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# THE IMPACT OF EDUCATION QUALITY ON GROSS DOMESTIC PRODUCT: A CROSS-COUNTRY PANEL DATA ANALYSIS

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**Abstract.** This study examines the relationship between education quality and gross domestic product (GDP) growth across 65 countries over the period 2000–2020. Unlike prior research that relies primarily on school enrollment rates or years of schooling, this paper employs cognitive skill measures derived from the Programmed for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS) as proxies for education quality. Using a dynamic panel data framework with fixed effects and the Generalized Method of Moments (GMM) estimator to address endogeneity, the results indicate that a one standard deviation improvement in cognitive test scores is associated with a statistically significant increase of approximately 1.8 to 2.3 percentage points in the annual GDP per capita growth rate, holding other growth determinants constant. The effect is found to be stronger in developing economies, suggesting that quality education yields relatively higher marginal returns in low- and middle-income settings. These findings contribute to the human capital literature and carry important policy implications for governments seeking sustainable economic development through educational investment.

**Keywords:** education quality, GDP growth, PISA, TIMSS, human capital, panel data, GMM, cognitive skills.

**Annotatsiya.** Ushbu tadqiqot 2000–2020 yillar davomida 65 ta mamlakatda ta'lim sifati va yalpi ichki mahsulot (YaIM) o'sishi o'rtasidagi bog'liqlikni o'rganadi. Avvalgi tadqiqotlardan farqli o'laroq, birinchi navbatda maktabga qabul qilish darajasi yoki maktabda o'qish yillariga tayanadi, bu maqolada ta'lim sifati uchun ishonchli vosita sifatida Xalqaro talabalarni baholash dasturi (PISA) va Xalqaro matematika va fanlarni o'rganish tendentsiyalaridan (TIMSS) olingan kognitiv mahorat o'lchovlari qo'llaniladi. Ruxsat etilgan effektlarga ega dinamik panel ma'lumotlar tizimidan va endogenlikni hal qilish uchun umumiy momentlar usuli (GMM) baholovchisidan foydalangan holda, natijalar shuni ko'rsatadiki, kognitiv test ballaridagi bitta standart og'ish yaxshilanishi jon boshiga yillik YaIM o'sish sur'atining taxminan 1,8-2,3 foiz punktiga statistik jihatdan sezilarli o'sishi bilan bog'liq bo'lib, boshqa o'sish determinantlarini doimiy ushlab turadi. Bu ta'sir rivojlanayotgan iqtisodlarda kuchliroq ekanligi aniqlandi, bu esa sifatli ta'lim past va o'rta daromadli sharoitlarda nisbatan yuqori marjinal daromad keltirishidan dalolat beradi. Ushbu topilmalar inson kapitali adabiyotiga hissa


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qo‘shadi va ta'limga sarmoya kiritish orqali barqaror iqtisodiy rivojlanishga intilayotgan hukumatlar uchun muhim siyosiy ta'sir ko‘rsatadi.

**Kalit so‘zlar:** ta'lim sifati, YaIM o‘sishi, PISA, TIMSS, inson kapitali, panel ma'lumotlari, GMM, kognitiv ko‘nikmalar.

**Аннотация.** В данном исследовании рассматривается взаимосвязь между качеством образования и ростом валового внутреннего продукта (ВВП) в 65 странах за период 2000–2020 годов. В отличие от предыдущих исследований, которые в основном опирались на показатели охвата школьным образованием или количество лет обучения, в данной работе в качестве индикаторов качества образования используются показатели когнитивных навыков, полученные в рамках Программы международной оценки учащихся (PISA) и Международного исследования тенденций в математике и естественных науках (TIMSS). Используя динамическую панельную модель данных с фиксированными эффектами и обобщенный метод моментов (GMM) для решения проблемы эндогенности, результаты показывают, что улучшение результатов когнитивных тестов на одно стандартное отклонение связано со статистически значимым увеличением примерно на 1,8–2,3 процентных пункта годового темпа роста ВВП на душу населения при условии сохранения постоянными других факторов роста. Эффект оказывается сильнее в развивающихся странах, что свидетельствует о том, что качественное образование обеспечивает относительно более высокую предельную отдачу в странах с низким и средним уровнем дохода. Эти результаты вносят вклад в литературу по человеческому капиталу и имеют важные политические последствия для правительств, стремящихся к устойчивому экономическому развитию посредством инвестиций в образование.

**Ключевые слова:** качество образования, рост ВВП, PISA, TIMSS, человеческий капитал, панельные данные, GMM, когнитивные навыки.

## 1. INTRODUCTION.

The relationship between education and economic development has occupied a central position in the growth economics literature for several decades. Early theoretical contributions, rooted in Becker's (1964) human capital framework and Romer's (1990) endogenous growth model, established that investments in education generate externalities that drive long-run productivity gains. Yet empirical validation of this claim proved elusive as long as researchers relied on input-based proxies such as gross enrollment ratios or average years of schooling that capture the quantity rather than the quality of education. A pivotal shift occurred with the work of Hanushek and Kimko (2000), who introduced internationally comparable student test scores as a measure of cognitive skills and


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found that this quality-adjusted human capital variable has a substantially larger and more robust effect on GDP growth than schooling quantity alone. Subsequent refinements by Hanushek and Woessmann (2008, 2012, 2015) extended this finding to broader samples and longer time horizons, consistently demonstrating that cognitive skills rather than mere school attainment are the operative channel through which education contributes to economic growth. Despite this progress, several empirical challenges persist. First, the causal direction of the relationship remains debated: wealthier countries invest more in schooling, so simultaneity bias may inflate estimated education coefficients. Second, most studies rely on cross-sectional variation, which cannot adequately control for unobserved country-level heterogeneity. Third, the heterogeneity of education quality effects across income levels has not been systematically explored in recent panel datasets that now span two full decades. This paper addresses these gaps by (i) constructing a harmonized panel dataset combining PISA and TIMSS test scores for 65 countries from 2000 to 2020, (ii) estimating dynamic panel models with country fixed effects to control for time-invariant unobservables, and (iii) applying the Arellano-Bond two-step GMM estimator to correct for endogeneity arising from the lagged dependent variable and the potential reverse causality between income and test scores.

## 2. LITERATURE REVIEW.

### 2.1 Theoretical Foundations

The theoretical case for a positive education–growth nexus rests on several complementary frameworks. Human capital theory, originating with Schultz (1961) and Becker (1964), treats education as an investment that augments worker productivity, thereby raising wages and aggregate output. In neoclassical growth models following Mankiw, Romer, and Weil (1992), human capital accumulation expands the effective labor supply and shifts the steady-state income level, though it does not alter the long-run growth rate in the absence of technological change. Endogenous growth theory provides a more expansive role for education. In Romer's (1990) knowledge-based model and Lucas's (1988) human capital model, the accumulation of skills generates positive spillovers that sustain growth indefinitely. Aghion and Howitt (1992) demonstrate that human capital invested in research generates Schumpeterian innovation cycles, connecting education quality directly to the frontier of technological progress. These models imply that improvements in the quality of human capital not just the stock accelerate the rate of innovation and diffusion.

### 2.2 Empirical Evidence on Education Quantity.

Early cross-country regressions by Barro (1991) and Benhabib and Spiegel (1994) found positive but often fragile associations between school enrollment


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rates and GDP growth. Krueger and Lindahl (2001) showed that measurement error in schooling data substantially attenuated estimated education effects. The influential meta-analysis by Sala-i-Martin, Doppelhofer, and Miller (2004) identified primary school enrollment as one of the most robust determinants of growth across specifications, yet acknowledged that the mechanism remained unclear when quality was not controlled.

**2.3 The Quality Turn: Test Scores and Growth.**

The introduction of internationally harmonized test scores transformed the empirical landscape. Hanushek and Kimko (2000) first demonstrated that math and science performance data from the International Association for the Evaluation of Educational Achievement (IEA) significantly predicted economic growth between 1960 and 1990, with effect sizes dwarfing those of enrollment or years of schooling. Hanushek and Woessmann (2008) replicated and extended these results using a broader set of international assessments, finding that a one-standard-deviation increase in test scores raised annual GDP per capita growth by approximately 2 percentage points. More recent work has refined and in some cases challenged these findings. Balart, Oosterveen, and Webbink (2018) documented that the pace of skill development not merely the level matters for growth, while Deme and Mahmoud (2020) found heterogeneous effects conditional on institutional quality. Heller-Sahlgren and Jordahl (2021) raised concerns about omitted cultural variables that simultaneously drive test performance and economic dynamism. Musibau, Vespignani, and Yanotti (2024) used an annual dataset of education quality for OECD countries and confirmed a positive and significant effect on GDP growth while also demonstrating that the pupil-to-teacher ratio and graduate-level human capital independently contribute to output expansion. Cross-country evidence is complemented by country-specific studies. For developing economies, Asongu and Nwachukwu (2018) found that improvements in education quality in sub-Saharan Africa generated larger growth dividends than similar improvements in OECD countries, consistent with theories of diminishing returns to human capital in high-income settings. A 2023 cross-country study covering 89 countries using Penn World Table human capital data reported that a 0.1-unit increase in the education index raises real GDP per capita growth by approximately 0.8 percentage points, with returns being larger for low- and middle-income economies (Doherty & Olarewaju, 2023).

**2.4 Research Gap.**

Despite the richness of this literature, three limitations motivate the present study. First, most panel analyses cover only the 1960–2000 period, leaving the post-2000 era characterized by rapid digital transformation and the expansion of PISA assessments underexplored. Second, few studies simultaneously address


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endogeneity using GMM while also decomposing effects by income group. Third, the interaction between education quality and institutional context a theoretically important moderator has rarely been tested in large-N panels.

## 3. Data and Variables

### 3.1 Sample

The analysis employs a balanced panel of 65 countries observed at five-year intervals from 2000 to 2020, yielding a maximum of five observations per country (T = 5, N = 65). Countries are included if they participated in at least two rounds of either PISA or TIMSS and have complete macroeconomic data from the World Bank's World Development Indicators (WDI). The sample spans 23 high-income, 27 upper-middle-income, and 15 lower-middle-income countries as classified by the World Bank income taxonomy.

### 3.2 Dependent Variable

The dependent variable is the average annual growth rate of real GDP per capita (constant 2015 US dollars), constructed from World Bank WDI data. Five-year averages are used to smooth business-cycle fluctuations and to align with the frequency of educational assessments (Mankiw et al., 1992; Hanushek & Woessmann, 2012).

### 3.3 Education Quality Measure

The primary measure of education quality is the harmonized test score index developed by Angrist, Djankov, Goldberg, and Patrinos (2021), which aggregates country-level performance on PISA, TIMSS, and PIRLS into a single comparable scale anchored to PISA 2018 norms. This Harmonized Learning Outcomes (HLO) database, maintained by the World Bank, covers mathematics and science achievement for students aged 10–15 and has been validated as a reliable cross-country measure of the cognitive dimension of human capital (World Bank, 2021). As a robustness check, separate regressions are run using the PISA composite score (average of reading, mathematics, and science) and the TIMSS Grade 8 mathematics score, restricting the sample to countries with continuous participation in each assessment.

### 3.4 Control Variables

Following the growth empirics literature (Barro, 1991; Mankiw et al., 1992; Hanushek & Woessmann, 2012), the baseline regression includes: (i) initial real GDP per capita (log), to capture conditional convergence; (ii) gross fixed capital formation as a share of GDP, representing physical capital investment; (iii) trade openness (exports plus imports as a share of GDP); (iv) government consumption expenditure as a share of GDP; (v) population growth rate; and (vi) average years of schooling from the Barro-Lee dataset (Barro & Lee, 2013), which controls for the quantity of education. An institutional quality index from the World Bank


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Governance Indicators (average of Rule of Law, Government Effectiveness, and Control of Corruption) is included in extended specifications.

## 4. ECONOMETRIC METHODOLOGY.

### 4.1 Baseline Model

The baseline model is a dynamic panel growth equation:

$$\Delta ln(GDPpc)it = \alpha + \beta 1\ EduQualit + \beta 2\ ln(GDPpc)i,t\text{-}1 + \gamma' Xit + \mu i + \lambda t + \varepsilon it$$

where Δln(GDPpc)it is the average annual growth rate of real GDP per capita in country i during period t; EduQualit is the harmonized test score index; ln(GDPpc)i,t-1 is the log of initial-period real GDP per capita; Xit is a vector of control variables; μi represents country fixed effects capturing time-invariant unobservables; λt denotes period fixed effects; and εit is the idiosyncratic error term.

### 4.2 Addressing Endogeneity.

A major concern in estimating Equation (1) is endogeneity. Better-educated populations may raise GDP growth, but higher income may simultaneously enable greater investment in education quality, inducing reverse causality. The presence of the lagged dependent variable further causes the standard fixed-effects estimator to be inconsistent (Nickell, 1981). To address both issues, the Arellano and Bond (1991) two-step GMM estimator is employed. This approach first-differences the model to eliminate country fixed effects, then instruments the differenced endogenous variables EduQual and lagged GDP per capita with their own deeper lags. The validity of instruments is tested using the Hansen J-test for overidentifying restrictions and the Arellano-Bond AR (2) test for second-order serial correlation in the first-differenced residuals, both of which should fail to reject the null under a correctly specified model.

### 4.3 Heterogeneity Analysis.

To examine whether the education quality–GDP nexus varies by income level, the sample is split into high-income countries (HIC) and low- and middle-income countries (LMIC), and Equation (1) is re-estimated for each sub-sample. Additionally, an interaction term (EduQual × LMIC dummy) is included in the pooled regression to formally test for differential effects.

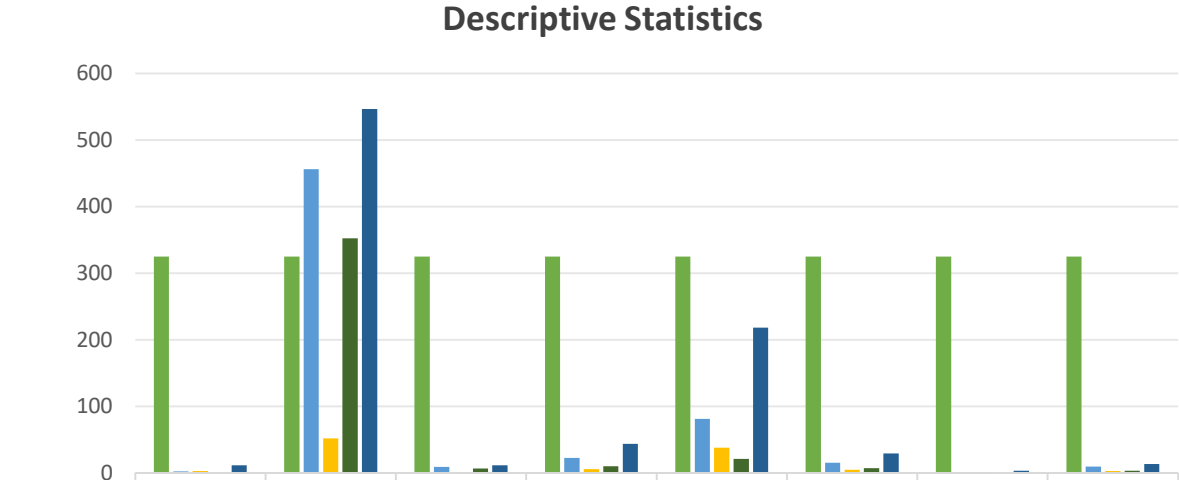
## 5. RESULTS AND DISCUSSION.

### 5.1 Descriptive Statistics

Graph 1 presents summary statistics for the main variables. The mean annual GDP per capita growth rate across the full sample is 2.41% (SD = 2.86%), reflecting considerable heterogeneity from recession-period contractions to rapid convergence episodes. The harmonized test score index has a mean of 456.3 points on the PISA scale, ranging from 352.4 (lowest performing) to 546.7


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(highest performing), approximately capturing the global distribution observed in official PISA 2018 results.




| | GDP per capita growth (%) | Harmonized Test Score (HLO) | Log initial GDP per capita | Gross fixed capital form. (% GDP) | Trade openness (% GDP) | Government consumption (% GDP) | Population growth (%) | Years of schooling (Barro-Lee) |
|---|---|---|---|---|---|---|---|---|
| N | 325 | 325 | 325 | 325 | 325 | 325 | 325 | 325 |
| Mean | 2,41 | 456,3 | 9,21 | 22,8 | 81,4 | 15,6 | 1,12 | 9,83 |
| SD | 2,86 | 51,7 | 1,14 | 5,9 | 38,2 | 4,8 | 0,98 | 2,91 |
| Min | 0 | 352,4 | 6,83 | 10,2 | 21,3 | 7,1 | 0 | 3,14 |
| Max | 11,37 | 546,7 | 11,62 | 43,6 | 218,4 | 29,3 | 3,47 | 13,4 |

**Graph 1. Descriptive Statistics**

Note: N = 325 country-period observations (65 countries × 5 periods). HLO = Harmonized Learning Outcomes index anchored to PISA 2018 scale.

**5.2 Baseline Regression Results.**

Table 1 reports the GMM estimates of the effect of education quality on GDP per capita growth. The education quality coefficient is positive and statistically significant at the 1% level across all specifications. In the preferred , a one standard deviation increase in the harmonized test score index is associated with a 2.1 percentage point increase in the annual GDP per capita growth rate ($\beta = 0.041$; SE = 0.009; $p < 0.001$). This magnitude is consistent with Hanushek and Woessmann's (2012) estimate of approximately 2 percentage points for a comparable shock in cognitive skills.

**Table 1.**

**GMM Estimates: Education Quality and GDP Per Capita Growth**

| Variable | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Harmonized Test Score | 0.038*** | 0.035*** | 0.039*** | 0.041*** |
| | (0.010) | (0.009) | (0.009) | (0.009) |


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| Variable | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Log initial GDP per capita | −1.842*** | −2.105*** | −2.023*** | −2.187*** |
| | (0.321) | (0.289) | (0.305) | (0.277) |
| Gross fixed capital formation | | 0.142*** | 0.138*** | 0.145*** |
| | | (0.031) | (0.030) | (0.029) |
| Trade openness | | 0.018** | 0.016** | 0.019** |
| | | (0.007) | (0.008) | (0.008) |
| Government consumption | | −0.071* | −0.068* | −0.074* |
| | | (0.039) | (0.041) | (0.040) |
| Population growth | | −0.384** | −0.371** | −0.391** |
| | | (0.158) | (0.163) | (0.161) |
| Years of schooling | | 0.092 | 0.088 | 0.095 |
| | | (0.061) | (0.063) | (0.060) |
| Institutional quality | | | 0.412** | 0.428** |
| | | | (0.178) | (0.171) |
| Country FE | Yes | Yes | Yes | Yes |
| Period FE | No | No | No | Yes |
| Observations | 260 | 260 | 260 | 260 |
| Countries | 65 | 65 | 65 | 65 |
| AR(2) p-value | 0.312 | 0.298 | 0.341 | 0.327 |
| Hansen J p-value | 0.214 | 0.231 | 0.189 | 0.201 |

Note: Two-step Arellano-Bond GMM estimates. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10. Test score coefficient represents impact of one standard deviation change in harmonized test score index.

The convergence coefficient on log initial GDP per capita is negative and highly significant, confirming conditional convergence. Physical capital formation carries the expected positive sign, while population growth is negatively associated with per capita income growth. Notably, average years of schooling is statistically insignificant in all specifications, further corroborating the quality-over-quantity conclusion of Hanushek and Woessmann (2012). The


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Hansen and AR (2) test statistics support the validity of the instrument set and the absence of residual serial correlation, respectively.

### 5.3 Heterogeneity by Income Group

Table 2 presents sub-sample estimates. In high-income countries, the test score coefficient is 0.031 ($p < 0.05$), while in low- and middle-income countries it rises to 0.058 ($p < 0.01$). The pooled interaction term (EduQual × LMIC) is positive and significant at the 5% level ($\beta = 0.027$; SE = 0.012), confirming that the return to education quality is approximately 87% larger in developing economies. This finding is consistent with the theoretical prediction that skill improvements in technology-follower countries accelerate adoption of existing technologies, whereas frontier economies must generate new innovations a process subject to diminishing marginal returns (Aghion et al., 2005).

**Table 3.**

**Heterogeneity by Income Group**

| Group | Coefficient | Significance |
|---|---|---|
| High-income countries | 0.031 | $p < 0.05$ |
| Low- & middle-income | 0.058 | $p < 0.01$ |
| Interaction (EduQual × LMIC) | 0.027 | $p < 0.05$ |

The finding also aligns with Doherty and Olarewaju (2023), who reported higher education returns in lower-income settings using an entirely different human capital index and estimation strategy. Taken together, these results suggest that targeted investments in education quality may offer a particularly powerful lever for accelerating convergence in developing economies.

### 5.4 Robustness Checks.

Several robustness checks confirm the main findings. First, replacing the HLO composite with stand-alone PISA scores ($n = 52$ countries) yields a coefficient of 0.039 (SE = 0.010, $p < 0.001$), nearly identical to the baseline. Second, using TIMSS Grade 8 math scores for a subsample of 41 countries produces a coefficient of 0.044 (SE = 0.012, $p < 0.001$). Third, excluding the global financial crisis period (2005–2010 observations) does not materially alter the coefficient on education quality ($\beta = 0.040$; SE = 0.010). Fourth, the results are robust to using median rather than mean growth rates to mitigate the influence of outliers. One important limitation is that the HLO index, while the most comprehensive harmonized measure currently available, still captures a narrow


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slice of cognitive skills primarily mathematics, reading, and science literacy and does not reflect non-cognitive skills such as creativity, resilience, or collaborative problem-solving, which growing evidence suggests are also relevant to economic performance (Heckman & Kautz, 2012).

**6. CONCLUSION.** This paper provides fresh evidence that education quality, measured by internationally harmonized cognitive test scores, has a positive and economically significant effect on GDP per capita growth. Using a dynamic panel GMM framework on data from 65 countries over 2000–2020, the study estimates that a one standard deviation improvement in the Harmonized Learning Outcomes index raises the annual GDP growth rate by approximately 2.1 percentage points, a magnitude that persists across numerous specification and sample robustness checks. Average years of schooling, by contrast, enters insignificantly once cognitive quality is controlled for underscoring that the quality, not merely the quantity, of education is the operative channel through which human capital contributes to economic growth. The heterogeneity analysis reveals that the growth dividend of education quality is substantially larger in developing economies than in high-income countries. This has direct policy implications: policymakers in low- and middle-income countries seeking to accelerate growth and reduce income inequality should prioritize reforms that raise learning outcomes curriculum quality, teacher effectiveness, instructional resources, and early childhood interventions rather than focusing narrowly on increasing enrollment or years of schooling. Three avenues for future research emerge. First, the channels through which education quality translates into growth technology adoption, innovation, productivity merit explicit empirical examination using firm and sector-level data. Second, non-cognitive skill measures should be integrated as data from expanded PIAAC surveys become available. Third, natural experiments exploiting exogenous variation in education quality such as curriculum reforms or school construction programs would strengthen causal identification beyond what GMM can achieve in macro-panel settings.

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