it}$]	Distance to Frontier $(A^{US}/A_i)_{t-1}$	Average Years of Schooling (Cohen & Soto) [CSSCH]	Average Years of Schooling (Lutz *et al.*) [IVSCH]	Average Years of Schooling (Barro & Lee) [BLSCH]	Teacher-Pupil Ratio (SEC) [TPSEC)	Salary of School Teacher (PRI)/ GDP Per Capita [SALPRI]	Govt. Educ. Expenditure per pupil (SEC)/ GDP Per Capita [EXSEC]	Retention Rate (1-Dropout Rate) (PRI) [RRPRI]	Non-Repetition Rate (SEC) [NRSEC]	MATH Test Scores (SEC) [MSSEC]	SCIENCE Test Scores (SEC) [SSSEC]	READING Test Scores (SEC) [RSSEC]
Total Sample Countries (89)													
$\Delta \ln A_{it}$	1.000												
$(A^{US}/A_i)_{t-1}$	0.068	1.000											
CSSCH	0.182**	-0.573**	1.000										
IVSCH	0.154**	-0.531**	0.945**	1.000									
BLSCH	0.191**	-0.547**	0.961**	0.937**	1.000								
TPSEC	0.116**	-0.410**	0.570**	0.555**	0.536**	1.000							
SLPRI	-0.106**	0.337**	-0.462**	-0.441**	-0.386**	-0.339**	1.000						
EXSEC	-0.068	0.326**	-0.305**	-0.292**	-0.177**	-0.051	0.516**	1.000					
RRPRI	0.188**	-0.423**	0.625**	0.579**	0.641**	0.374**	-0.249**	-0.073	1.000				
NRSEC	0.076	-0.086**	0.291**	0.311**	0.218**	0.051	-0.255**	-0.111**	0.122**	1.000			
MSSEC	0.157**	-0.196**	0.439**	0.429**	0.418**	0.281**	-0.216**	0.150**	0.480**	0.081	1.000		
SSSEC	0.185**	-0.288**	0.597**	0.525**	0.521**	0.351**	-0.268**	0.080	0.483**	0.126**	0.628**	1.000	
RSSEC	0.122	-0.299**	0.463**	0.356**	0.417**	0.217**	-0.343**	0.163**	0.295**	0.042	0.474**	0.542**	1.000
High Income Developed Countries (26)													
$\Delta \ln A_{it}$	1.000	0.379**	-0.116	-0.145	-0.070	0.043	-0.051	0.012	-0.145	0.048	0.105	0.010	0.166**
$(A^{US}/A_i)_{t-1}$		1.000	-0.542**	-0.436**	-0.440**	-0.226**	0.183**	-0.164**	-0.081	0.301**	0.055	-0.009	0.065
CSSCH			1.000	0.836**	0.886**	0.180**	-0.241**	0.182**	0.146	-0.012	0.104	0.223**	0.275**
Low and Middle Income Developing Countries (63)													
$\Delta \ln A_{it}$	1.000	0.182**	0.120**	0.106**	0.152**	0.017	-0.061	-0.054	0.128**	0.060	0.150	0.281**	0.019
$(A^{US}/A_i)_{t-1}$		1.000	-0.371**	-0.316**	-0.327**	-0.230**	0.232**	0.325**	-0.219**	-0.060	0.373**	0.336**	0.149
CSSCH			1.000	0.930**	0.936**	0.360**	-0.426**	-0.402**	0.430**	0.419**	0.092	0.309**	-0.216

Notes: $\Delta \ln A_{it}$ indicates Total Factor Productivity (TFP) Growth for country 'i' over period't'. $(A^{US}/A_i)_{t-1}$ specifies one period lagged distance to technology frontier measured by the logarithm of relative TFP gap between the US and the sample country 'i'. Schooling years are measured for population aged 25 years and above. PRI and SEC stand for primary and secondary level of education, respectively. Estimation period is 1970-2007. The period 2000-2007 is used for the last observation while averaging data for 5 year. TFP growth ($\Delta \ln A$) is calculated in 5-year differences. Human capital quantity & quality and control variables (not reported), for instance, inflation rate (INF_{it}), trade openness measured by the ratio of the sum of export and import to GDP (OP_{it}), the ratio of foreign direct investment inflow to GDP (FDI_{it}), and the ratio of private sector credit to GDP (PC_{it}) are measured in 5-year averages. Total sample countries are divided into developed and developing according to the World Bank's country classification based on the 2008 GNI per capita. Two asterisks (**) indicate 5% level of significance.

Table A4: Panel TFP Growth Estimates [Using Interaction between Quantity & Quality (Primary) of Human Capital]

HK_{it} ^{Quantity}: Average Years of Schooling for Population aged 25 Years and Above (Cohen and Soto, 2007) (CSSCH)

HK_{it} ^{Quality}:	**EDUCATIONAL INPUT**			**EDUCATIONAL OUTPUT**				
[Primary (PRI) Level]	Teacher-Pupil Ratio (PRI)	Salary of School Teacher (PRI)/ GDP Per Capita	Govt. Education Expenditure (PRI)/ GDP Per Capita	Retention Rate (1-Dropout Rate) (PRI)	Non-Repetition Rate (PRI)	MATH Test Scores (PRI)	SCIENCE Test Scores (PRI)	READING Test Scores (PRI)
	[TPPRI]	[SALPRI]	[EXPRI]	[RRPRI]	[NRPRI]	[MSPRI]	[SSPRI]	[RSPRI]
Regression:	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
$(\ln HK^{Quantity}$	0.030**	0.007**	0.016**	0.009**	0.009**	0.040**	0.026**	0.040**
$\times \ln HK^{Quality})_{it}$	(2.036)	(2.318)	(2.133)	(2.495)	(2.429)	(2.056)	(2.721)	(2.239)
$\ln(A^{US}/A_i)_{t-1}$	0.126**	0.126***	0.117**	0.117***	0.103**	0.466**	0.399***	0.290***
	(2.456)	(2.884)	(2.560)	(2.799)	(2.518)	(2.633)	(3.316)	(2.713)
INF_{it}	-0.019***	-0.017***	-0.014**	-0.017***	-0.017***	0.003	-0.590***	-0.026***
	(-2.727)	(-2.855)	(-2.510)	(-2.657)	(-2.845)	(0.395)	(-5.417)	(-8.582)
$\ln OP_{it}$	0.005	-0.009	0.0005	-0.0005	0.0087	-0.001	-0.015	0.082
	(0.273)	(-0.404)	(0.023)	(-0.0250)	(0.402)	(-0.015)	(-0.271)	(1.223)
FDI_{it}	0.530	1.020**	0.706*	0.579	0.810**	0.229	0.724*	-0.551
	(1.434)	(2.515)	(1.804)	(1.533)	(2.082)	(0.362)	(1.799)	(-0.841)
$\ln PC_{it}$	0.025*	0.0275*	0.034**	0.032**	0.020	0.090	0.093	0.0174
	(1.924)	(1.668)	(2.579)	(2.033)	(1.387)	(1.656)	(1.579)	(0.445)
$TROP_{it}$	-0.050**	-0.0762***	-0.052**	-0.058***	-0.068***	-0.252*	-0.194*	-0.177**
	(-2.12)	(-3.534)	(-2.240)	(-2.822)	(-3.525)	(-1.837)	(-2.023)	(-2.221)
Constant	-0.222*	-0.161	-0.239*	-0.212*	-0.206	-0.860*	-0.663*	-0.757*
	(-1.695)	(-1.073)	(-1.749)	(-1.665)	(-1.442)	(-1.941)	(-1.733)	(-1.731)
Hansen-test (p)	0.711	0.697	0.871	0.811	0.620	0.511	0.902	0.244
AR(2)-test (p)	0.520	0.334	0.393	0.235	0.535	0.187	0.259	0.732
No. of Countries	89	89	86	87	88	44	33	45
No. of Obs.	522	505	504	502	521	182	161	188

Notes: Dependent variable is the total factor productivity (TFP) growth for country 'i' over period't' ($\Delta \ln A_{it}$). Independent variables include human capital quantity (HK_{it} ^{Quantity}), human capital quality (HK_{it} ^{Quality}), distance to frontier $[(A^{US}/A_i)_{t-1}]$ and control variables, for instance, inflation rate measured by the growth rate of consumer price index (INF_{it}), trade openness measured by the ratio of the sum of export and import to GDP (OP_{it}), the ratio of foreign direct investment inflow to GDP (FDI_{it}), the ratio of private sector credit to GDP (PC_{it}), dummy variable for tropical ($TROP_{it}$) countries. 'ln' stands for natural logarithm. PRI indicates primary level of education. Figures in parentheses ( ) are t-values significant at 1% level (***), or 5% level (**), or 10% level (*). Hansen test measures the validity of the instruments where the null hypothesis is that the instruments are not correlated with the residuals. The null hypothesis in AR(2) test is that the error terms in the first difference regression exhibit no 2nd order serial correlation. All results satisfy the F-test for the joint significance of the estimated coefficients and the AR(1) test for 1st order serial correlation, however, they are not reported to conserve space. 2nd to 4th lags of the explanatory variables are taken as instruments for the differenced equation, whereas 1st difference of the explanatory variables is taken as instruments for the level equation in the System GMM. Robust Standard Errors are used. Time dummies are included but not reported for brevity. Using school attainment data from Lutz *et al.* (2007) at IIASA-VID (IVSCH), Barro and Lee (2001) (BLSCH) and Baier *et al.* (2005) (BDSCH) produces similar results but not reported to conserve space.

Table A5: Panel TFP Growth Estimates [Using Independent and Interaction between Quantity & Quality (Primary) of Human Capital]

$HK_{it}^{Quantity}$:	Average Years of Schooling for Population aged 25 Years and Above (Cohen and Soto, 2007)							
$HK_{it}^{Quality}$:	**EDUCATIONAL INPUT**			**EDUCATIONAL OUTPUT**				
[PRI]	TPPRI	SALPRI	EXPRI	RRPRI	NRPRI	MSPRI	SSPRI	RSPRI
Regression:	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Panel A: Human Capital Quantity and the interaction between Quantity and Quality								
$\ln HK_{it}^{Quantity}$	0.028	-0.028	-0.009	-0.194	-4.028	-0.643	-0.435	-0.304
	(1.492)	(-0.498)	(-0.375)	(-1.311)	(-1.642)	(-1.616)	(-1.373)	(-1.392)
$(\ln HK^{Quantity}$	0.026^{*}	0.012	0.019^{*}	0.061^{*}	0.951^{*}	0.211^{*}	0.131^{*}	0.113^{*}
$\times \ln HK^{Quality})_{it}$	(1.835)	(1.444)	(1.932)	(1.840)	(1.747)	(2.012)	(1.671)	(1.807)
$\ln(A^{US}/A_i)_{t-1}$	0.223^{***}	0.124^{**}	0.100^{***}	0.238^{***}	0.772^{***}	0.520^{***}	0.277^{*}	0.262^{***}
	(4.264)	(2.311)	(2.998)	(3.252)	(5.805)	(3.235)	(1.856)	(2.783)
Hansen-test (p)	0.990	0.981	0.999	0.674	0.040	0.535	0.835	0.944
AR(2)-test (p)	0.453	0.449	0.858	0.295	0.199	0.370	0.388	0.960
Panel B: Human Capital Quality and the interaction between Quantity and Quality								
$\ln HK_{it}^{Quality}$	-0.058	0.008	-0.004	0.022	-0.388	0.209	0.051	0.249
	(-1.378)	(0.460)	(-0.210)	(0.461)	(-1.463)	(1.255)	(0.469)	(1.374)
$(\ln HK^{Quantity}$	0.042^{*}	0.008^{***}	0.016^{**}	0.014^{**}	0.013^{***}	0.027^{*}	0.026^{**}	0.028^{***}
$\times \ln HK^{Quality})_{it}$	(1.802)	(2.791)	(2.172)	(2.054)	(2.714)	(1.942)	(2.580)	(2.917)
$\ln(A^{US}/A_i)_{t-1}$	0.123^{**}	0.121^{**}	0.107^{**}	0.239^{***}	0.098	0.429^{**}	0.357^{***}	0.280^{***}
	(2.142)	(2.428)	(2.397)	(3.071)	(1.608)	(2.374)	(3.254)	(2.781)
Hansen-test (p)	0.324	0.926	0.956	0.832	0.092	0.660	0.993	0.796
AR(2)-test (p)	0.702	0.341	0.177	0.289	0.901	0.180	0.276	0.879
Panel C: Human Capital Quantity, Quality and the interaction between Quantity and Quality								
$\ln HK_{it}^{Quantity}$	-0.026	-0.143	-0.032	-0.591	-3.048	-1.173	0.736	-0.778
	(-0.682)	(-1.081)	(-0.763)	(-1.605)	(-1.649)	(-1.610)	(1.552)	(-1.500)
$\ln HK_{it}^{Quality}$	-0.058	-0.037	-0.029	-0.151	-0.485	-0.353	-0.159	0.028
	(-0.784)	(-0.896)	(-1.240)	(-1.152)	(-0.887)	(-0.991)	(-1.171)	(0.0947)
$(\ln HK^{Quantity}$	0.069^{*}	0.028	0.026	0.153^{*}	0.718^{*}	0.352^{*}	0.377	0.253^{*}
$\times \ln HK^{Quality})_{it}$	(1.779)	(1.441)	(1.617)	(1.805)	(1.732)	(1.753)	(1.657)	(1.784)
$\ln(A^{US}/A_i)_{t-1}$	0.201^{***}	0.107^{**}	0.103^{***}	0.214^{***}	0.564^{***}	0.364^{**}	0.402^{***}	0.453^{***}
	(4.391)	(2.519)	(3.102)	(3.351)	(5.760)	(2.673)	(3.972)	(3.466)
Hansen-test (p)	0.990	0.990	0.990	0.674	0.016	0.993	0.997	0.208
AR(2)-test (p)	0.360	0.420	0.905	0.295	0.675	0.204	0.908	0.967

Notes: See notes to Table A4. Constant and control variables, namely, INF_{it}, OP_{it}, FDI_{it}, PC_{it}, and $TROP_{it}$ are included but not reported for brevity.

Table A6: Panel TFP Growth Estimates (Using Interaction between Quantity & Quality (Primary) of Human Capital) [*Developed versus Developing Countries*]

HK_{it} ^{Quantity}: Average Years of Schooling for Population aged 25 Years and Above (Cohen and Soto, 2007)

HK_{it} ^{Quality}:	**EDUCATIONAL INPUT**			**EDUCATIONAL OUTPUT**				
[PRI]	TPPRI	SALPRI	EXPRI	RRPRI	NRPRI	MSPRI	SSPRI	RSPRI
Regression:	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Panel A: Developed Countries (26)								
(ln$HK^{Quantity}$	0.033	0.069*	0.027*	0.028	0.085*	0.054	0.059*	0.129*
× ln$HK^{Quality}$)$_{it}$	(1.11)	(1.73)	(1.74)	(0.22)	(1.81)	(1.26)	(1.68)	(1.98)
$\ln(A^{US}/A_i)_{t-1}$	0.398***	0.741***	0.636***	0.668***	0.732***	0.397***	0.541***	0.494***
	(3.63)	(3.36)	(7.29)	(2.84)	(10.7)	(3.87)	(5.86)	(3.51)
Hansen-test (p)	0.991	0.090	0.936	0.821	0.940	0.990	0.990	0.990
AR(2)-test (p)	0.317	0.535	0.374	0.689	0.210	0.160	0.535	0.747
No. of Countries	26	26	26	24	26	19	21	21
No. of Obs.	156	156	156	141	156	88	112	91
Panel B: Developing Countries (63)								
(ln$HK^{Quantity}$	0.053*	0.012**	0.023*	0.154**	0.007**	0.114**	0.031*	0.014*
× ln$HK^{Quality}$)$_{it}$	(1.86)	(2.25)	(1.67)	(2.33)	(2.40)	(2.37)	(1.71)	(1.72)
$\ln(A^{US}/A_i)_{t-1}$	0.323***	0.367***	0.241*	0.509*	0.089**	0.905***	0.532***	0.089***
	(4.10)	(4.70)	(2.00)	(1.97)	(2.27)	(4.23)	(3.21)	(3.37)
Hansen-test (p)	0.920	0.818	0.684	0.897	0.999	0.993	0.990	0.999
AR(2)-test (p)	0.277	0.202	0.266	0.269	0.248	0.509	0.213	0.732
No. of Countries	63	63	60	63	62	25	12	24
No. of Obs.	366	349	348	361	365	94	49	97

Notes: See notes to Table A4.Constant and control variables, namely, INF_{it}, OP_{it}, FDI_{it}, PC_{it}, and $TROP_{it}$ are included but not reported for brevity.

Table A7: Panel TFP Growth Estimates [Using Level and Growth of Interaction between Quantity & Quality (Primary) of Human Capital]

HK_{it} ^{Quantity}: Average Years of Schooling for Population aged 25 Years and Above (Cohen and Soto, 2007)

HK_{it} ^{Quality}:	**EDUCATIONAL INPUT**			**EDUCATIONAL OUTPUT**				
[PRI]	TPPRI	SALPRI	EXPRI	RRPRI	NRPRI	MSPRI	SSPRI	RSPRI
Regression:	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
(ln$HK^{Quantity}$	0.028**	0.006**	0.020**	0.012***	0.014***	0.044***	0.033**	0.033**
× ln$HK^{Quality}$)$_{it}$	(2.113)	(2.177)	(2.577)	(3.408)	(3.368)	(3.08)	(2.54)	(2.044)
(Δln$HK^{Quantity}$	0.0006	-0.080	-0.381	0.001	0.001	-6.156	-2.559	0.741
×Δ ln$HK^{Quality}$)$_{it}$	(1.419)	(-0.275)	(-1.483)	(1.032)	(1.127)	(-1.56)	(-1.47)	(0.295)
$\ln(A^{US}/A_i)_{t-1}$	0.133***	0.096**	0.110**	0.113***	0.100**	0.326**	0.384***	0.239***
	(3.149)	(2.556)	(2.489)	(3.016)	(2.198)	(2.29)	(4.11)	(2.860)
INF_{it}	-0.017**	-0.020***	-0.017***	-0.015**	-0.015**	-0.319***	-0.458	-0.026***
	(-2.389)	(-3.588)	(-3.071)	(-2.187)	(-2.443)	(-3.36)	(-1.06)	(-13.00)
$\ln OP_{it}$	0.010	0.015	-0.007	-0.009	0.013	0.050	0.076	0.071
	(0.559)	(0.661)	(-0.310)	(-0.402)	(0.608)	(0.81)	(1.23)	(1.416)
FDI_{it}	0.650*	0.958**	0.823**	0.512	0.856**	-0.007	0.394	-0.330
	(1.722)	(2.283)	(1.999)	(1.451)	(2.138)	(-0.015)	(1.04)	(-0.847)
$\ln PC_{it}$	0.0172	0.013	0.032***	0.036**	0.015	0.036	0.060	0.028
	(0.999)	(0.864)	(2.799)	(2.495)	(0.931)	(0.70)	(1.25)	(0.777)
$TROP_{it}$	-0.066**	-0.077***	-0.042*	-0.044**	-0.068***	-0.128	-0.218**	-0.142**
	(-2.559)	(-3.480)	(-1.830)	(-2.266)	(-3.213)	(-1.32)	(-2.22)	(-2.531)
Constant	-0.221	-0.172	-0.216	-0.226**	-0.254*	-0.780**	-0.952**	-0.680**
	(-1.584)	(-1.263)	(-1.615)	(-1.992)	(-1.805)	(-2.43)	(-2.22)	(-2.326)
Hansen-test (p)	0.980	0.968	0.991	0.929	0.913	0.852	0.985	0.467
AR(2)-test (p)	0.840	0.560	0.291	0.296	0.552	0.910	0.526	0.747
No. of Countries	89	88	85	87	88	41	31	37
No. of Obs.	516	499	503	500	520	156	150	166

Notes: See notes to Table A4.

Table A8: TFP Growth Estimates (Using Interaction between Quantity & Quality (Primary) of Human Capital) [*With Internal as well as External Instruments*]

HK_{it} ^{Quantity}:	Average Years of Schooling for Population aged 25 Years and Above (Cohen and Soto, 2007)							
HK_{it} ^{Quality}:	**EDUCATIONAL INPUT**			**EDUCATIONAL OUTPUT**				
[PRI]	TPPRI	SALPRI	EXPRI	RRPRI	NRPRI	MSPRI	SSPRI	RSPRI
Regression:	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
($\ln HK^{Quantity}$	0.030*	0.006**	0.014*	0.008**	0.009**	0.028**	0.035***	0.053**
$\times \ln HK^{Quality})_{it}$	(1.888)	(2.099)	(1.909)	(2.261)	(2.489)	(2.384)	(3.553)	(2.570)
$\ln(A^{US}/A_i)_{t-1}$	0.137***	0.111***	0.126***	0.116***	0.112***	0.241***	0.347***	0.344**
	(2.881)	(3.010)	(3.150)	(3.284)	(3.097)	(2.812)	(3.752)	(2.694)
INF_{it}	-0.016**	-0.015**	-0.012**	-0.017***	-0.016***	-0.001	-0.601***	-0.027***
	(-2.591)	(-2.508)	(-2.193)	(-2.810)	(-2.738)	(-0.226)	(-5.147)	(-7.955)
$\ln OP_{it}$	-0.008	-0.016	0.001	-0.008	0.004	0.026	0.0351	0.112
	(-0.444)	(-0.716)	(0.043)	(-0.363)	(0.225)	(0.371)	(0.663)	(1.422)
FDI_{it}	0.542	1.091**	0.683*	0.648	0.853**	0.118	0.427	-0.833
	(1.423)	(2.540)	(1.785)	(1.662)	(2.162)	(0.248)	(1.320)	(-0.999)
$\ln PC_{it}$	0.027*	0.025	0.031**	0.031*	0.020	0.0402	0.0283	0.003
	(1.761)	(1.523)	(2.125)	(1.884)	(1.297)	(0.791)	(0.745)	(0.088)
$TROP_{it}$	-0.052**	-0.069***	-0.061***	-0.058***	-0.074***	-0.119*	-0.176**	-0.193**
	(-2.596)	(-3.363)	(-3.203)	(-3.222)	(-3.904)	(-1.980)	(-2.216)	(-2.580)
Constant	-0.179	-0.099	-0.225	-0.161	-0.190	-0.534**	-0.620*	-0.939*
	(-1.321)	(-0.694)	(-1.639)	(-1.227)	(-1.297)	(-2.352)	(-2.022)	(-1.763)
Hansen-test (p)	0.795	0.778	0.891	0.894	0.733	0.070	0.968	0.267
AR(2)-test (p)	0.550	0.416	0.563	0.238	0.603	0.130	0.171	0.651
No. of Countries	87	87	84	85	86	43	32	44
No. of Obs.	509	492	492	489	508	179	158	185

Notes: See notes to Table A4. External **i**nstruments for quantity of human capital are 'life expectancy' and 'the ratio of public educational expenditure to GDP', whereas external instruments for quality of human capital are 'effectiveness of legislature' and 'the number of scientific and technical journal articles per thousand labours'.

Table A9: Panel TFP Growth Estimates (Using Interaction between Quantity & Quality (Primary) of Human Capital) [*With Mincerian 7% Return on School Attainment*]

HK_{it} ^{Quantity}:	Mincerian specification for human capital quantity (MSCH) using 7% return and Average Years of Schooling for Population aged 25 Years and Above (Cohen and Soto, 2007) (CSSCH)							
HK_{it} ^{Quality}:	**EDUCATIONAL INPUT**			**EDUCATIONAL OUTPUT**				
[PRI]	TPPRI	SALPRI	EXPRI	RRPRI	NRPRI	MSPRI	SSPRI	RSPRI
Regression:	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
($\ln HK^{Quantity}$	0.093***	0.057**	0.053*	0.045**	0.050**	0.226**	0.120**	0.039**
$\times \ln HK^{Quality})_{it}$	(2.65)	(2.38)	(1.69)	(2.49)	(2.15)	(2.40)	(2.59)	(2.54)
$\ln(A^{US}/A_i)_{t-1}$	0.112***	0.137**	0.091**	0.113***	0.132**	0.509***	0.536***	0.320***
	(3.22)	(2.52)	(2.20)	(2.82)	(2.10)	(2.85)	(3.74)	(3.19)
INF_{it}	-0.015***	-0.021***	-0.022***	-0.011	-0.011	0.008	-0.716***	-0.025***
	(-2.98)	(-3.80)	(-3.50)	(-1.56)	(-1.26)	(0.66)	(-5.39)	(-2.88)
$\ln OP_{it}$	-0.016	-0.004	-0.0116	-0.003	0.014	-0.021	0.058	0.073
	(-0.81)	(-0.17)	(-0.60)	(-0.17)	(0.54)	(-0.23)	(0.76)	(1.11)
FDI_{it}	0.780**	0.757**	0.764*	0.639*	0.653	0.136	1.036	0.148
	(2.26)	(2.13)	(1.90)	(1.68)	(1.07)	(0.25)	(1.00)	(0.19)
$\ln PC_{it}$	0.023*	0.026*	0.041***	0.021	0.027*	0.093	0.046	0.034
	(1.67)	(1.68)	(2.86)	(1.35)	(1.96)	(1.57)	(1.07)	(0.75)
$TROP_{it}$	-0.036*	-0.043*	-0.025	-0.044**	-0.064**	-0.162	-0.339**	-0.200**
	(-1.86)	(-1.94)	(-1.04)	(-2.13)	(-2.05)	(-1.01)	(-2.56)	(-2.09)
Constant	-0.116	-0.272	-0.189	-0.187	-0.315	-1.024**	-0.924**	-0.814**
	(-1.00)	(-1.54)	(-1.44)	(-1.42)	(-1.60)	(-2.56)	(-2.28)	(-2.38)
Hansen-test (p)	0.947	0.974	0.989	0.804	0.620	0.577	0.922	0.314
AR(2)-test (p)	0.650	0.313	0.229	0.508	0.535	0.139	0.422	0.220
No. of Countries	89	89	86	87	88	44	33	45
No. of Obs.	522	505	504	502	521	182	161	188

Notes: See notes to Table A4.

Table A10: Cross-Sectional TFP Growth Estimates (Using Interaction between Quantity & Quality of Human Capital)

$HK_i^{Quantity}$:	Average Years of Schooling for Population aged 25 Years and Above (Cohen and Soto, 2007)							
$HK_i^{Quality}$:	**EDUCATIONAL INPUT**			**EDUCATIONAL OUTPUT**				
[PRI & SEC]	TPSEC	SALPRI	EXSEC	RRPRI	NRSEC	MSSEC	SSSEC	RSSEC
Regression:	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
$(\ln HK^{Quantity}$	0.004***	0.001***	0.003***	0.001***	0.001***	0.002***	0.002***	0.002***
$\times \ln HK^{Quality})_i$	(3.27)	(3.05)	(3.30)	(3.555)	(3.699)	(3.456)	(3.344)	(3.726)
$\ln(A^{US}/A_i)_{1970}$	0.015***	0.014***	0.014***	0.017***	0.017***	0.018***	0.018***	0.018***
	(7.60)	(8.06)	(6.94)	(10.57)	(10.90)	(10.97)	(10.25)	(12.36)
INF_i	-0.0002***	-0.0003***	-0.0003***	-0.0002***	-0.0003***	-0.0004	-0.0005	-0.0004***
	(-4.38)	(-3.70)	(-3.20)	(-3.539)	(-3.918)	(-0.0430)	(-0.005)	(-5.324)
$\ln OP_i$	-0.001	-0.001	-0.002	-0.001	-0.001	0.0006	0.0002	-0.001
	(-0.66)	(-0.68)	(-0.76)	(-0.740)	(-0.600)	(0.031)	(0.138)	(-0.618)
FDI_i	0.106	0.117	0.029	0.199***	0.197***	0.119**	0.122**	0.172**
	(1.20)	(1.35)	(0.28)	(2.931)	(2.810)	(2.093)	(2.089)	(2.275)
$\ln PC_i$	0.005***	0.005***	0.004**	0.005***	0.005***	0.003**	0.003**	0.002
	(4.15)	(3.46)	(2.44)	(4.454)	(4.511)	(2.220)	(2.472)	(1.358)
$TROP_i$	-0.002	-0.004**	-0.001	-0.003**	-0.004**	-0.004**	-0.005**	-0.004**
	(-1.01)	(-2.21)	(-0.61)	(-2.015)	(-2.341)	(-2.274)	(-2.554)	(-2.422)
Constant	-0.034***	-0.031***	-0.030**	-0.036***	-0.036***	-0.035***	-0.037***	-0.020**
	(-3.21)	(-2.83)	(-2.47)	(-3.753)	(-3.445)	(-3.783)	(-3.885)	(-2.182)
R-Squared	0.631	0.593	0.502	0.619	0.613	0.769	0.759	0.820
Hansen-test (p)	0.561	0.825	0.735	0.148	0.185	0.511	0.372	0.168
C-test (p-val)	0.283	0.705	0.560	0.388	0.297	0.235	0.171	0.343
No. of Countries	87	87	85	83	82	43	43	35

Notes: See notes to Table A4. Dependent variable is the total factor productivity (TFP) growth over 1970-2007. GMM instruments for quantity of human capital are 'life expectancy' and 'the ratio of public educational expenditure to GDP', whereas instruments for quality of human capital are 'effectiveness of legislature' and 'the number of scientific and technical journal articles per thousand labours'. Hansen-test measures the validity of the instruments where the null hypothesis is that the instruments are not correlated with the residuals. C-test (also known as Difference-in-Sargan test) measures the exogeneity of one or more instruments where the null hypothesis is that the instruments are exogenous.

Table A11: Recent Cross-Sectional TFP Growth Estimates (Using Interaction between Quantity & Quality of Human Capital)

$HK_i^{Quantity}$:	Average Years of Schooling for Population aged 25 Years and Above (Cohen and Soto, 2007) (CSSCH)										
$HK_i^{Quality}$:	PISA (2003) SCIENCE Test Scores **[PSCI]**	PISA (2003) MATH Test Scores **[PMATH]**	TIMSS (2003) SCIENCE Test Scores **[TSCI]**	TIMSS (2003) MATH Test Scores **[TMATH]**	Altinok & Murseli, (2007) Quality of Human Capital in Mathematics **[QIHC-M]**	Altinok & Murseli, (2007) Quality of Human Capital in Science **[QIHC-S]**	Altinok & Murseli, (2007) Quality of Human Capital in Reading **[QIHC-R]**	Altinok & Murseli, (2007) General Index on Quality of Human Capital **[QIHC-G]**	Hanushek & Kimko, (2000) Educational Quality Index **[QHANK]**	Bosworth & Collins, (2003) Educational Quality With Institutions **[QBC]**	Hanushek & Woessmann, (2009b) Cognitive Skills **[COGNITIVE]**
Regression:	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**
$(\ln HK^{Quantity} \times \ln HK^{Quality})_i$	0.001**	0.0008*	0.001**	0.001**	0.001***	0.001***	0.001***	0.001***	0.001**	0.002**	0.004***
	(2.40)	(1.70)	(2.42)	(2.43)	(3.33)	(4.13)	(3.22)	(3.09)	(2.297)	(2.29)	(3.056)
$\ln(A^{US}/A_i)_{1970}$	0.015***	0.015***	0.019***	0.019***	0.017***	0.017***	0.017***	0.017***	0.017***	0.015***	0.018***
	(7.85)	(8.44)	(10.9)	(10.9)	(13.0)	(9.56)	(11.2)	(13.0)	(9.730)	(6.89)	(13.32)
INF_i	-0.0008	0.0005	-0.0004	-0.0004	-0.0001	0.0008	-0.0002***	-0.0002***	-0.0002***	-0.0002***	-0.0003**
	(-0.94)	(0.64)	(-0.59)	(-0.58)	(-0.95)	(0.063)	(-3.46)	(-3.81)	(-3.692)	(-2.71)	(-4.151)
$\ln OP_i$	0.0002	0.003*	-0.0008	-0.0008	-0.001	0.002	-0.002	-0.003	-0.0028	-0.001	-0.002
	(0.14)	(1.89)	(-0.35)	(-0.35)	(-0.79)	(0.97)	(-0.99)	(-1.49)	(-1.294)	(-0.61)	(-1.168)
FDI_i	0.0148	-0.024	0.152**	0.151**	0.131**	0.045	0.147**	0.171***	0.195***	0.123	0.179***
	(0.27)	(-0.67)	(2.50)	(2.45)	(2.12)	(0.76)	(2.32)	(2.84)	(2.808)	(1.54)	(2.992)
$\ln PC_i$	0.002	0.002	0.005***	0.005***	0.006***	0.005***	0.006***	0.006***	0.006***	0.004**	0.003**
	(1.60)	(1.38)	(2.90)	(2.85)	(5.24)	(3.83)	(3.95)	(5.00)	(4.164)	(2.17)	(2.246)
$TROP_i$	-0.005***	-0.007***	-0.005**	-0.005**	-0.005**	-0.004*	-0.005**	-0.004**	-0.004**	-0.002	-0.003
	(-4.04)	(-4.67)	(-2.38)	(-2.33)	(-2.36)	(-1.80)	(-2.13)	(-2.08)	(-2.098)	(-1.24)	(-1.553)
Constant	-0.021***	-0.026***	-0.034***	-0.034***	-0.033***	-0.046***	-0.028***	-0.027***	-0.029***	-0.030***	-0.021**
	(-2.94)	(-3.07)	(-3.48)	(-3.45)	(-3.54)	(-4.70)	(-2.91)	(-2.95)	(-3.133)	(-2.77)	(-2.637)
R-Squared	0.65	0.70	0.76	0.76	0.72	0.72	0.73	0.74	0.607	0.641	0.820
Hansen-test (p-val)	0.333	0.395	0.322	0.340	0.129	0.176	0.218	0.220	0.128	0.883	0.284
C-test (p-val)	0.654	0.969	0.265	0.256	0.549	0.954	0.690	0.725	0.312	0.634	0.290
No. of Countries	36	29	29	29	64	49	59	65	73	73	49

Notes: See notes to Table A10.