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Education Quality and Economic Growth: A New International Measure of Quality of Education

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Abstract

This paper explores the impact of education quality on economic growth in 37 OECD countries. We developed a new dataset that combines mixed-frequency data, including low-frequency data (every three years) from the Programme for International Student Assessment (PISA) and annual data from the World Development Indicators (WDI), covering the period from 2000 to 2018. Our study investigates the relationship between education quality and economic growth. We found that a 1% increase in educational quality contribute to an annual economic growth rate of 2.8%. This result is significantly higher than previous research, which, based on cross-sectional PISA data, reported growth rates ranging from 0.4% to 2.3%.

Keywords: economic growth, education quality, PISA data
JEL classification: O47, F64, C31

1. Introduction

A key insight of endogenous growth theory is the significant role that education plays in enhancing labor productivity and fostering economic growth. Educated workers are not only more productive but also more likely to contribute to technological advancements that drive overall productivity growth. Furthermore, high-quality education is crucial in fostering an economy's creative potential, promoting entrepreneurship, and encouraging the development of new technologies (Abad-Segura et al., 2020).

Despite the acknowledged importance of education, empirical evidence regarding the impact of educational quality on economic growth across countries using panel data remains limited. Early studies primarily focused on the quantity of education, such as years of schooling or enrollment rates, when exploring its relationship with economic growth (see Aghion et al., 2009; Barro, 1991; Barro & Lee, 1993; Benhabib & Spiegel, 1994; Levine & Renelt, 1992; Sequeira, 2007). Influential works by Schultz (1961), Becker (1964), Nelson and Phelps (1966), Mincer (1974), Benhabib and Spiegel (2005), Breton (2012), and Diebolt and Hippe (2019) suggest that increased educational attainment leads to higher rates of economic growth. Hanushek and Woessmann (2007), along with Krueger and Lindahl (2001), analyzed the impact of education on growth using average years of schooling as an indicator.

The OECD (2015) emphasizes that mere enrollment does not always equate to educational success and suggests that more focus should be placed on improving education quality. In line with this, this chapter explores the role of education quality as a predictor of economic growth.Basu and Bhattarai (2012) and Hanushek and Woessmann (2012a) have pointed out, metrics such as mean years of schooling, class size, and academic degree levels are insufficient in capturing the quality of education. Increasing school attendance or average years of schooling does not necessarily translate into higher economic growth if the quality of education is poor. Therefore, education quality has emerged as a more critical determinant of human capital's contribution to economic progress (Hanushek & Woessmann, 2012a).

This study makes two primary contributions to the literature examining the role of education quality in economic growth. First, we develop a novel mixed-frequency dataset to measure education quality by combining the low-frequency (every three years) Programme for International Student Assessment (PISA) data with the higher-frequency (annual) World Development Indicators (WDI) data for 37 OECD countries spanning

2000 to 2018. PISA survey is conducted every three years by the Organisation for Economic Co-operation and Development (OECD), assesses the skills and knowledge of 15-year-old students in reading, mathematics, and science, providing valuable insights into the quality of education systems worldwide.

Secondly, we build on the research conducted by Hanushek and Woessmann (2012, 2015, 2021), who investigated the impact of international test scores in science and math on economic growth in OECD countries. Unlike previous studies, which primarily used cross-sectional analysis, we employ panel data and consider all three PISA assessment domains—mathematics, science, and reading—as indicators of education quality. Our empirical findings indicate that the quality of education significantly and positively impacts economic growth, and this effect is substantially more pronounced than the effect of the quantity of education. Specifically, we find that a 1% increase in education quality enhances economic growth by 2.8%, a figure considerably higher than previous estimates, which range from 0.4% to 2.3%.

Our paper contributes to two strands of empirical literature: the relationship between education and economic growth, and the specific impact of education quality on economic growth. Numerous studies have established a strong link between education and economic growth. Traditionally, early research on the education-growth nexus measured education in terms of school enrollment rates (Becker, 1964; Barro, 1991; Levine & Renelt, 1992; Mankiw et al., 1992; Benos & Karagiannis, 2010; Phillips & Chen, 2011), educational attainment (Nelson & Phelps, 1966; Krueger & Lindahl, 2001; Aghion et al., 2009; Madsen & Murtin, 2017), and average years of schooling (Benhabib & Spiegel, 1994; Barro, 2001; Cohen & Soto, 2007; Teixeira & Queirós, 2016; Ahsan & Haque, 2017; Diebolt & Hippe, 2022). While these studies primarily focused on the quantity of education, relatively little attention has been paid to the quality-growth association, mainly due to a lack of quality-focused data.

Recent evidence suggests that the quality of education is a crucial determinant of economic growth, beyond the simple measure of years of schooling (Hanushek & Kimko, 2000; Hanushek & Woessmann, 2008, 2012, 2015, 2021; Bergbauer, 2019; Deme & Mahmoud, 2020; Heller-Sahlgren & Jordahl, 2021). Although some earlier studies found positive effects of education quality on economic growth (Balart et al., 2018; Breton, 2015; Hanushek & Woessmann, 2008, 2012, 2015), more recent studies, such as Deme and Mahmoud (2020), reported weaker effects in specific contexts, such as Sub-Saharan Africa. In Table 1, we spresent a summary of the literature which show the impact of quality education on economic growth. Column 2 (Sample) provides information regarding the scope of each study, including the number of countries or regions covered, as well as the time period analyzed. Column 3 (HDI (Quality)) describes the specific indicator of education quality used in each study, such as test scores (TS) in subjects like science and mathematics, graduate record examination (GRE) scores, or pupil-teacher ratio (PTR). Lastly, Column 4 (Impact of Quality of Education on Economic Growth) summarizes the main findings of each study, detailing the effect of education quality on real GDP per capita, expressed as the percentage increase in GDP per capita resulting from improvements in educational quality.

The methodologica novelty of this research lies in the examination of the impact of education quality on economic growth using a newly constructed annual PISA dataset with panel dimensions. This dataset allows us to investigate more robustly the impact of education quality by encompassing all three PISA scores—mathematics, science, and reading—on economic growth. Importantly, we employ mixed-frequency data, where the low-frequency PISA data is complemented by high-frequency WDI data using a well-established interpolation methodology (Cho-Lin Procedure).

The remainder of this study is organized as follows. Section 2 discusses the conceptual framework. In Section 3, we describe the data and methodology used in the study, and in Section 4, we present a new annual international dataset on education quality for 37 OECD countries covering the period from 2000 to 2018. Section 5 presents the empirical findings regarding the impact of education on economic growth, while Section 6 concludes with a discussion of the implications of these findings.

2. Conceptual Framwork

The classical theory of economic growth can be expressed as:

$$Y_{it} = f(K_{it}, L_{it}, A_{it},) \tag{1}$$

Where Y_{it} is the total output, L_{it} is the total labour, K_{it} refers to the total capital stock, and A_{it} is the level of technological progress.

Mankiw, Romer and Weil (1992) augment the neoclassical growth model and empirically examine the growth theory determined by three factors: physical capital (K_{it}), human capital (H_{it}), and labour (L_{it}), expressed in a Cobb–Douglas production function:

$$Y_{it} = K^{\alpha}{}_{i,t}\, H^{\phi}{}_{i,t}(A_{i,t}L_{i,t})^{1-\alpha-\phi} \tag{2}$$

Where i denotes country, t is the time-variant; α, ϕ represent the elasticity of growth to capital, human capital, labour and $\alpha + \phi = 1$. Also, the efficiency unit of labour is generated by multiplying the labour by technical efficiency ($A_{i,t}$), assuming exogenous growth for labour supply and technical change. Note, to determine the role of change in economic growth with respect to a change in labour, we start by eliminating the bracket in Equation 2:

$$Y_{it} = K^{\alpha}{}_{i,t}\, H^{\phi}{}_{i,t} A_{i,t}{}^{1-\alpha-\phi} L_{i,t}{}^{1-\alpha-\phi} \quad (3)$$

Then, we differentiate with respect to $L_{i,t}$

$$\frac{\partial Y_{it}}{\partial L_{i,t}} = K^{\alpha}{}_{i,t}\, H^{\phi}{}_{i,t} A_{i,t}{}^{1-\alpha-\phi}\, (1-\alpha-\phi) L_{i,t}{}^{(1-\alpha-\phi)-1} \quad (4)$$

$$\frac{\partial Y_{it}}{\partial L_{i,t}} = K^{\alpha}{}_{i,t}\, H^{\phi}{}_{i,t} A_{i,t}{}^{1-\alpha-\phi}\, (1-\alpha-\phi) L_{i,t}{}^{-\alpha-\phi} \quad (5)$$

Recall that $\alpha + \phi = 1$, therefore $-\alpha - \phi = -1$

$$\frac{\partial Y_{it}}{\partial L_{i,t}} = K^{\alpha}{}_{i,t}\, H^{\phi}{}_{i,t} A_{i,t}{}^{1-\alpha-\phi}\, (1-\alpha-\phi) L_{i,t}{}^{-1} \quad (6)$$

$$\frac{\partial Y_{it}}{\partial L_{i,t}} = \frac{(1-\alpha-\phi) A_{i,t}{}^{1-\alpha-\phi} K^{\alpha}{}_{i,t}\, H^{\phi}{}_{i,t}}{L_{i,t}} \quad (7)$$

$$\frac{\partial Y_{it}}{\partial L_{i,t}} = \frac{(1-\alpha-\phi) K^{\alpha}{}_{i,t}\, H^{\phi}{}_{i,t} (A_{i,t})^{1-\alpha-\phi}}{L_{i,t}} \quad (8)$$

Where $\frac{\partial Y_{it}}{\partial L_{i,t}}$ in Equation 8 is change in economic growth (∂Y_{it}) with respect to change in labour ($\partial L_{i,t}$), while holding all other factors constant. We apply the same procedure to Equation 2 to calculate the change in economic growth with respect to change in human capital (H):

$$\frac{\partial Y_{it}}{\partial H_{i,t}} = K^{\alpha}{}_{i,t}\, (\phi) H^{\phi}{}_{i,t} (A_{i,t} L_{i,t})^{1-\alpha-\phi} \quad (9)$$

$$\frac{\partial Y_{it}}{\partial H_{i,t}} = \phi\, K^{\alpha}{}_{i,t}\, H^{\phi}{}_{i,t} (A_{i,t} L_{i,t})^{1-\alpha-\phi} \quad (10)$$

Recall that $\alpha + \phi = 1$, therefore $\phi - 1 = -\alpha$, we substitute $\phi - 1$ with $-\alpha$

$$\frac{\partial Y_{it}}{\partial H_{i,t}} = \phi\, K^{\alpha}{}_{i,t}\, H^{-\alpha}{}_{i,t}(A_{i,t}L_{i,t})^{1-\alpha-\phi} \tag{11}$$

$$\frac{\partial Y_{it}}{\partial H_{i,t}} = \phi(K_{i,t}\, H_{i,t})\, (A_{i,t}L_{i,t})^{1-\alpha-\phi} \tag{12}$$

$$\frac{\partial Y_{it}}{\partial H_{i,t}} = \phi K_{i,t}\, H_{i,t}\, (A_{i,t}L_{i,t})^{1-\alpha-\phi} \tag{13}$$

Note, $\frac{\partial Y_{it}}{\partial H_{i,t}}$ in Equation 13 is the change in economic growth (∂Y_{it}) with respect to change in human capital ($\partial H_{i,t}$) and the expression $\phi K_{i,t}\, H_{i,t}\, (A_{i,t}L_{i,t})^{1-\alpha-\phi}$ is the marginal product of human capital. It shows how the output Y changes with respect to a small change in the input factor H, while holding all other factors constant. This indicates that the marginal product of human capital is determined by several factors: the share of human capital (ϕ), the share of physical capital (α), the productivity of technology (A), the amount of labour input (L), and the amount of capital input (K).

3. A New Annual International Dataset of Quality of Education for 37 OECD Countries (2000-2018)

In this section, we combine several statistical procedures to interpolate PISA data on education outcomes for the 37 OECD countries. PISA data from 2000 to 2008 is available only for these 37 countries, which are: Austria, Australia, Belgium, Brazil, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Iceland, Ireland, Indonesia, Israel, Italy, Japan, Korea (Rep.), Latvia, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Russian Federation, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States. PISA data is collected every three years, resulting in only a limited number of years being available. To convert the missing observations from a tri-annual to an annual series, we developed a two-step procedure:

- We built factors to capture all the available annual series from WDI for education quality proxies.
- We used factors created in the first step to perform the interpolation of PISA data using Chow–Lin methodology.

3.1 First step: Annual Education Factors from WDI

We construct three factors to proxy for education quality from WDI: pupil–teacher ratios, education expenditure and education staff compensation for 37 OECD countriesfrom 2000 to 2018. The factors capture the same indicator with different levels of education (i.e., secondary and tertiary). McMahon (2000) and Gyimah et al. (2006) suggest that education cannot be separated by levels; investment in all levels of education is essential in a nation. We considered both secondary and tertiary levels since students sitting the PISA test are 15 years old. The three factors are given by:

$$R_{t,i} \ = \ [R_{ti}^{LowSec}, R_{ti}^{Sec}, R_{ti}^{UpSec}, R_{ti}^{Ter}\ ] \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots .. (14)$$

$$C_{t,i} \ = \ [C_{ti}^{tot}, C_{ti}^{Sec}, RC_{ti}^{Ter}\ ] \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (15)$$

$$E_{t,i} \ = \ [E_{ti}^{CurSec}, E_{ti}^{CurTer}, E_{ti}^{CurTot}, E_{ti}^{GovSec}, E_{ti}^{GovTer}, E_{ti}^{GovTot}, \ \ E_{ti}^{GovGDP}, E_{ti}^{Sec}, E_{ti}^{Ter}\ \ ] \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \ \ (16)$$

In Equation 14, factor *R* considers education quality in terms of pupil–teacher ratios. The superscript for *R* represents the four educational levels considered: low secondary, secondary, upper-secondary and tertiary. In Equation 15, factor C refers to education compensation and incorporates measures of education (teachers and non-teachers), staff compensation (in the form of salaries, retirement fund contributions, allowances and benefits) as a percentage of total expenditure in public institutions; the superscript i represents two educational levels—secondary and tertiary—as well as total education compensation.

In Equation 16, factor *E* considers different expenditures in education. The superscript for *E* includes current education expenditure as a proportion of total expenditure in public institutions for two educational levels (secondary and tertiary) and the total (E_{it}^{CurSec},E_{it}^{CurTer},E_{it}^{CurTot}), government expenditure per student as a proportion of GDP per capita (E_{it}^{GovSec}, E_{it}^{GovTer}) at the two education levels (secondary and tertiary); total government expenditure on education as a proportion of GDP (E_{it}^{GovGDP}); total government expenditure on education as a proportion of government expenditure on secondary and tertiary education (E_{it}^{Sec},E_{it}^{rTer}). Definitions of these of each variables are presented in Appendix A Table A1.

We then calculate a weighted average of all factors for individual countries ($totqua\ = (factcomp\ +\ factexp\ +\ factptr$/3), where: $totqua$ is the weighted average of all the factors, $factcomp$ is the factor for education compensation, $factexp$

is the factor for education expenditure and $factptr$ is the factor for pupil–teacher ratio. The resulting annual series and the Chow–Lin intertemporal method is used to interpolate the low-frequency PISA education outcomes in the next step.

One of the challenges in this step is dealing with missing information in some of the WDI series.We address this issue deal with the missing data in the annual observation of WDI, we grouped countries into the following categories:

- Group (1): OECD countries with HCDI ≥ 80% (i.e., Japan, the Republic of Korea, Finland, Ireland, Australia, Sweden, Netherlands and Canada)
- Group (2): OECD countries with HCDI lower than 80% but higher than 70% (i.e., Germany, Austria, Slovenia, Czech Republic, the United Kingdom (UK), Portugal, Denmark, Norway, Italy, Switzerland, New Zealand, France, Israel, the US, Belgium, Estonia, Poland, Spain, Iceland, Russian Federation, Latvia, Hungary)
- Group (3): OECD countries with HCDI rank between lower than 70% but higher than 60% (i.e., Slovak Republic, Luxembourg, Turkey, Chile and Mexico)
- Group (4): OECD countries with HCDI rank between lower than 60% but higher than 50% (i.e., Brazil and Indonesia).

Figure 1 illustrates the classifications of OECD countries by HCDI used for this procedure.

3.2 Second Step: Interpolating PISA Data Using the Chow–Lin Procedure

This study follows Chow and Lin (1971) by applying a temporal regression-based interpolation technique that relates lower-frequency indicator series ($PISA_t$), where *PISA* could be reading scores, maths scores or science scores and t is a tri-annual series (3y), to a higher-frequency benchmark series ($FACTOR_k$), observed in every year k to obtain an annual interpolated series (X_k). We used PISA data (scored data on education outcomes reading, maths and science, which is released every three years [3y]) and interpolated with a factor of World Bank education quality indicators (i.e., pupil–teacher ratios, education expenditure and education compensation). In the first step, the values of $PISA_t$ are regressed on the annual values of the related series, denoted by $FACTOR_k$:

$$PISA_t^{3y} = \beta FACTOR_{i,k}^{y} + e_k \tag{17}$$

The estimated coefficient, $\hat{\beta}$, is used to estimate the low-frequency target series from the high-frequency indicator series by applying the annual observations of the indicator series, $FACTOR_k$, to obtain a preliminary annual interpolated series, X_k^*

$$X_k^* = \hat{\beta} FACTOR_{i,k}^y + U_k \tag{18}$$

In the second step, the interpolated series (X_k^*), is obtained by distributing the difference between the tri-annual value of Y_t^{3y}, and the sum of values of X_k^* in each year across tri-annual using an AR (1) process. In this step, the distribution is subject to the following condition:

$$\sum_{t=1_k}^{3_k} X_k^* = FACTOR_k^y + U_k \tag{19}$$

where X_k^* contains observations for each of the years (k). This final condition ensures that the sum of the tri-annual log changes in the interpolated series (X_k^*), sums to the annual log change of the actual data. To allow for serial correlation in model residuals, Bournay and Laroque (1979) suggest that the stochastic errors term evolves over time as follows:

$$e_k = \rho_{k-1} + \mu \tag{20}$$

where μ_k is white noise random variable with mean zero and constant variance ($\mu_k \sim$ N (0, σ^2) and the estimated ρ should be different from zero and less than 1 (i.e., $|\hat{\rho}| < 1$). The ρ value is the strength of persistence of the interpolation model. Smith (2001) suggests that setting ρ to 0.50 produces efficient and reliable observations. Also, selecting ρ 0.90 indicates a strong correction between the tri-annual series PISA and the annual related series (WDI education quality proxies) as in Dagum and Cholette (2006). Following Smith (2001), our correlation coefficient ρ is set at 0.90, 0.50, and 0.10 for our Chow–Lin estimation.There are two important implications of the Chow–Lin method. First, the movement of the indicator series is only transferred to the interpolated series if the annualised growth rate in the indicator series and the growth rate in the low-frequency variable are correlated. Second, the method assumes that the linear relationship observed in the regression of the low-frequency variable on the tri-annualised indicator variable also holds between the yearly series ($FACTOR_k$) and the true, but unobserved, tri-annual values of $PISA_t$. In Figure 2, the results of the interpolation procedure described above for 37 OECD countries from 2000 to 2018 are presented. In Column 1, 2 and 3 are the results for math, reading and science respectively. These results are compared to a simpler linear interpolation. The blue dashed line represents the linear interpolation, while the dark brown, green, and light brown lines represent the three different estimations from our proposed interpolation procedure, using different parameters: ρ (rho) values of 0.10, 0.50, and 0.90. In line with the literature, we will apply a balanced value of $\rho = 0.5$ for the next estimation.

4. Data and Methodology

In this section we described the data and the methodology used to estimate the impact of the new developed index of quality education on economic growth.

4.1 Data

The study utilizes annual panel data from 37 OECD countries for the period between 2006 and 2018. The selection of this time frame and the countries included was based on data availability. Although we collected data from 2000 to 2018, the PISA data from the earlier surveys conducted in 2000 and 2003 is heavily unbalanced and has therefore been excluded from this analysis.The data for the proxy for education quality (PISA outcomes) was sourced from the OECD database. The PISA data is considered a reliable standard index for education quality. PISA is an international assessment for education outcomes that comprises reading, maths and science. It measures 15-year-olds' ability to use their reading, maths and science knowledge and skills to meet real-life challenges. This data poses some limitations because it is measured every three years. We use the interpolated PISA data in the previous section of education quality from 2006 to 2018 for this estimations. We also include a measure of education quantity based on the average years of schooling in each country each year. A greater quantity of education is expected to promote economic growth (Hanushek & Woessmann, 2021).

GDP per capita growth, GDPC level and other determinants of growth, such as average years of schooling, gross fixed capital formation (annual growth), government size and trade openness, were sourced from the World Bank (2020). The other control variables included have been suggested in previous theoretical and empirical literature. Barro and Lee (1993) suggest that a country's growth of real income tends to be negatively related to the starting level of income; we include the value of real GDP per capita in 2006 for the 37 countries as the initial level of real GDP per capita. Romero-Avila and Strauch (2008) and Asimakopoulos and Karavias (2016), suggest that government size boosts economic growth in line with the Keynesian school of thought.

Conversely, Landau (1983) and Dar and AmirKhalkhali (2002) suggest that government size negatively affects economic growth. Moreover, gross fixed capital formation and trade openness are expected to have a positive relationship with economic growth based on the Cobb–Douglas (1928) production function, Helpman and Krugman (1985) and Grossman and Helpman (1991). Data description and sources are available in Appendix A.

4.2 Methodology

In this section, we present an econometric model based on the work of Hanushek and Woessmann (2012, 2021) to explore the role of education in economic growth, which is represented by our newly developed annual indicator (presented in Section 3). Our benchmark can be expressed as:

$$\begin{aligned}\Delta \ln GDP_{i,t} = {} & \alpha_{0i} + \beta_{0t} + \beta_1 GDP2006_i + \beta_2 \Delta \ln Edu\ quality_{i,t} + \beta_3 \Delta \ln Edu\ quantity_{i,t} \\ & + \beta_4 Z_{i,t} + \gamma_t + \varepsilon_{i,t} \qquad (21)\end{aligned}$$

Where: the dependent variable is real GDP per capita annual growth rate. The explanatory variables include GDP 2006_i represents GDP in 2006 (i.e., for initial GDP level); $\Delta \ln Edu\ quality_{i,t}$ is the change in the log of education quality (mean international test scores averaging maths, reading and science scores). $\Delta \ln Edu\ quantity_{i,t}$ is the change in the log of education quantity (the average years of schooling). Following Hanushek and Woessmann (2008), this study defines education quality as 'the mean international test scores' and education quantity as the average year of schooling. Additional control variables ($Z_{i,t}$) comprise gross fixed capital formation growth, change in government size and change in trade openness. The annual gross fixed capital formation growth measures the value of acquisitions of new or existing fixed assets by the business sector, governments and households and deducts disposals of fixed assets; government size is measured as the ratio of government expenditure to the total output of an economy in percentage terms; and trade openness is calculated as exports plus imports as a proportion of GDP. The subscripts i and t denote country and period, respectively, α_{0i} and β_{0t} are the unobserved time-invariant and country-invariant individual effect, and $\varepsilon_{i,t}$ is an idiosyncratic disturbance term.To examine a possible non-linear relationship, we included the square of education quality in some of our estimations.

5. Empirical Results

In these section we provide estimations of our benchmak model and assess the robustnesses of our estimation to different model specification.

5.1 The Impact of Quality of Education on Economic Growth, 2006–2018

This section presents the empirical findings on the impact of our new measure of education quality on economic growth for 37 OECD countries. We employed panel analysis using annual data from 2006 to 2018 using unbalanced panel data. The omission of data from the first two PISA surveys (2000 and 2003) is based on the fact that data for many countries has not been collected by the survey. In Table 2, we present the estimations of Equation 21. Columns 2 and 3 show the POLS estimations across eight different cases, while columns 4 and 5 display the cross-sectional fixed-effect results. Additionally, columns 6 and 7 provide the outcomes of the cross-sectional and time fixed-effect model. Columns 2, 4, and 6 present results from models that exclude the quantity of education as a control variable, whereas columns 3, 5, and 7 include this variable.

In Table 2, a 1% increase in the quality of education is associated with a 2.8% growth in GDP per capita when using the most restrictive model (Column 6). In the pooled ordinary least squares (POLS) estimation, a 1% increase in education quality is estimated to result in a 3.5% increase in GDP per capita, which is significant at the 1% level and underscores its substantial contribution to economic growth. In the cross-sectional fixed-effects models, the estimated effects range from 2.2% to 3.3%, all of which are significant at either the 1% or 5% level. The results from the period and cross-sectional fixed-effects models are similar, with estimates falling between 2.6% and 3.1%, all significant at the 1% level.

Figure 3 compares the key findings of our more restrictive model (Column 6) with previous results found in the literature. Our analysis indicates that a 1% increase in education quality correlates with a 2.8% increase in GDP per capita growth, which is higher than the results reported in several significant studies. Compared to the findings of Hanushek and Woessmann (2012), who identified a 1.98% effect, our estimate is approximately 41% higher, pointing to a stronger impact of education quality on economic growth. Breton (2015) estimated a 2.2% impact, which is 27% lower than our findings, while Balart et al. (2018) reported a 2.3% effect, 18% lower than our estimate.

Our result surpasses the 2.5% reported by Sultan, Dey, and Tareque (2022) by about 12%, further reinforcing the robustness of our analysis in emphasizing the potential gains from improved education quality. In contrast, Deme and Mahmoud (2020) and Baldwin, Borelli, and New (2011) found much lower effects, with the latter reporting only 0.4%, which is significantly lower (85% less) than our estimate.

Furthermore, the initial GDP level in 2006 has a consistently positive and highly significant effect on subsequent growth, indicating the presence of convergence dynamics, where economies with lower initial GDP levels tend to grow faster. On the other hand, years of schooling show a positive but statistically insignificant impact on economic growth, suggesting that the quantity of education alone may not be a strong determinant of economic growth, particularly when education quality is considered. Gross Fixed Capital Formation shows a positive and occasionally significant impact, indicating that capital investments can enhance growth, although this effect is not robust across all models. Government size, despite varying coefficient estimates, consistently fails to show a significant relationship with GDP growth, implying that the direct impact of government spending may be limited in this context. Lastly, trade openness exhibits a negative but statistically insignificant effect, suggesting that increased openness may not necessarily lead to economic growth.

5.2 Robustnessess Analysis

In this section, we conduct a robustness analysis in accordance with established literature to determine whether our benchmark model is resilient to the instrumental variable approach (Table 3) and to examine the nonlinear relationship between the quality of education and economic growth (Table 4). Amongs others, Hanushek and Woessmann (2008 and 2012) suggest that education quality and real GDP per capita may be determined jointly. We addresses the potential issue of reverse causality by using lagged variables for all control variables to mitigate simultaneity effects. Particularly, we follow Barro (2001), Sequeira (2007), Pegkas, Staikouras, and Tsamadias (2019), and Murray (2006) by employing one-year lags for the independent variables applying a Instrumental Variable (IV) estimation and Two-Stage Least Squares (2SLS). In Table 3, Column 2 and 3, the results of the first-stage and second-stage (respectively).[1] First-stage results

[1] For studies that address endogeneity issues in the education–growth model, see Barro (2001), Hanushek and Kimko (2000), and Hanushek and Woessmann (2012). Instrumental variable (IV) diagnostic checks, including tests for weak instruments and assessments of over-identifying restrictions (available upon request), indicate that the instruments used are not weak, and the IV regression provides consistent estimates

indicate that a 1% increase in education quality is associated with a 3.0% rise in GDP per capita, while the second-stage show a 2.8% increase in GDP per capita.

In Table 4 we explore the inclusion of a quadratic term for education quality to ascertain a possible non-linearity in the effect of the improvement of the quality of education on economic growth as observed in some empirical studies (Ramos & Mourelle 2019; Motusek & Tzeremes, 2019). The results reveal that the coefficient of the square of education quality growth is not statistically significant, while the effect of quality of education is close to 2.8%.

6. Conclusion

This study offers new insights into the relationship between education quality and economic growth, building upon and expanding the existing literature on human capital. Our findings indicate that a 1% increase in education quality is associated with a 2.8% increase in GDP per capita growth, which is substantially higher than estimates reported in previous studies. We developed a novel mixed-frequency dataset that combines 3-year PISA data with one-year quality education data from the WDI for 37 OECD countries spanning from 2000 to 2018. This approach addresses the limitations faced by previous researchers who primarily relied on cross-sectional or low-frequency PISA data, allowing us to provide more precise and timely insights into the effects of education quality on economic growth. While the quantity of education remains important, its impact on economic growth is smaller than quality of education. Our results also suggest that recent advancements in educational quality in OECD countries have a more pronounced impact on economic growth than previously believed.

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Tables and Figures

Table 1: Empirical Studies on Roles of Education Qualitty on Real GDP per Capita

Authors	Sample	HDI (Quality)	Impact of Quality of Education on Economic Growth
1. Hanushek and Kimko (2000)	31 countries 1960–1990	TS (science + maths)/2	TS increases real GDP Per capita by 1.4%
2. Hanushek and Woessmann (2008)	50 countries 1960–2000	TS (science + maths)/2	TS increases real GDP Per capita by 1.98% OECD by1.73% Higher Income Countries 2.2% Lower Income Countries 1.287%
3. Hanushek and Woessmann (2012)	50 countries 1960–2000	TS (science + maths)/2	TS increases real GDP Per capita by 1.98%
4. Breton (2015)	49 countries 1985–2005	TS (science + maths)/2 and schooling 2005	TS increases real GDP Per capita by 2.2%
5. Balart et al. (2018)	50 countries 1964–2003	TS (science + maths)/2(PISA 2006)	TS increases real GDP Per capita by 2.30%
6. Deme and Mahmoud (2020)	Sub-African 2003–2016	GRE scores	GRE increases real GDP Per capita by 0.40%
7. Heller-Sahlgren and Jordahl (2021)	50 OECD countries 1960–2016	TS (science + maths)/2 TIMSS	TS increases real GDP Per capita by 1.4%, TIMSS by 0.60%
8. Baldwin, Borrelli and New (2011)	US 1988–1996 and 1997–2005	PTR	PTR increases real GDP Per capita by 0.40%
9. Sultana, Dey and Tareque (2022)	93 developing and 48 developed nations 1980–2008	PTR	PTR increases real GDP Per capita by 2.28% in developed nations, and PTR decreases GDP by 2.50% in developing nations

Source: Author's computation.
Notes: TS = test scores, PRT = pupil–teacher ratio, GRE = Graduate Record Examination

Table 2: Main Results: Education Quality as a Determinant of GDP.
Dependent Variable: Annual Growth Rate of Real GDP Per Capita, 2006–2018

Variables	POLS		Cross-section (fixed effect)		Period and cross-section (fixed effect)	
GDP 2006	3.311** [9.531]	3.271** [9.791]				
Education quality	0.035** [0.014]	0.033** [0.014]	0.022* [0.012]	0.026** [0.013]	0.031** [0.013]	0.028** [0.014]
Years of schooling		0.022 [0.022]		0.008 [0.023]		0.02 [0.021]
GF capital formation	0.037 [0.203]	0.013 [0.185]	0.17* [0.09]	0.022 [0.010]	0.028 [0.201]	0.005 [0.183]
Government size	0.007 [0.032]	0.012 [0.034]	0.02 [0.02]	0.002 [0.022]	0.01 [0.03]	0.015 [0.032]
Trade openness	–0.004 [0.004]	–0.004 [0.003]	–0.0016 [0.002]	–0.004 [0.003]	–0.003 [0.003]	–0.004 [0.003]
Cluster (country)	Yes	Yes	Yes	Yes	Yes	Yes
Period effect	Yes	Yes			Yes	Yes
Country effect	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.096	0.05	0.032	0.03	0.11	0.11
Observation	434	434	434	434	434	434
countries	37	37	37	37	37	37

Note: The table reports the main results (POLS and fixed-effect model) of the relationship between education quality and economic growth. We use ΔlnEducation quality, Δlnyears of schooling, annual growth of gross fixed capital formation, Δ government size, and Δ trade openness. Robust Huber-White standard errors are reported in parentheses; each model includes fixed country and period effects. The number of periods is 19 for all the estimations in this table. ***($p < 0.01$), **($p < 0.05$), *($p < 0.1$) indicate the significance at the 1%, 5% and 10% levels, respectively.

Table 3: IV-2SLS (with Fixed Effect).
Dependent Variable: Annual Growth Rate of Real GDP Per Capita, 2006–2018

Variables	First-stage estimates	Second-stage estimates
Education quality $_{t-1}$	0.030**	0.028**
	[0.014]	[0.014]
Years of schooling $_{t-1}$	0.025	0.02
	[0.023]	[0.021]
GF Capital formation$_{t-1}$	0.027	0.005
	[0.19]	[0.18]
Government size$_{t-1}$	0.017	0.015
	[0.032]	[0.032]
Trade openness$_{t-1}$	–0.003	–0.004
	[0.003]	[0.003]
Cluster (country)	Yes	Yes
Year dummies	Yes	Yes
Country dummies	Yes	Yes
R-squared	0.0469	0.0469
Observation	434	434
No. of countries	37	37
Instrument validity Test	5.536	
	[0.237]	

Note: The table reports IV-2SLS with fixed-effect estimation on the relationship between education quality and economic growth. Robust Huber-White standard errors are reported in parentheses; each model includes fixed country and period effects. The number of periods is 19 for all the estimations in this table. ***($p < 0.01$), **($p < 0.05$), *($p < 0.1$) indicate the significance at the 1%, 5% and 10% levels, respectively. t-1 represents one-year lag.

Table 4: Impact of Square of Education Quality Growth on Economic Growth**.** Dependent Variable: Annual Growth Rate of Real GDP Per Capita, 2006–2018

Variables	POLS	Cross-section (fixed effect)	Period and cross-section (fixed effect)
GDP 2006	3.371***		
	[0.857]		
Education quality	0.033**	0.025*	0.028**
	[0.015]	[0.013]	[0.014]
Square of educat. quality	0.004	–0.0009	–0.0019
	[0.006]	[0.007]	[0.007]
Years of schooling	0.022	0.008	0.019
	[0.022]	[0.0066]	[0.020]
Gross fixed capital formation	0.014	0.029	0.004
	[0.185]	[0.147]	[0.183]
Government size	0.012	0.003	0.015
	[0.033]	[0.023]	[0.032]
Trade openness	–0.004	–0.004	–0.004
	[0.0034]	[0.0028]	[0.003]
Cluster (country)	Yes	Yes	Yes
Year dummies	Yes		Yes
Country dummies	Yes	Yes	Yes
R-squared	0.05	0.03	0.05
Observation	434	434	434
No. of countries	37	37	37

Note: Robust Huber-White standard errors are reported in parentheses; each model includes fixed country and period effects. The number of periods is 19 for all the estimations in this table. ***($p < 0.01$), **($p < 0.05$), *($p < 0.1$) indicate the significance at the 1%, 5% and 10% levels, respectively.

Figure 1: OECD Countries Classification by HCDI

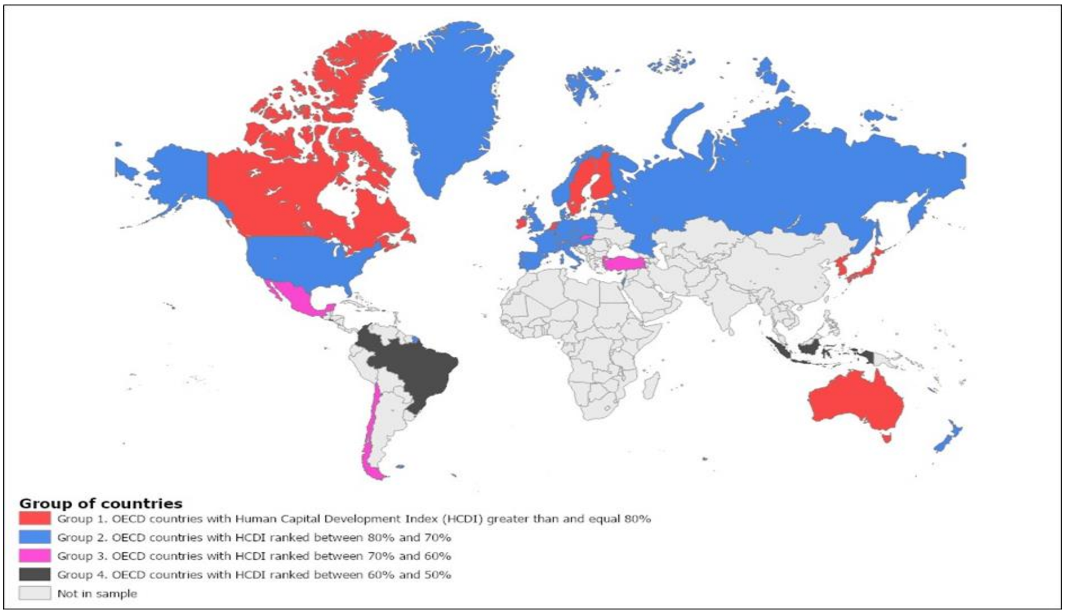
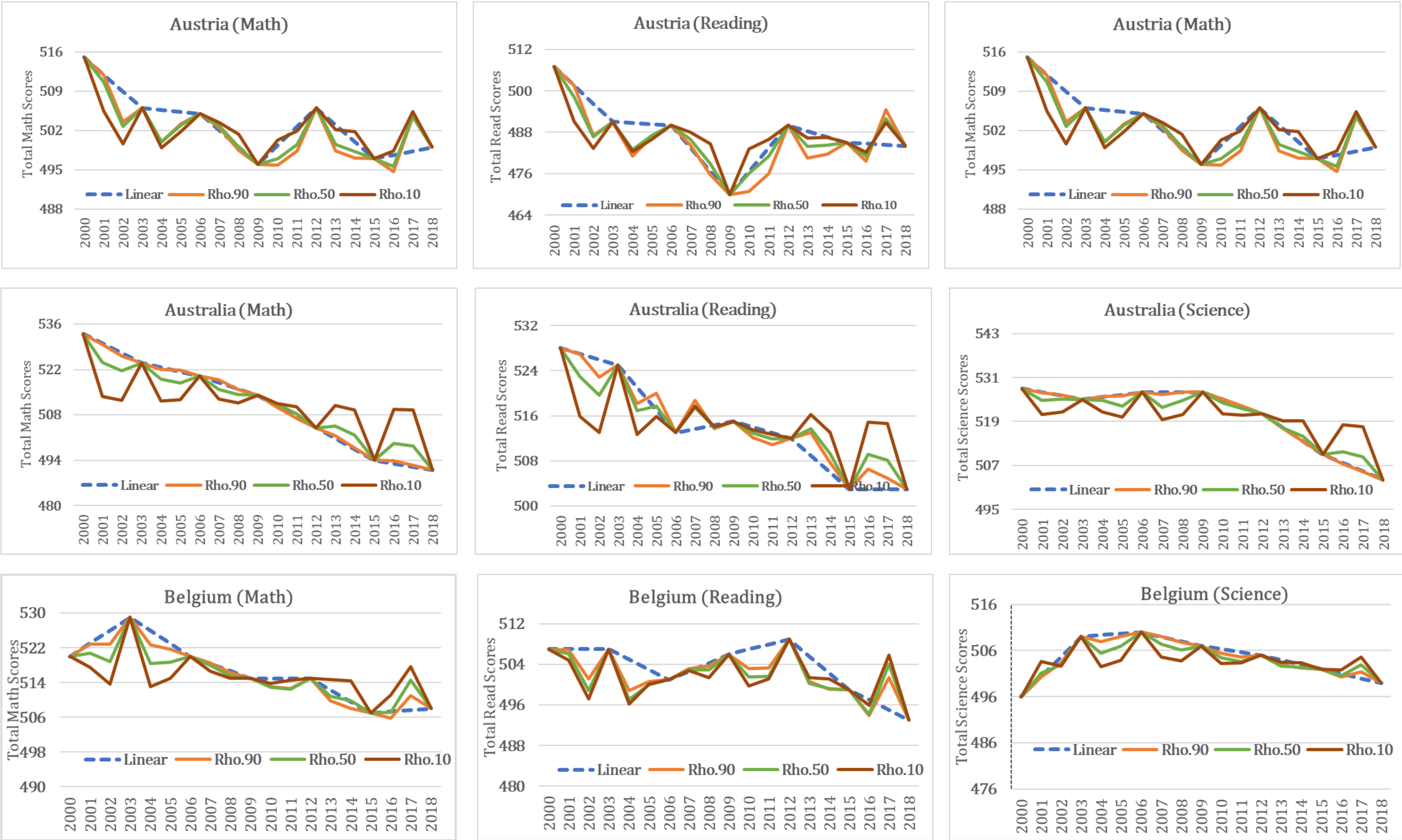
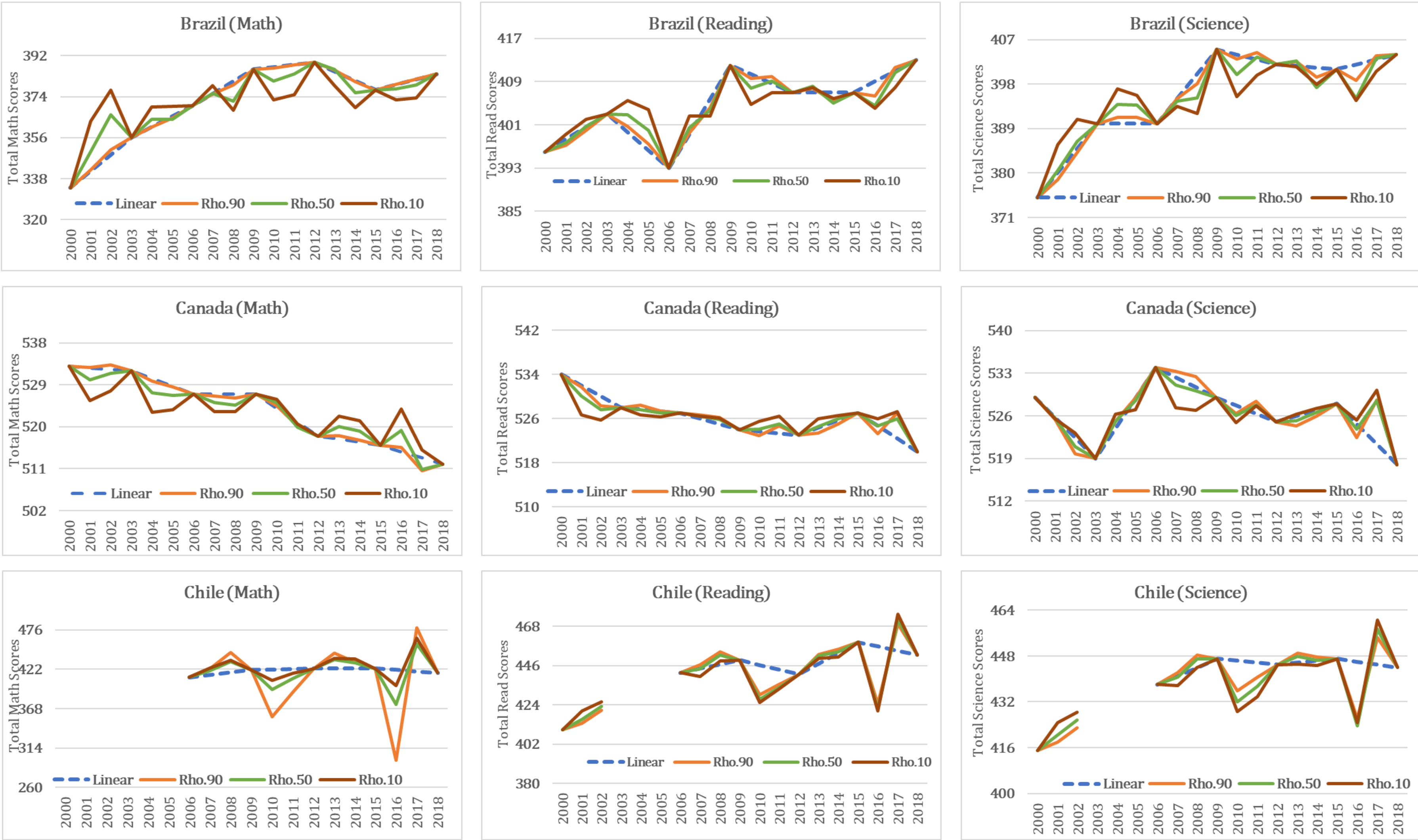
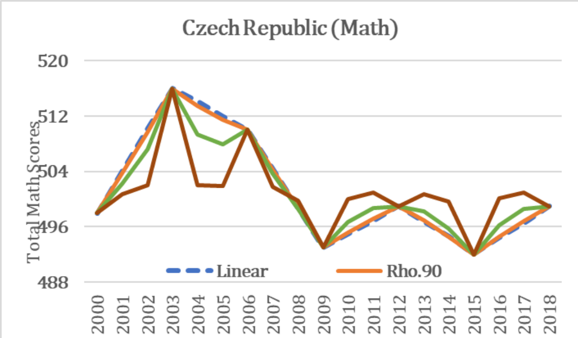
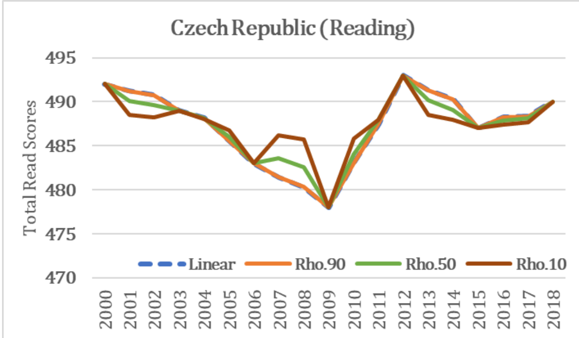


Figure 2: New Measure of Quality Education Based on PISA for 37 OECD Countries (2000-2018)




Brazil (Math)
Total Math Scores
392
374
356
338
320
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Brazil (Reading)
Total Read Scores
417
409
401
393
385
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Brazil (Science)
Total Science Scores
407
398
389
380
371
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Canada (Math)
Total Math Scores
538
529
520
511
502
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Canada (Reading)
Total Read Scores
542
534
526
518
510
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Canada (Science)
Total Science Scores
540
533
526
519
512
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Chile (Math)
Total Math Scores
476
422
368
314
260
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Chile (Reading)
Total Read Scores
468
446
424
402
380
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Chile (Science)
Total Science Scores
464
448
432
416
400
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Czech Republic (Math)
Total Math Scores
520
512
504
496
488
Linear
Rho.90
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Czech Republic (Reading)
Total Read Scores
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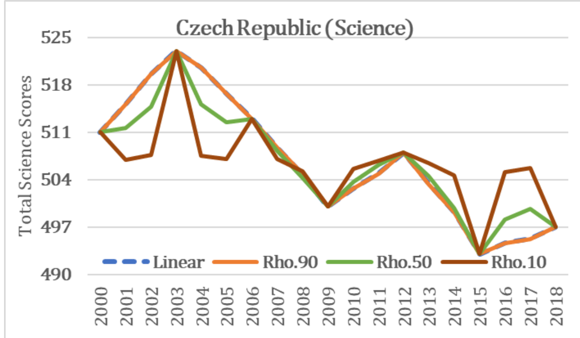
490
485
480
475
470
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Czech Republic (Science)
Total Science Scores
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518
511
504
497
490
Linear
Rho.90
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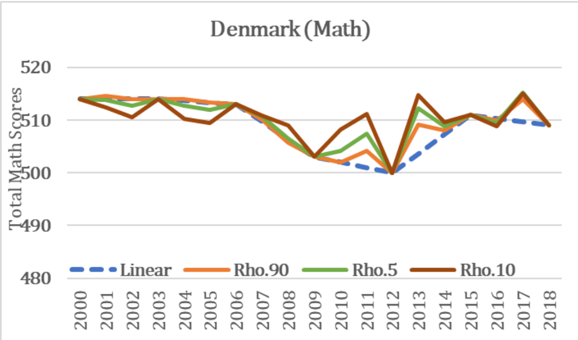
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Denmark (Math)
Total Math Scores
520
510
500
490
480
Linear
Rho.90
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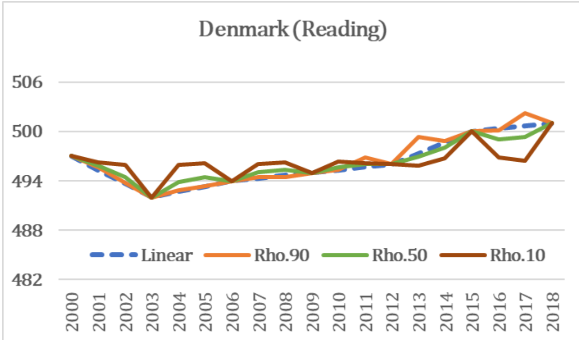
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Denmark (Reading)
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494
488
482
Linear
Rho.90
Rho.50
Rho.10
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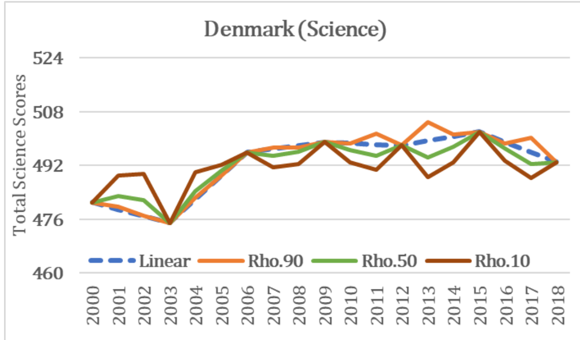
Denmark (Science)
Total Science Scores
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460
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Rho.10
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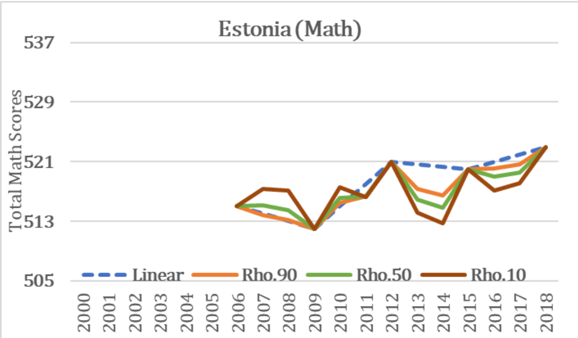
Estonia (Math)
Total Math Scores
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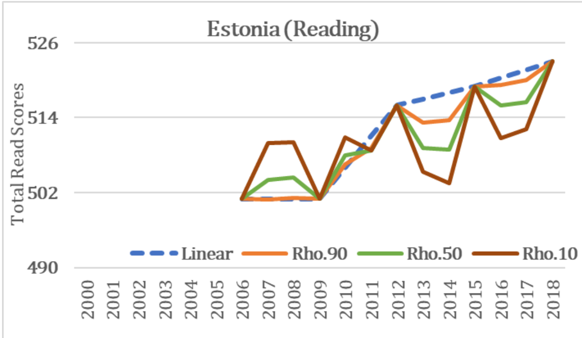
529
521
513
505
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Estonia (Reading)
Total Read Scores
526
514
502
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Linear
Rho.90
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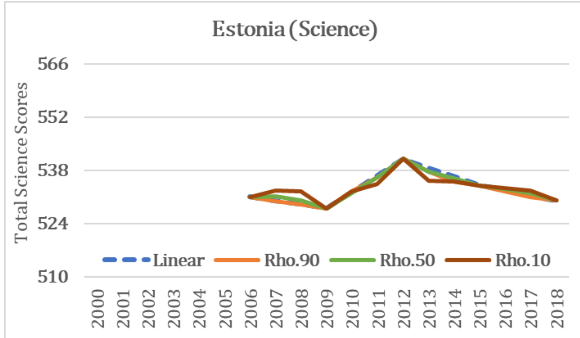
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Estonia (Science)
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524
510
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Rho.50
Rho.10
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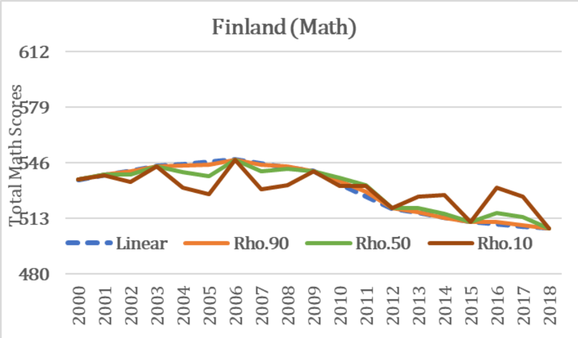
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Rho.10
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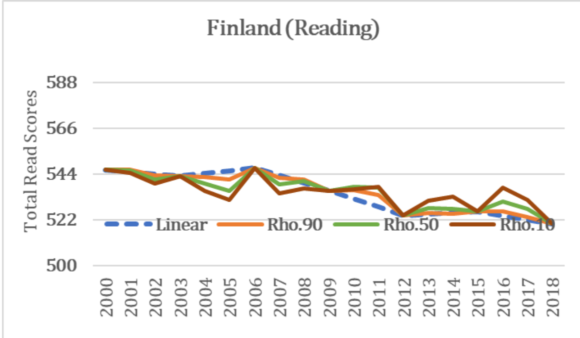
Finland (Reading)
Total Read Scores
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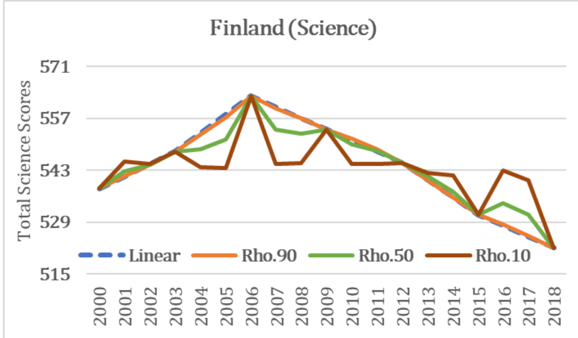
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018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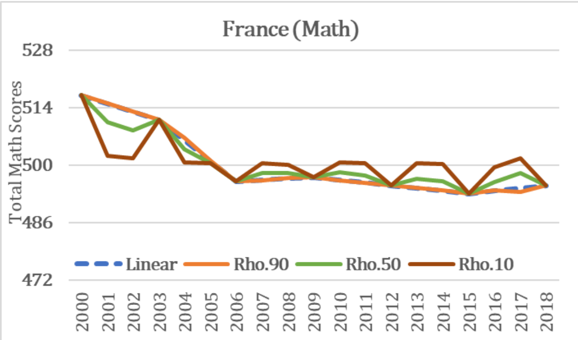
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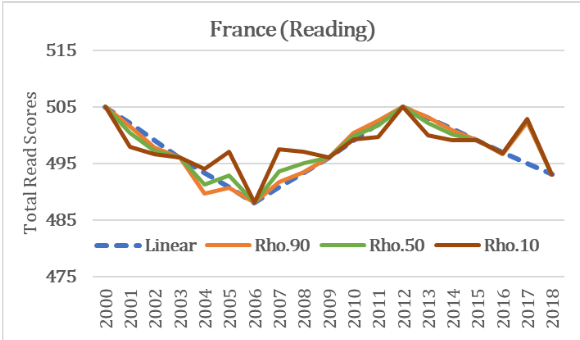
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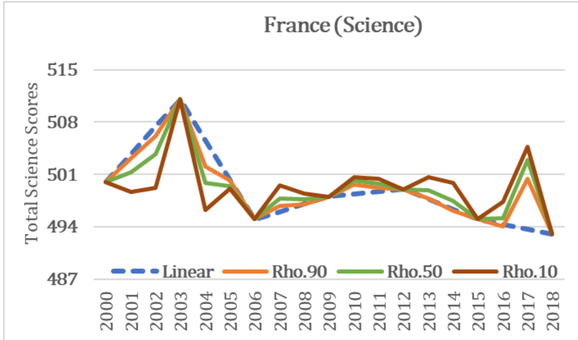
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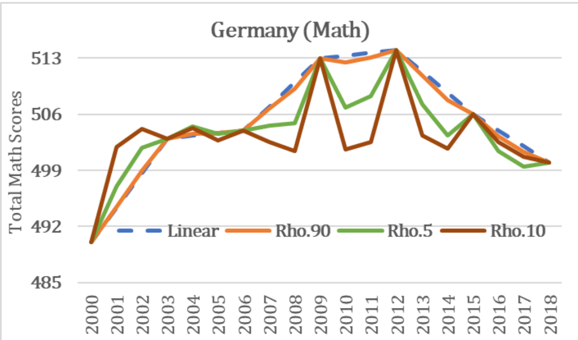
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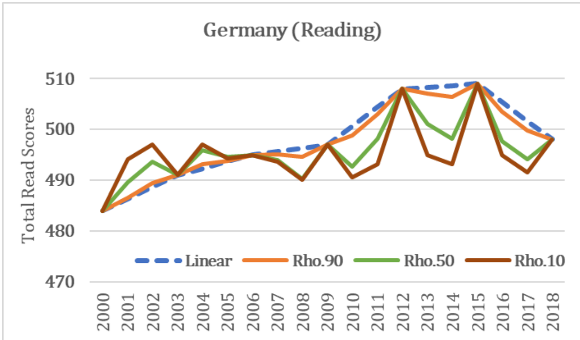
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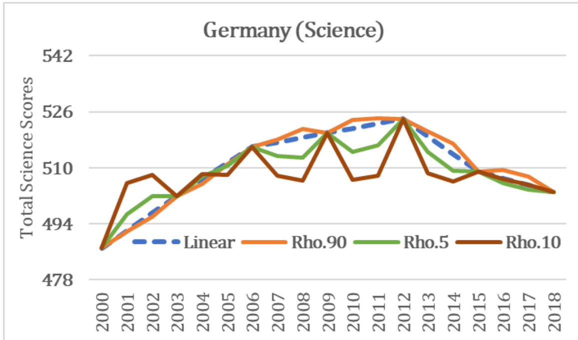
Germany (Science)
Total Science Scores
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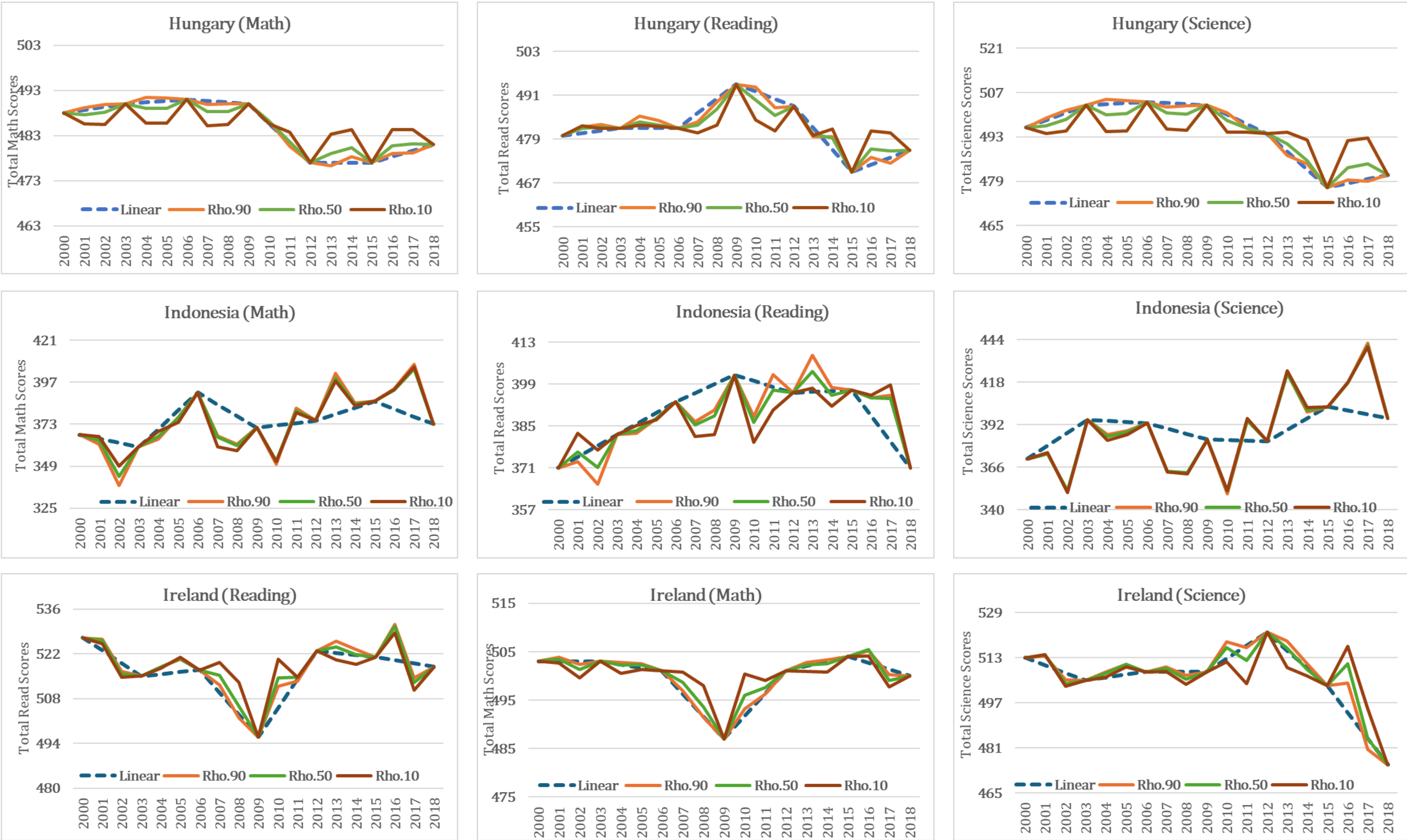
Hungary (Math)
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Hungary (Reading)
Total Read Scores
Hungary (Science)
Total Science Scores
Indonesia (Math)
Total Math Scores
Indonesia (Reading)
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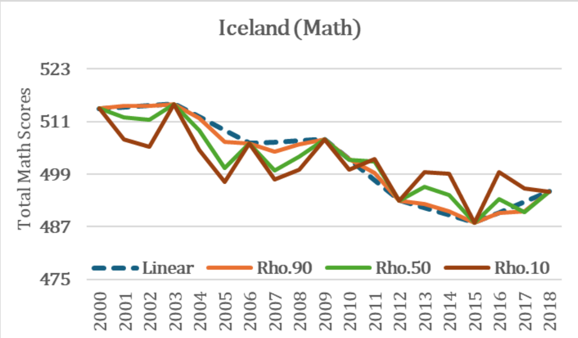
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Total Math Scores
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Rho.10
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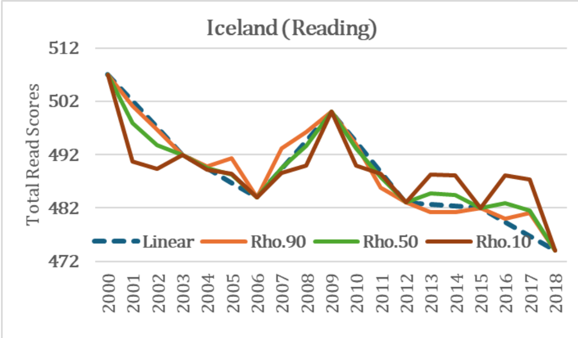
Iceland (Reading)
Total Read Scores
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Linear
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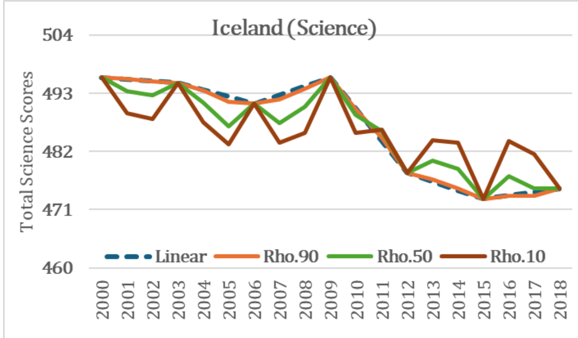
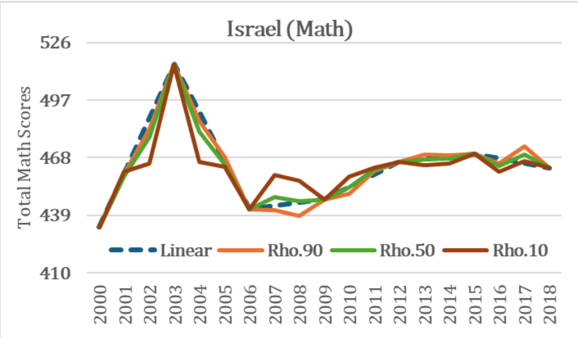
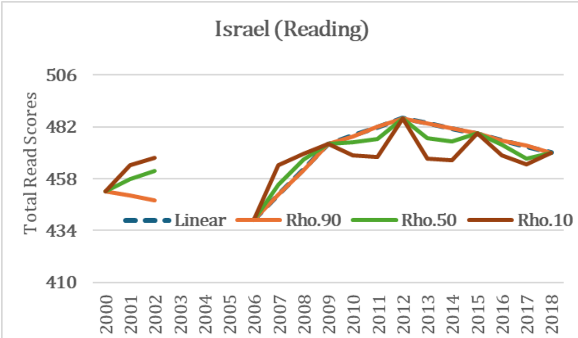
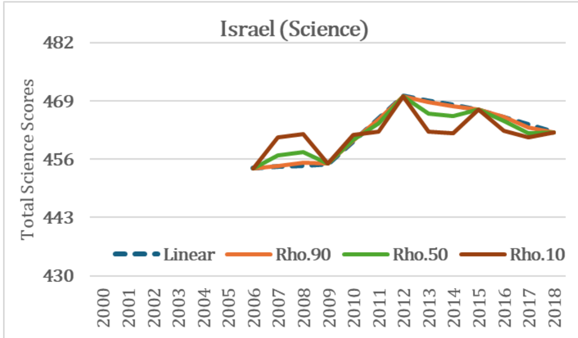
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Iceland (Science)
Total Science Scores
504
493
482
471
460
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Israel (Math)
Total Math Scores
526
497
468
439
410
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Israel (Reading)
Total Read Scores
506
482
458
434
410
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Israel (Science)
Total Science Scores
482
469
456
443
430
Linear
Rho.90
Rho.50
Rho.10
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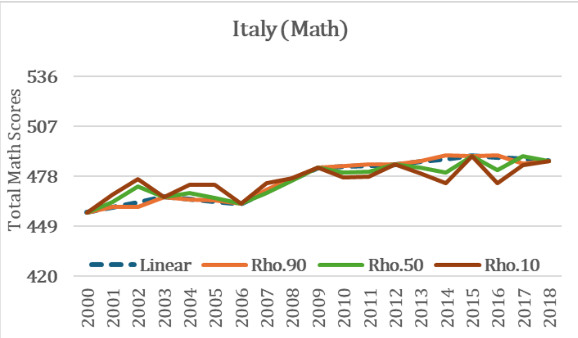
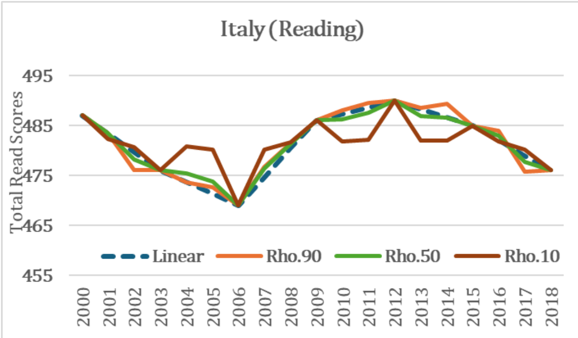
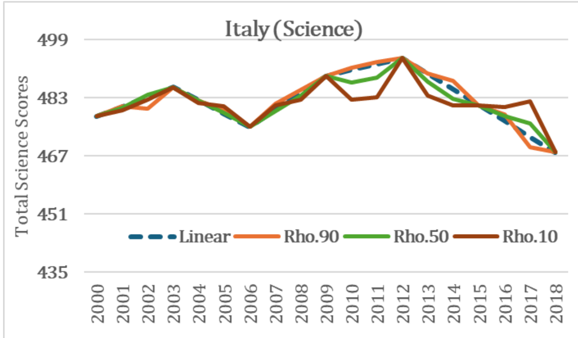

Italy (Math)
Total Math Scores
536
507
478
449
420
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Italy (Reading)
Total Read Scores
495
485
475
465
455
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Italy (Science)
Total Science Scores
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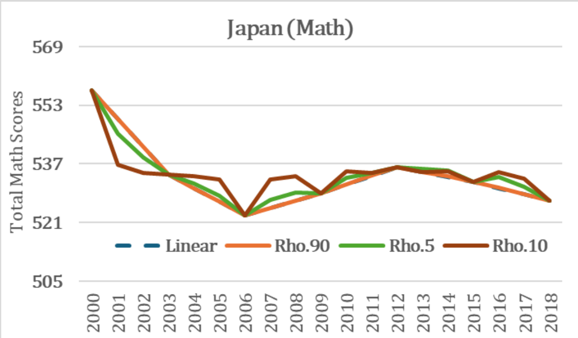
467
451
435
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Japan (Math)
569
553
537
521
505
Total Math Scores
Linear
Rho.90
Rho.5
Rho.10
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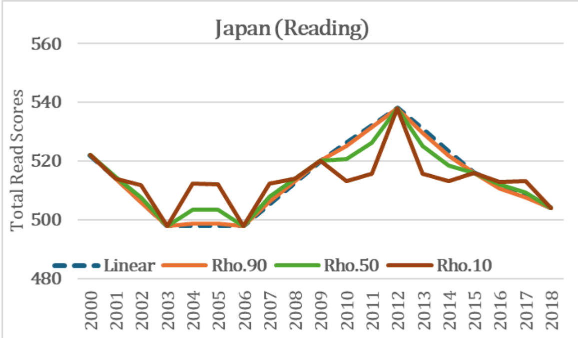
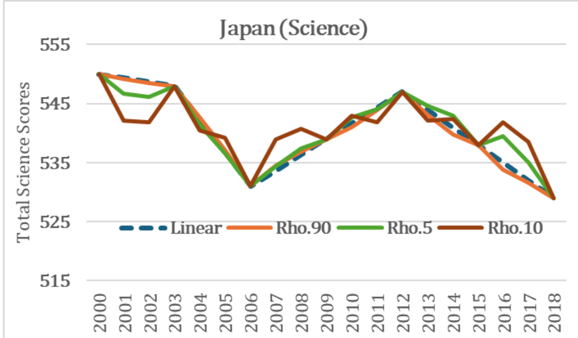
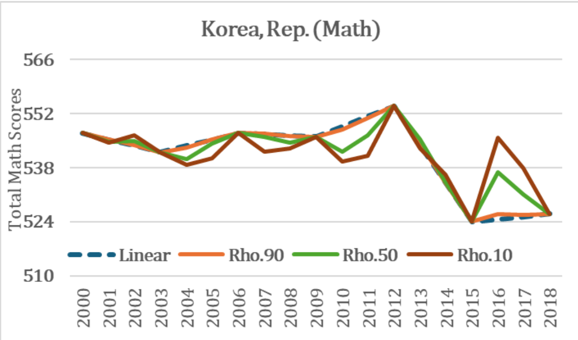

Japan (Reading)
560
540
520
500
480
Total Read Scores
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Japan (Science)
555
545
535
525
515
Total Science Scores
Linear
Rho.90
Rho.5
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Korea, Rep. (Math)
566
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524
510
Total Math Scores
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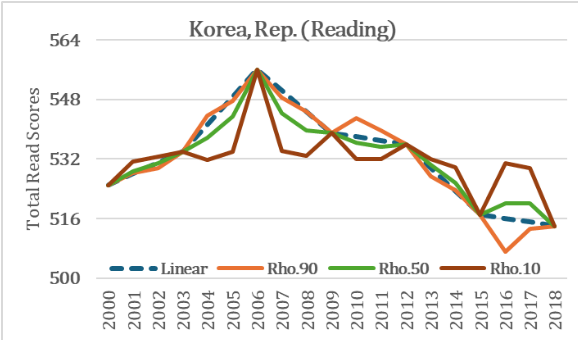
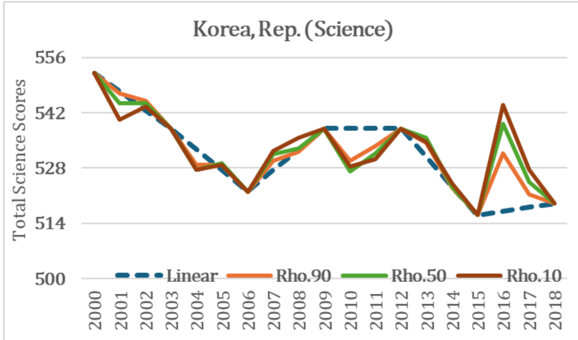
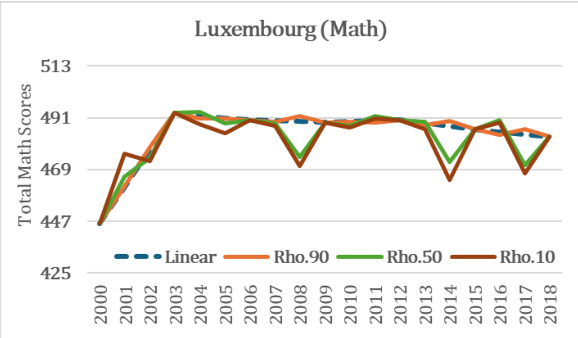
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Korea, Rep. (Reading)
564
548
532
516
500
Total Read Scores
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Korea, Rep. (Science)
556
542
528
514
500
Total Science Scores
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Luxembourg (Math)
513
491
469
447
425
Total Math Scores
Linear
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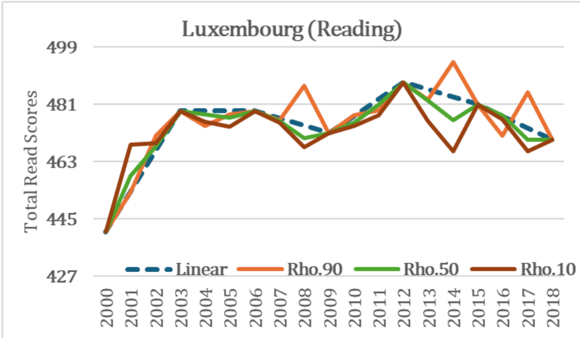
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Luxembourg (Reading)
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427
Total Read Scores
Linear
Rho.90
Rho.50
Rho.10
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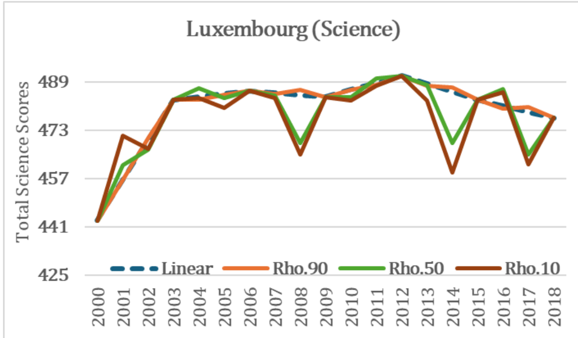
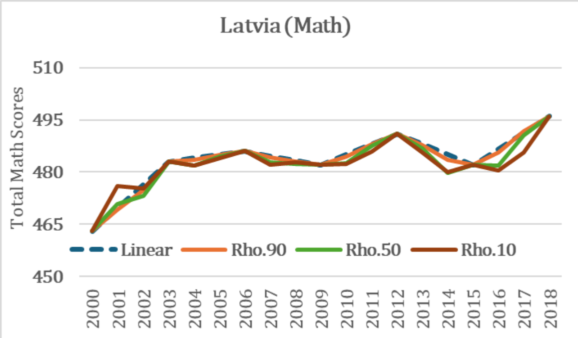
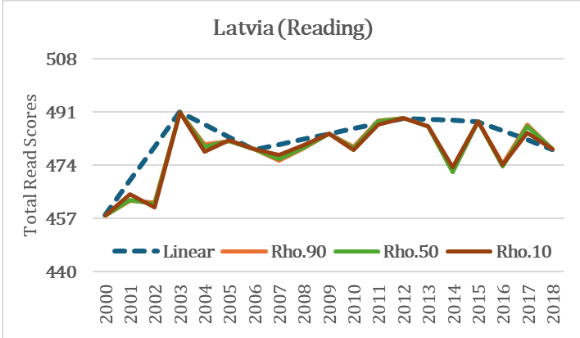
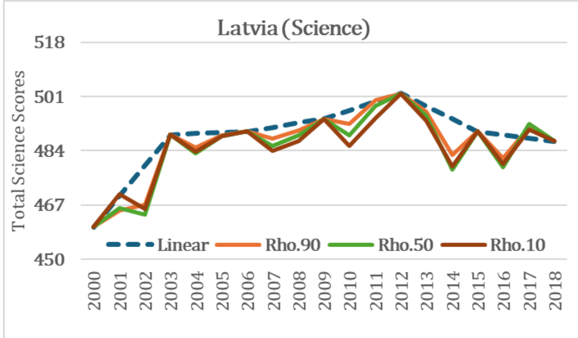
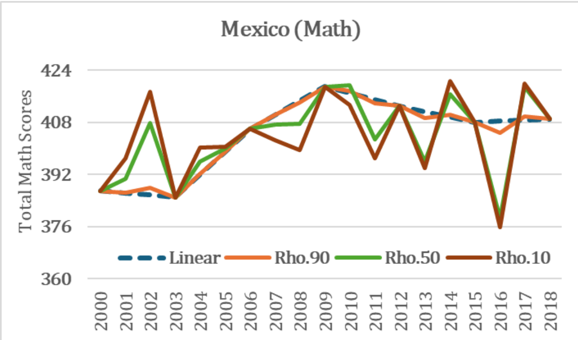

Luxembourg (Science)
489
473
457
441
425
Total Science Scores
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Latvia (Math)
Total Math Scores
510
495
480
465
450
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Latvia (Reading)
Total Read Scores
508
491
474
457
440
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Latvia (Science)
Total Science Scores
518
501
484
467
450
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Mexico (Math)
Total Math Scores
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376
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Rho.10
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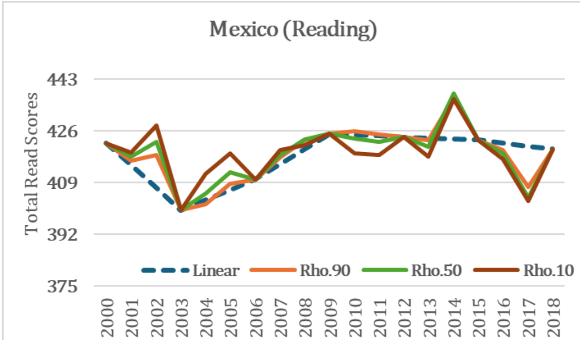
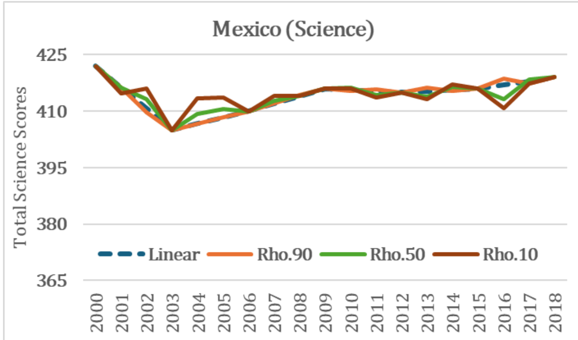
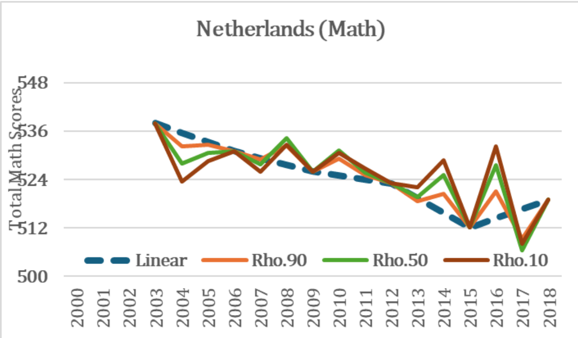
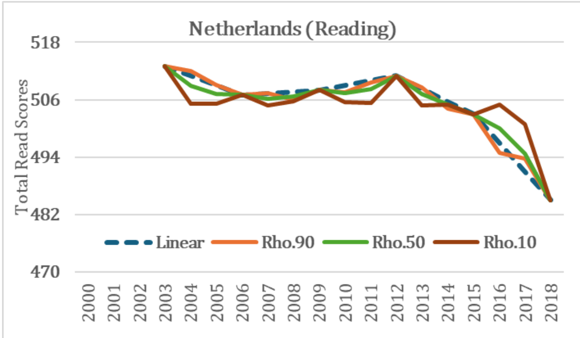
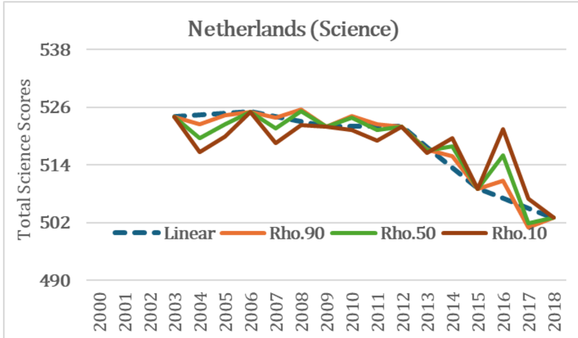
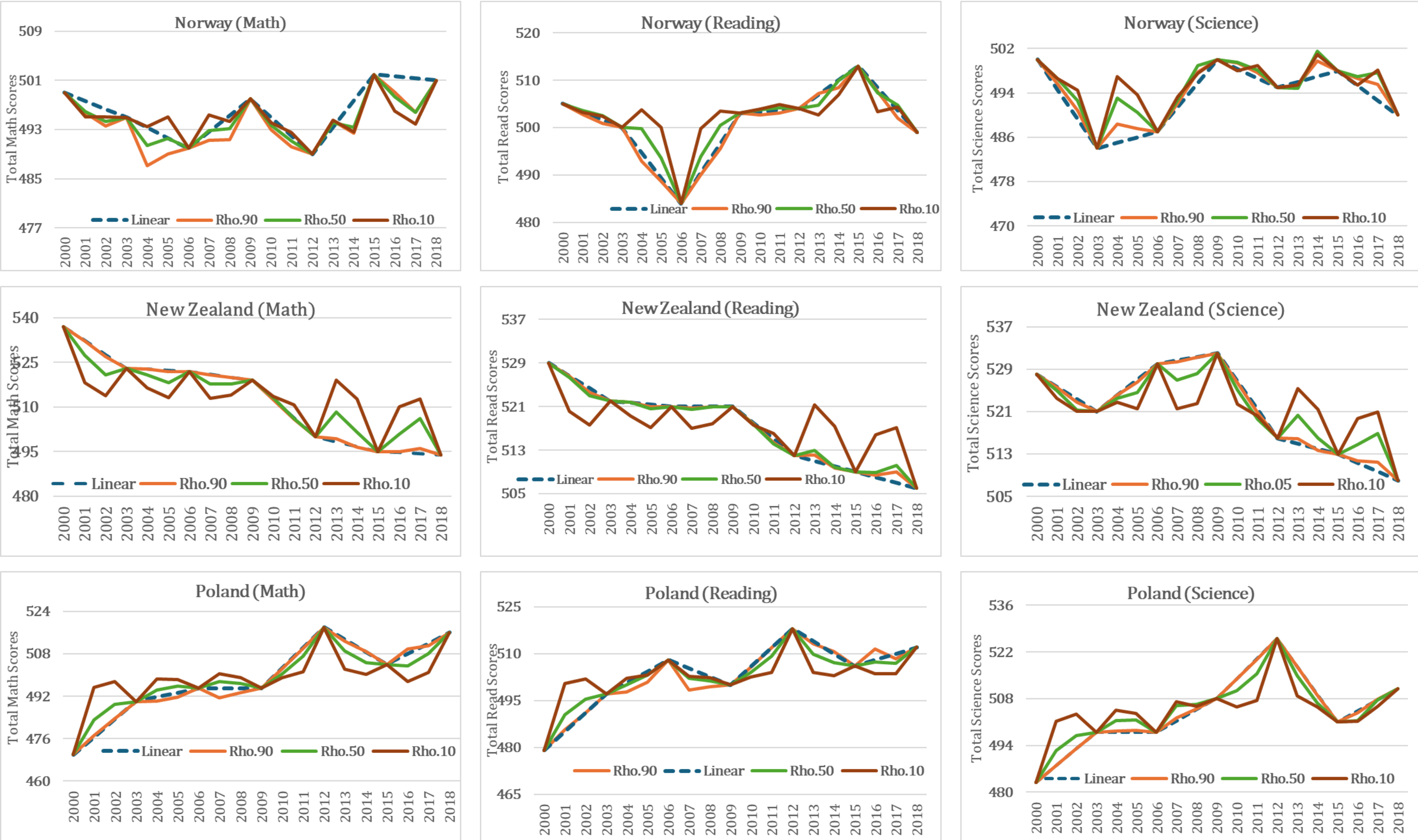

Mexico (Reading)
Total Read Scores
443
426
409
392
375
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Mexico (Science)
Total Science Scores
425
410
395
380
365
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Netherlands (Math)
Total Math Scores
548
536
524
512
500
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Netherlands (Reading)
Total Read Scores
518
506
494
482
470
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Netherlands (Science)
Total Science Scores
538
526
514
502
490
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Norway (Math)
Total Math Scores
509
501
493
485
477
Linear
Rho.90
Rho.50
Rho.10
Norway (Reading)
Total Read Scores
520
510
500
490
480
Linear
Rho.90
Rho.50
Rho.10
Norway (Science)
Total Science Scores
502
494
486
478
470
Linear
Rho.90
Rho.50
Rho.10
New Zealand (Math)
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510
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Rho.10
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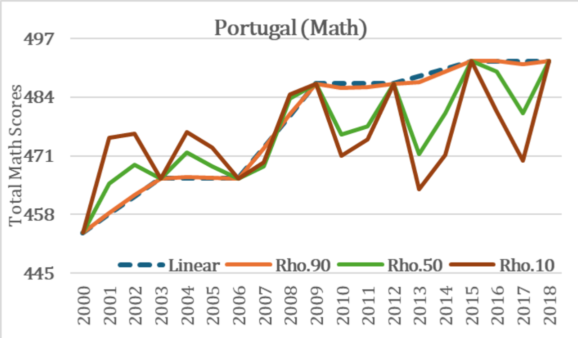
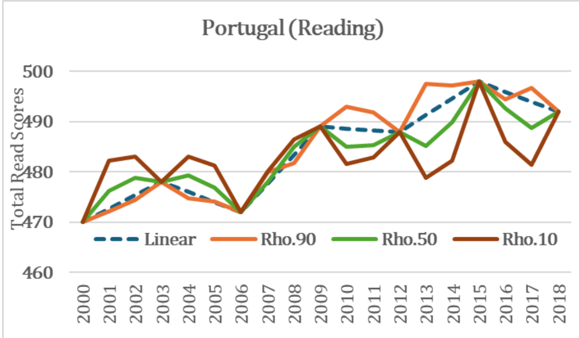
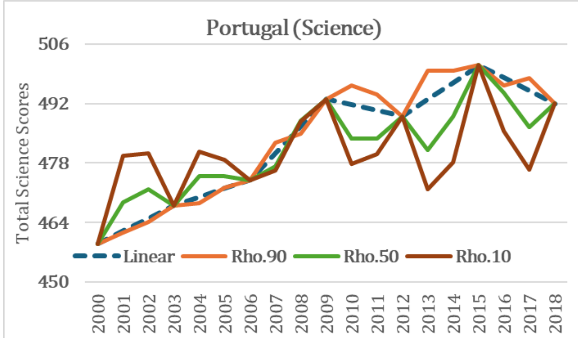
529
521
513
505
Linear
Rho.90
Rho.50
Rho.10
New Zealand (Science)
Total Science Scores
537
529
521
513
505
Linear
Rho.90
Rho.05
Rho.10
Poland (Math)
Total Math Scores
524
508
492
476
460
Linear
Rho.90
Rho.50
Rho.10
Poland (Reading)
Total Read Scores
525
510
495
480
465
Rho.90
Linear
Rho.50
Rho.10
Poland (Science)
Total Science Scores
536
522
508
494
480
Linear
Rho.90
Rho.50
Rho.10
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Portugal (Math)
Total Math Scores
Linear
Rho.90
Rho.50
Rho.10

Portugal (Reading)
Total Read Scores
Linear
Rho.90
Rho.50
Rho.10

Portugal (Science)
Total Science Scores
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Rho.50
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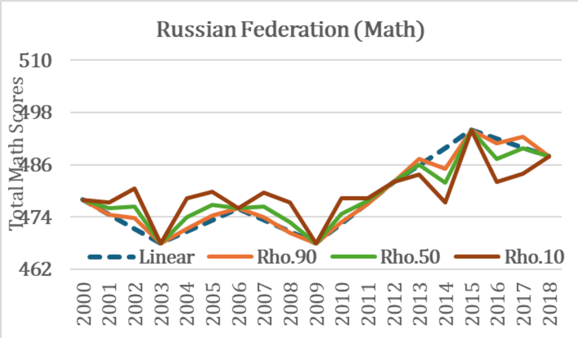
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Total Math Scores
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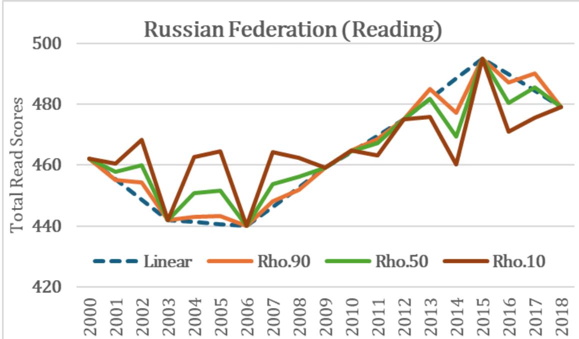
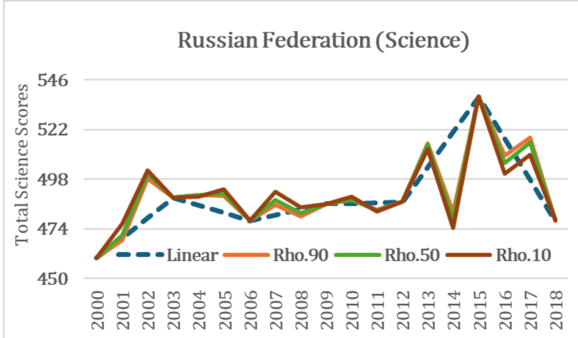
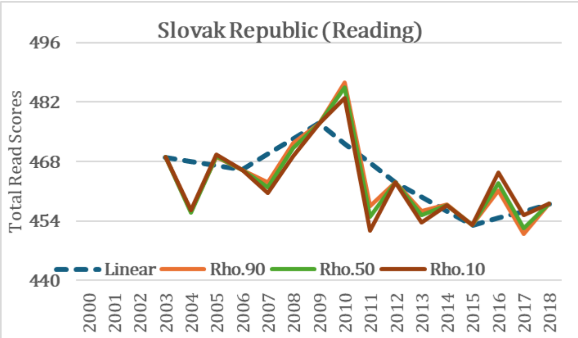
Rho.10

Russian Federation (Reading)
Total Read Scores
Linear
Rho.90
Rho.50
Rho.10

Russian Federation (Science)
Total Science Scores
Linear
Rho.90
Rho.50
Rho.10

Slovak Republic (Reading)
Total Read Scores
Linear
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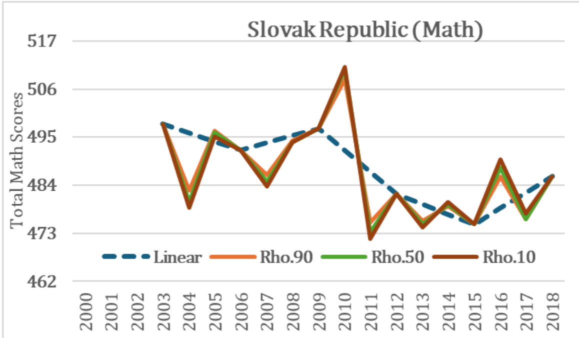
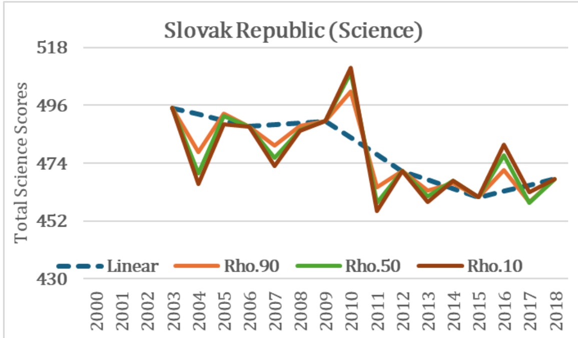
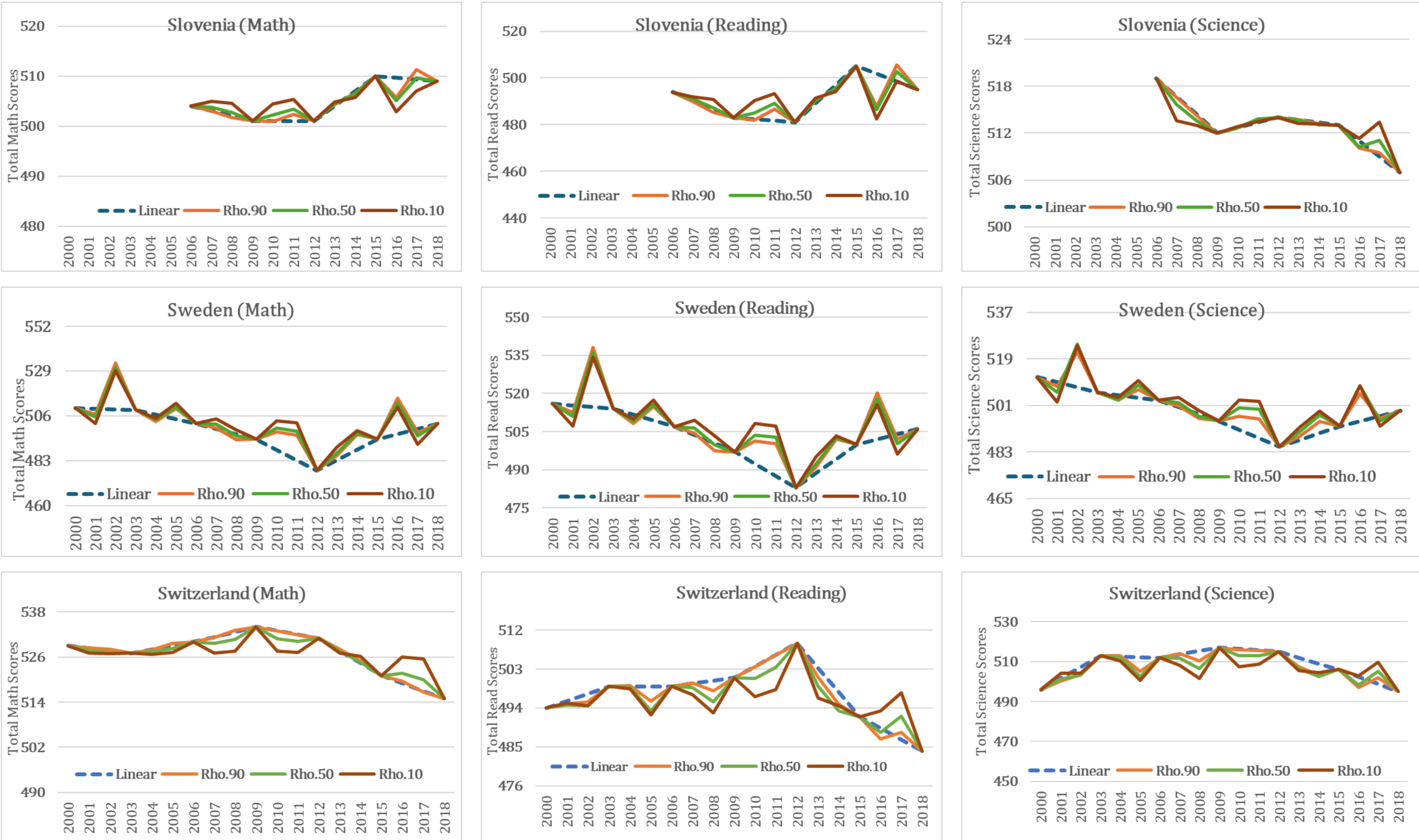
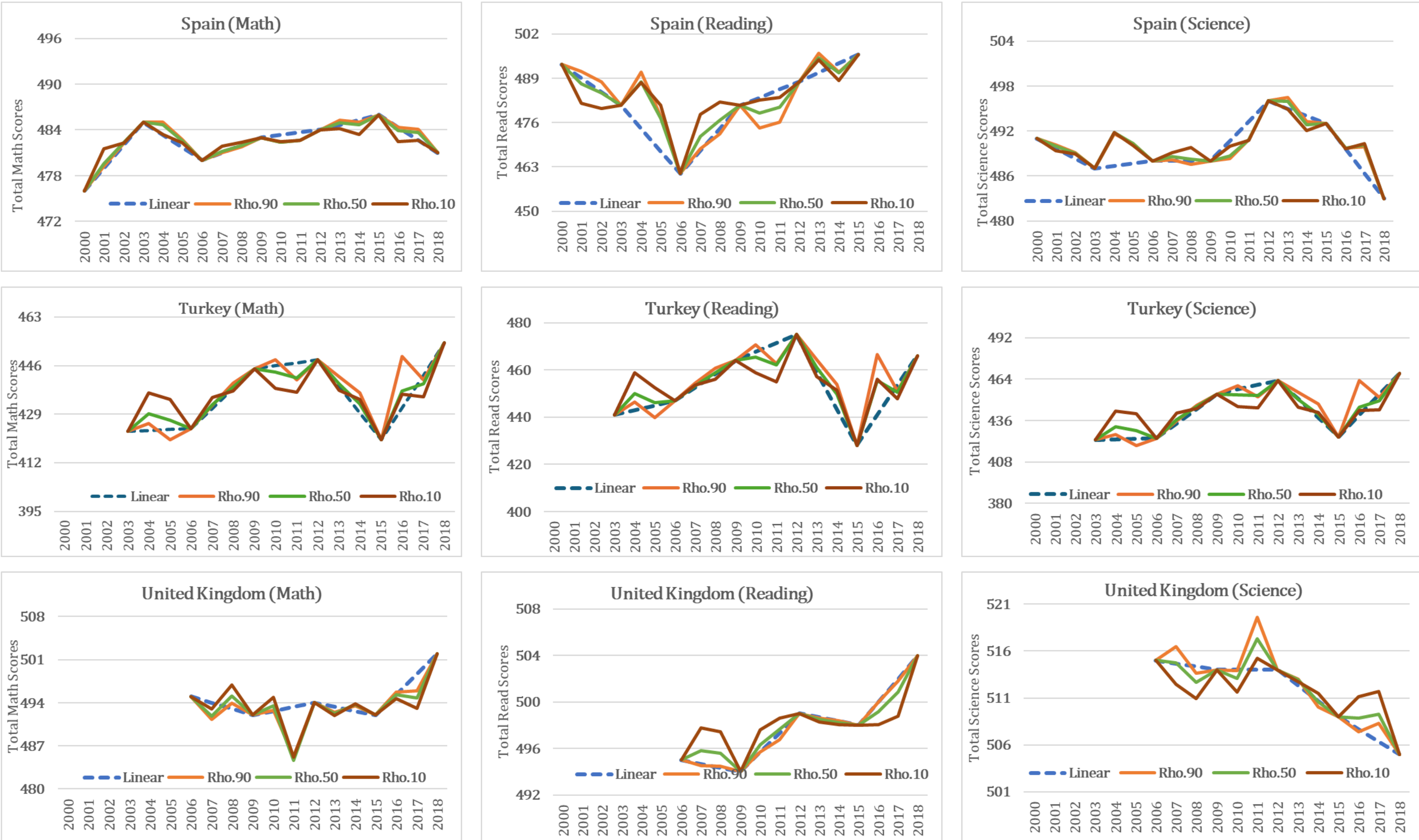
Rho.10

Slovak Republic (Math)
Total Math Scores
Linear
Rho.90
Rho.50
Rho.10

Slovak Republic (Science)
Total Science Scores
Linear
Rho.90
Rho.50
Rho.10


Slovenia (Math)
Total Math Scores
Linear
Rho.90
Rho.50
Rho.10
Slovenia (Reading)
Total Read Scores
Slovenia (Science)
Total Science Scores
Sweden (Math)
Sweden (Reading)
Sweden (Science)
Switzerland (Math)
Switzerland (Reading)
Switzerland (Science)


Spain (Math)
Total Math Scores
Spain (Reading)
Total Read Scores
Spain (Science)
Total Science Scores
Turkey (Math)
Total Math Scores
Turkey (Reading)
Total Read Scores
Turkey (Science)
Total Science Scores
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Total Math Scores
United Kingdom (Reading)
Total Read Scores
United Kingdom (Science)
Total Science Scores
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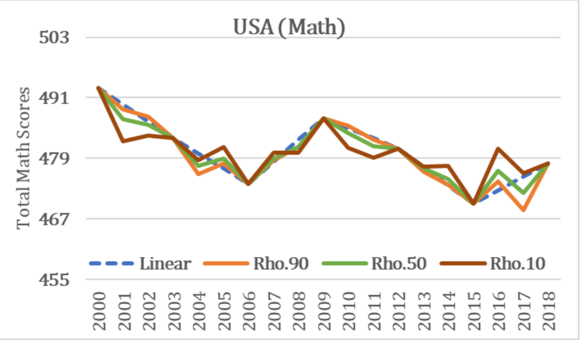
Rho.90
Rho.50
Rho.10


USA (Math)
Total Math Scores
503
491
479
467
455
Linear
Rho.90
Rho.50
Rho.10
2000
2001
2002
2003
2004
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2006
2007
2008
2009
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2011
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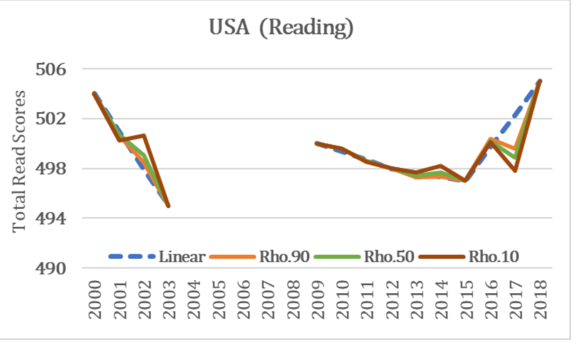
2018


USA (Reading)
Total Read Scores
506
502
498
494
490
Linear
Rho.90
Rho.50
Rho.10
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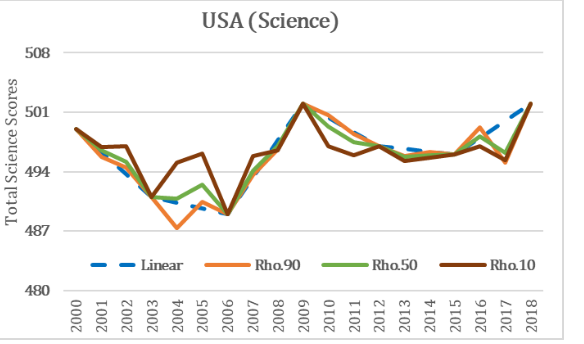
USA (Science)
Total Science Scores
508
501
494
487
480
Linear
Rho.90
Rho.50
Rho.10
2000
2001
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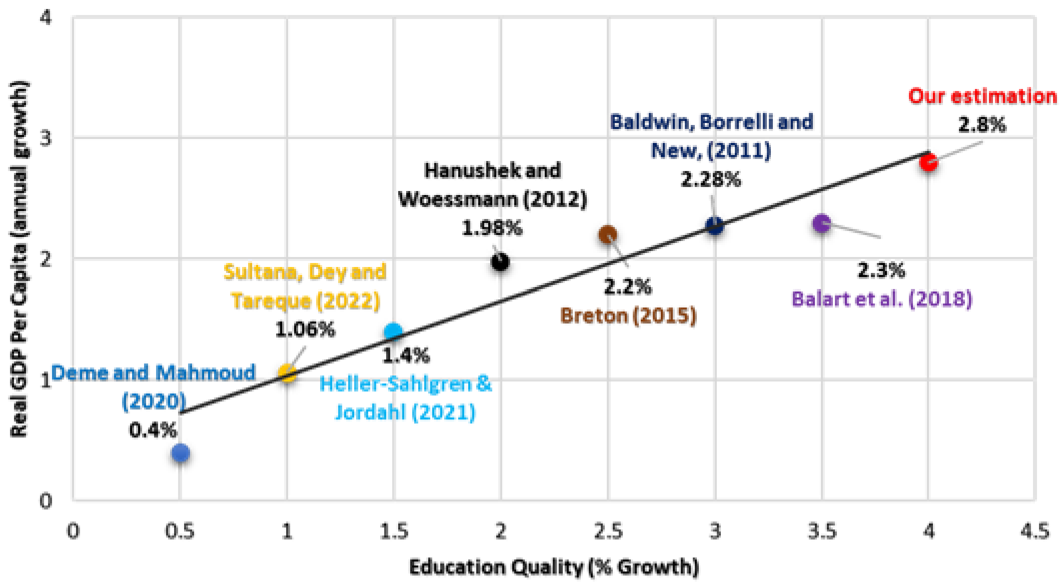
2017
2018

Figure 3: The Impact of Quality of Education and Economic Growth (Literature Comparison)



Appendix A: Data Sources and Descriptive Statistics

Table A1: Definitions of Education Quality from WDI

Variables	Description	Measurement
PupTeaRatioLowSec	Pupil–teacher ratio, lower secondary	Lower secondary school pupil–teacher ratio is the average number of pupils per teacher in lower secondary school.
PupTeaRatioSec	Pupil–teacher ratio, secondary	Secondary school pupil–teacher ratio is the average number of pupils per teacher in secondary school.
PupTeaRatioUpSec	Pupil–teacher ratio, upper-secondary	Upper-secondary school pupil–teacher ratio is the average number of pupils per teacher in upper-secondary school.
PupTeaRatioTer	Pupil–teacher ratio, tertiary	Tertiary school pupil–teacher ratio is the average number of pupils per teacher in tertiary school.
AllEdStaffComp	All education staff compensation	All staff (teacher and non-teachers) compensation is expressed as a percentage of direct expenditure in public educational institutions (instructional and non-instructional) of the specified level of education.
AllEdStaffCompSec	All education staff compensation, secondary	All staff (teacher and non-teachers) compensation is expressed as a percentage of direct expenditure in public educational institutions (instructional and non-instructional) of the specified level of education.
AllEdStaffCompTer	All education staff compensation, tertiary	All staff (teacher and non-teachers) compensation is expressed as a percentage of direct expenditure in public educational institutions (instructional and non-instructional) of the specified level of education.
CurrEdExpSec	Current education expenditure, secondary	Current education expenditure, secondary is expressed as a percentage of total expenditure in secondary public educational institutions (instructional and non-instructional) of the specified level of education. Current expenditure is consumed within the current year and would have to be renewed if needed in the following year
CurrEdExpTer	Current education expenditure, tertiary	Current expenditure is expressed as a percentage of direct expenditure in public educational institutions (instructional and non-instructional) of the tertiary level of education.
CurrEdExp	Current education expenditure, total	Current education expenditure, total is expressed as the total government expenditure in public educational institutions (instructional and non-instructional).
GovExppsSec	Government expenditure per student, secondary	Government expenditure per student is the average general government expenditure (current, capital, and transfers) per student in the given level of education, expressed as a percentage of GDP per capita
GovExppsTer	Government expenditure per student, tertiary	Government expenditure per student is the average general government expenditure (current, capital, and transfers) per student in the given level of education, expressed as a percentage of GDP per capita
GovExpEdGDP	Government expenditure on education, total	General government expenditure on education (current, capital, and transfers) is expressed as a percentage of GDP. It includes expenditure funded by transfers from international sources to the government.

Variables	Description	Measurement
GovExpEd	Government expenditure on education, total	General government expenditure on education (current, capital, and transfers) is expressed as a percentage of total general government expenditure on all sectors (including health, education, social services, etc.). It includes expenditure funded by transfers from international sources to the government.
ExpSec	Expenditure on secondary education	Expenditure on secondary education is expressed as a percentage of total general government expenditure on education.
ExpTer	Expenditure on tertiary education	Expenditure on tertiary education is expressed as a percentage of total general government expenditure on education.

Source: World development indicators, World Bank

Table A2: Description of variables used in regression analysis

Variables		Measurement	Definition
GDP	Real GDP Per Capita Growth	%	Growth of Real Gross Domestic Product Per Capita (Real GDP)
Year of Sch	Year of Schooling	Mean	The average number of years the population older than 25 participated in formal education
Science	Science Scores	Scores	Measures 15-year-olds' ability to use their science skills to meet real-life challenges.
Math	Math Scores	Scores	Measures 15-year-olds' ability to use their math skills to meet real-life challenges.
Reading	Reading Scores	Scores	Measures 15-year-olds' ability to use their reading skills to meet real-life challenges.
Eduqua	Education Quality	Scores	Average of the 3 text scores - (Math + Reading + Science)/3. It measures the 15-year-olds' ability to use their reading, mathematics, and science knowledge and skills to meet real-life challenges.
Government Size	Government Size	%	Government spending as percent of GDP
Capital Formation	Gross Fixed Capital Formation Growth	%	It measures the value of acquisitions of new or existing fixed assets by the business sector, governments and households minus disposals of fixed assets (in annual growth)
Trade Openness	Trade Openness	%	Exports plus imports as percent of GDP

The data for education quality (PISA) was sourced from the OECD database (www.oecd.org/pisa/data); real GDP per capita growth, real GDP at the level, and other determinants of growth such as Year of schooling, secondary school enrolment, capital formation, government size, and trade openness from World Bank .