ECON Honor Thesis
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Cross-country growth regressions to investigate TFP growth and GDP growth

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1. Introduction

This paper conducts a cross-country empirical study of investigating GDP growth and TFP growth. The multiple linear regression with instrumental variable estimation is used to study GDP growth. The regression also analyzes the correlation between determinants of GDP growth and TFP growth. In addition, the nonlinear programming approach is applied to normalizing math test scores from different international test programs so that we have test scores comparable across countries of broader growth experiences. These normalized scores are then used to examine the correlation between education quality and TFP growth.

Much the previous research studying the economic growth from 1950 to 1990 has concluded that empirical studies of GDP growth and TFP growth are consistent with neoclassical growth models and endogenous growth theories. However, there is a continuous widening of the world income distribution under the recent period from 1990 to 2014. Assuming that the structural parameters of countries are not very different, the observed widening under the recent period questions the conditional convergence in neoclassical growth model. Moreover, this recent period has many events such as the advance of information and communication technology, more gender equality, and more democracy. Thus, determinants of GDP growth during the recent period may differ from those in previous periods. However, this possible difference has not been studied. Thus, this paper exploits new data sources and empirical strategies to investigate GDP growth. The investigation is used to assess whether empirical evidence of GDP growth is consistent with neoclassical growth models under the recent period from 1990 to 2014. This paper also investigates whether determinants of GDP growth also relates with TFP growth.

The multiple linear regression with instrumental variable estimation is adopted to conduct a cross-country empirical study of GDP growth and TFP growth. The multiple linear regression model allows us to explicitly control for many factors that simultaneously affect growth rates. Thus, the model measures the effect of one factor on growth rates by netting out effects of other factors in the model on growth rates. Moreover, by adding many factors to the multiple linear regression model, more of the variations in growth rates can be explained (Wooldridge, 2013). Previous growth regression mostly used years of schooling as a measurement of human capital. However, doing so assumes that same years of schooling leads to the same increase in productive human capital, regardless of difference in education quality. Thus, the study will apply a nonlinear programming approach to building a more comprehensive dataset of education quality. Then, the dataset is used to explore the correlation between education quality and TFP growth.

This paper investigates GDP growth and TFP growth. Section 2 reviews previous researches on GDP growth and TFP growth. Section 3 describes the data we analyze. Section 4 illustrates empirical strategy to research GDP growth and TFP growth. Section 5 shows results of our study and discussions on results. We find that the initial level of real GDP per capita is not negatively correlated with subsequent GDP growth. Determinants of GDP growth correlate with TFP growth during the period 2000-2014. Also, the cross-country growth regressions indicate the significant positive correlation between education quality and TFP growth.

2. Literature Review

In neoclassical growth models such as the Solow Model (Solow, 1956), a production function has a form $\mathrm{Y} = \mathrm{B}K^{\alpha}L^{1-\alpha}$. Y is real GDP. K is physical capital. L is labor. B is total factor productivity. The models assume diminishing returns to capital accumulation by requiring that α is between 0 and 1. Thus, the capital per capita has the steady-state quantity, which is determined by the condition that the change of capital per person per total factor productivity is equal to zero. In these models, an economy that begins with the quantity of capital per person below its steady-state level will experience growth in capital per worker k and real GDP per capita y along the transition path to the steady state. The growth rate of k gradually declines along its transition to the steady state due to diminishing returns to capital accumulation. Thus, the further an economy is below its steady state value of k, the faster the capital accumulates. This indicates that a country's growth rate of real GDP per capita y tends to be negatively related with its starting level of real GDP per capita. Once an economy reaches its steady state value of k, y grows at the rate proportional to total factor productivity growth. Overall, neoclassical growth models imply that the long-run growth rate of output per capita is merely determined by the total factor productivity growth. However, changes in the investment rate, the population growth rate, the level of physical capital per capita, and the labor force composition affect the difference between the current level of output per capita and the long-run output per capita. Thus, these changes will make the economy grow faster or slower than its long-run growth as it transits to the steady-state level of output per capita.

The empirical study done by Barro (1997) confirmed many implications of neoclassical growth models. Barro (1997) does cross-country regressions to determine real GDP per capita growth. The regressions are done for a panel data from 1965 to 1990 of roughly 114 countries. Barro runs three-stage least-squares regressions to investigate how these independent variables affect real GDP per capita growth. The results are that the further a country is below its steady state of real GDP per capita, the higher economic growth. The regressions also indicate that human capital and rule of law are positively correlated with economic growth. Fertility rate, government consumption and inflation are negatively correlated with economic growth. Following the Barro's analysis, more empirical analysis of determinants of GDP were done to confirm neoclassical growth models (Hanushek & Woessmann, 2012).

Neoclassical growth models assume that the total factor productivity growth is exogenous and leave it unexplained. Endogenous growth theories study these factors. They treat TFP as the way inputs to the production process are transformed into output. The Romer Model (Romer, 1990) treats TFP as the number of new ideas (or the invention of a new variety of intermediate good). In this model, researchers search for new ideas due to interests in profiting from their inventions. In the Romer Model, the production equation for new ideas is $\dot{A} = \theta L_A^{\lambda} A^{\phi}$. θ is the rate of producing new ideas. L_A is the number of people attempting to discover new ideas. λ is some parameter between zero and one. λ reflects an externality associated with duplication: some of the ideas created by an individual researcher may not be new to the economy as a whole. $\phi > 0$ reflects a positive knowledge spillover in research. Much of the knowledge in previous researches spilled over to future researchers. Based on this equation, the growth rate of TFP is equal to $\lambda n/(1-\phi)$, while n is the population growth rate. Thus, the growth rate of TFP is determined by an externality associated with duplication, positive knowledge spillovers, and the population growth.

As an alternative to the Romer Model, the Schumpeterian model (Elias & Thompson, 1993) treats total factor productivity as quality improvements in intermediate goods instead of the invention of a new variety of intermediate good. New technology replaces old technology, leading to the increase of total factor productivity of the economy. The process for the growth rate of TFP is the same as that in the Romer model despite thinking about the increase of TFP in different ways. These two models indicate that factors that embrace the invention of ideas, even if they do not promote sustained growth in the long-term, will increase TFP growth.

Loko and Diouf (2009) did a cross-country empirical study of TFP growth. They used a panel data of 62 countries from 1970 to 2005. First, they used principle component analysis to identify key combinations of policy, human capital, and institutional conditions associated with TFP growth. Secondly, they used a dynamic panel data model to identify TFP growth patterns. They regressed TFP growth on the initial income per capita, the average inflation, other institutional factors including the trade openness and the level of education. The results suggest that raising human capital, increasing the level of trade openness, rationalizing governmental control and increasing female labor force participation are conducive of higher TFP growth. The results of this study confirm the implications of endogenous growth theories, since endogenous growth theories above explain TFP in terms of the invention of ideas due to human capital, technology transfer, and policies affecting the previous two.

Endogenous growth theories illustrate that human capital is important for TFP growth. Most study today measures human capital in terms of education quantity rather than education quality. Doing so fails to consider how education quality affects TFP growth. Gustafsson (2013) applied a nonlinear programming approach to normalizing test scores from multiple achievement test programs. This approach does not require test programs contain one common countries. Thus, this allows the inclusion of two regional test programs SACMEQ and SERCE. These normalized test scores are used to measure education quality in cross-country growth regressions. He measures a country's education quality by using the average of test scores of a country across years.

In sum, although GDP growth from 1965 to 1990 is consistent with neoclassical growth models, little research has been done to investigate whether the consistency holds during the recent period from 1990 to 2014. Also, whether determinants of GDP growth affect TFP growth need further research. This paper will conduct a cross-country study to investigate TFP growth and GDP growth by using similar empirical strategies (multiple regression analysis with instrumental variable methods) as previous research. By mainly using years of schooling to measure human capital, previous research has not developed credible evidence on the correlation between education quality and TFP growth. This paper will apply a nonlinear programming approach similar with the approach adopted by Gustafsson (2013) to building a data set of education quality for countries of broader growth experiences. This dataset is then used to explore how education quality and education quantity relate with TFP growth.

3. Data

The source for panel data of real GDP, TFP and population is Penn World Table version 9.0 (PWT9). It covers 182 countries between 1950 and 2014. Specifically, we use Real GDP at constant 2011 national prices (rgdpna) to calculate GDP growth rates. We used TFP at constant national prices (rtfpna) to calculate TFP growth rates (Feenstra, 2015).

Barro-Lee Education Attainment data v2.1, Feb.2016 collects panel data of years of schooling for 146 countries for both male and female for the group aged 25 and over from 1950 to 2010 (Barro & Lee, 2013). World Fertility Data 2015 presents a panel data on total fertility (the mean number of children women have by age 50) for 201 countries from 1960 to 2015 (United Nation, 2015). The World Development Indicators (WDI) provides panel data on life expectancy at birth for over 200 countries from 1960 to 2014 (The World Bank, 2012). The data source for government final consumption expenditure is from World Bank national accounts data for 265 countries from 1960 to 2016 (The World Bank, 2017). The IMF international Financial Statistics contains a panel data for over 200 countries on inflation rate for the period 1960-2016 (IMF, 2018).

Panel data of Voice and accountability index and Rule of law index for over 200 countries from 2004-2015 comes from The World Governance Indicators Data (WGI). Voice and accountability index captures perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association and a free media. Rule of law index is also obtained from WGI. It is used to measure democracy. Rule of law captures perceptions of the extent to which agents have confidence in and abide by the rules of society (Daniel, 2010). One limitation of this data is that it only covers the short period 2004-2015. We do not have information of how Voice and accountability and Rule of law relates with long-term growth rates during previous periods, such as the growth rate during 1965-1990. Thus, similar with what Barro (1997) did in growth regressions, we only use Rule of law in 2000 and Voice and accountability in 2000 to measure variations of them across countries.

Panel data of math scores of multiple international student achievement tests (ISATs) over 100 countries under the recent period from 2000 to 2014 are used to measure education quality. The data comes from World Bank Educational Statistics. Two international student achievement tests (PISA and TIMSS) are used. Mathematical performance for PISA measures the mathematical literacy of a 15-year-old to formulate, employ and interpret mathematics in a variety of contexts to describe, predict, and explain phenomena. PISA covers math scores in 2000, 2003, 2006, and 2009. 72 countries have at least one PISA scores. TIMSSS assesses student achievement in mathematics in 2003, 2007 for 61 countries. Two regional student achievement tests are used. SACMEQ measures math achievement scores for 16 countries in Southern and Eastern African in 2000 and 2007. SERCE assesses learning achievement in mathematics for 16 Latin American countries in 2006 (World Bank, 2017). One limitation of these tests is that they are not designed for cross-country regressions. A nonlinear programming approach is developed to transform scores from multiple ISATs so that transformed scores are comparable on a common scale.

4. Empirical strategy

4a. Investigate GDP growth during 1965-1990 and during 1990-2014

The first research question is to compare GDP growth during 1965-2014 with GDP growth during 1965-1990. One hypothesis is that some variables correlating with GDP growth during 1965-1990 have different correlations with GDP growth during 1990-2014.

To investigate this hypothesis, cross-country growth regressions are conducted for two periods 1965-1990 and 1990-2014 separately.

Our base regression is:

$$(1)\ GDPGR_{\,i,t} \;=\; \beta_0 + \beta_1 * y_{it} + \beta_2 * MHK_{it} + \beta_3 * FHK_{it} + \beta_4 * FTR_{it} + \beta_5 * LIFE_{it} + \beta_6 * Govt_{it} + \beta_7 * Inf_{it} + \beta_8 * RLW_{it} + \beta_9 * DEM_{it} + \beta_{10} * \mathrm{DEMSQAR}_{it} + \beta_{11} * \mathrm{Log}[y_{it} - sample\ mean(y_{it})] * MHK_{it} + \beta_{12} * \mathrm{Log}[y_{it} - samplemean(y_{it})] * FHK_{it} + u_{it}$$

To investigate GDP growth for 1965-1990, $GDPGR$ is GDP growth rates for three sub-periods 1965-1975, 1975-1985, and 1985-1990. y, the log initial level of real GDP per capita at the beginning of each sub-period. MHK, the initial level of male schooling at the beginning of each sub-period. FHK, the initial level of female schooling at the beginning of each period. FTR, the log average fertility rate for each sub-period; LIFE, the log average life expectancy for each sub-period; Govt, the average ratio of government consumption to real GDP for each sub-period; Inf, the average inflation rate for each sub-period; RLW, rule of law index in 2000; DEM, voice and accountability index in 2000; DEMSQAR, voice and accountability index squared in 2000; The last two variables in the regression above, interaction terms between the initial level of schooling and the deviation from the mean level of GDP per capita; u, the common error term. For each indicator, i represents the country and t represents the period.

To investigate GDP growth for 1990-2014, the same regression as above is completed. $GDPGR$ represents GDP growth rates for three sub-periods 1990-2000, 2000-2010, and 2010-2014. Independent variables are same as before except they are for different sub-periods.

Overall, multiple linear regressions above study how variables correlate with variations of GDP growth across countries for two different periods. These regressions have the same form as cross-country growth regressions done by Barro (1997). To research GDP growth of certain period, the period is divided into three sub-periods. By doing so, the regression has multiple observations on the same countries. This allows us to control for certain unobserved characteristics of countries, which facilitates casual inference (Wooldridge, 2011). In contrast with most growth regressions, we add the initial level of female schooling to growth regressions. This allows us to investigate whether female education still does not have positive correlation with GDP growth during the recent period 1990-2014.

Moreover, variables in these regressions are selected to test the consistency between empirical evidence and growth models. The coefficient β_1 before the initial log level of GDP per capita measures conditional convergence in neoclassical growth models by controlling effects of structure parameters including population, fertility rate, education, and so on. Initial level of schooling is used to measure average human capital. Using the initial level of schooling allows us to consider human capital has effects on growth rates only when some time has to passed. Also, it decreases the possibility that we are in a favorable condition that supports both high investment in human capital and high GDP level. Thus, coefficients β_2 and β_3 estimate the relationship between human capital and growth rates for male group and female group separately. The coefficient β_4 before fertility rate allows us to test the implication of neoclassical growth models that high fertility decreased capital accumulation and thus GDP growth (because investment is used to provide capital for new worker instead of increasing capital per worker). The coefficient β_5 measures how life expectancy positively correlates with GDP growth probably by increasing the productivity of human capital or negatively correlates with GDP growth probably by increasing population growth. The coefficient β_6 measures how government consumption correlates with investment rate and thus GDP growth. The coefficient β_7 measures the correlation between inflation and GDP growth. Coefficients β_8 and β_9 measures how rule of law and democracy index correlates with GDP growth. The coefficient β_{10} accounts for nonlinear relation between democracy and GDP growth. Coefficients β_{11} and β_{12} estimates interaction effects between years of schooling and GDP on GDP growth.

4b. Instrumental variable estimation

One limitation of the base regression is that initial level of years of schooling could be endogenous. Higher initial level of years schooling probably means more investment in education. Since a government budget is constrained, this higher investment might lead to less government spending on other factors affecting GDP growth (such as capital accumulation). Thus, initial level of years of schooling could be negatively correlated with factors in the error term increasing GDP growth. Thus, initial level of years of schooling might have negative correlation with GDP growth. This negative correlation might lead us to underestimate the positive effects of years of schooling on GDP growth. The Hausman Test for endogeneity is conducted to show that the initial level of female schooling is endogenous and thus instrumental variable estimation should be conducted. The first step is to estimate the reduced form for the initial level of female schooling by regressing it on all exogenous variable. Then the residual of the regression is obtained. The second step is to add the residual to the base regression equation (1) and test for significance of the residual (Wooldridge, 2011). The result is that the residual has positive correlation with GDP growth at 1% level (Table 4). This illustrates that the initial level of female schooling is endogenous. Thus, OLS estimates in base regression (1) are not consistent. The instrumental variable estimation is used to uncover the correlation between the initial level of schooling and GDP growth.

In contrast with growth regressions, base regression (1) includes the initial level of female schooling. Thus, we do not use earlier levels of female schooling as instrumental variable. Instead, we use the ratio of population aged 0-14 per total population (children ratio) as a potential instrumental variable for the initial level of female schooling.

To conduct instrumental variable estimation, we firstly investigate the correlation between female education and children ratio.

The regression equation is:

$$(2)\ FHK_{i,t} = \beta_0 + \beta_1 * y_{it} + \beta_2 * MHK_{it} + \beta_3 * CHILD_{it} + \beta_4 * FTR_{it} + \beta_5 * LIFE_{it} + \beta_6 * Govt_{it} + \beta_7 * Inf_{it} + \beta_8 * RLW_{it} + +\beta_9 * DEM_{it} + \beta_{10} * \mathrm{Log}[y_{it} - sample\ mean(y_{it})] * MHK_{it} + \beta_{11} * \mathrm{Log}[y_{it} - samplemean(y_{it})] * FHK_{it} + \beta_{12} * \mathrm{DEMSQAR}_{it} + u_{it}$$

where CHILD is children ratio. Other variables are discussed before in 4A.

The result of this regression indicates the negative correlation between children ratio and the initial level of female schooling. One percent increase in the children ratio correlates with 0.0283 year decrease in the initial level of female schooling at 1% significance level (Table 5). However, this regression result does not mean that the increase in children ratio causes the reduction in the initial level of female schooling. This only implies the negative correlation between the children ratio and the initial level of female schooling. This negative correlation is consistent with the existing literature that higher level of female education is correlated with later age of marriage and less child birth per female because women investing in formal education plan for careers and focus less on motherhood (Goldin, 2006). Thus, assuming that the children ratio is uncorrelated with error terms in the base regression (1), the children ratio is used as an instrumental variable for the initial level of female schooling. Thus, we constructed a predicted initial level of female schooling based on the regression (2).

Once we have this predicted initial level of female schooling, it is used as the instrumental variable for the initial level of female schooling.

The regression equation is:

$$(3)\ GDPGR_{i,t} = \beta_0 + \beta_1 * y_{it} + \beta_2 * MHK_{it} + \beta_3 * IVFHK_{it} + \beta_4 * FTR_{it} + \beta_5 * LIFE_{it} + \beta_6 * Govt_{it} + + \beta_7 * Inf_{it} + \beta_8 * RLW_{it} + +\beta_9 * DEM_{it} + \beta_{10} * \mathrm{DEMSQAR}_{it} + \beta_{11} * \mathrm{Log}[y_{it} - sample\ mean(y_{it})] * MHK_{it} + \beta_{12} * \mathrm{Log}[y_{it} - samplemean(y_{it})] * FHK_{it} + u_{it}$$

where IVFHK is the predicted initial level of female schooling based on the regression (2). Other variables are discussed before in 4A.

4c. Correlations between determinants of GDP growth with TFP growth

Cross-country growth regressions are used to explore whether determinants of GDP growth correlate with TFP growth.

The regression equation is:

$$(4)\ TFPGR_{i,t} = \beta_0 + \beta_1 * y_{it} + \beta_2 * MHK_{it} + \beta_3 * FTR_{it} + \beta_4 * LIFE_{it} + \beta_5 * Govt_{it} + \beta_6 * Inf_{it} + \beta_7 * RLW_{it} + \beta_8 * DEM_{it} + \beta_9 * \text{Log}[y_{it} - sample\ mean(y_{it})] * MHK_{it} + u_{it}$$

where TFPGR represents TFP growth. Other variables are discussed before in 4A.

TFPGR is TFP growth rates for two sub-periods 2000-2007 and 2007-2014. We regress TFP growth rates of each sub-period on the corresponding independent variables in the equation (4).

4d. Analyze the correlation between education quality and TFP growth

Education quality has not been added to growth regressions previously. However, endogenous growth theories emphasize that the discovery of new ideas is important for total factor productivity growth. Education quality may well be positively correlated with the discovery of new ideas. Therefore, it makes sense that education quality is positively correlated with TFP growth.

Cross-country regression to investigate the correlation

A cross-country regression is used to investigate the correlation between education quality and TFP growth. Math scores of achievement tests are used to measure education quality.

The regression equation is:

$$(5)\ TFPGR_{i,t} = \beta_0 + \beta_1 * y_{it} + \beta_2 * \text{NTS} + \beta_3 * MHK_{it} + \beta_4 * FTR_{it} + \beta_5 * LIFE_{it} + \beta_6 * Govt_{it} + \beta_7 * Inf_{it} + \beta_8 * RLW_{it} + \beta_9 * DEM_{it} + +\beta_{10} * \text{Log}[y_{it} - sample\ mean(y_{it})] * MHK_{it} + u_{it}$$

where TFPGR represents TFP growth; NTS, the initial level of normalized math test scores at the beginning of each sub-period. Other variables are discussed before in 4A.

TFPGR is TFP growth rates for two sub-periods 2000-2007 and 2007-2014. We regress TFP growth rates of each sub-period on the initial level of normalized math scores for that sub-period and other corresponding independent variables in the equation (5).

A nonlinear programming approach to normalizing test scores

The regression equation (5) above uses normalized test scores across countries. Since scores of international student assessment tests are not comparable across test programs, the nonlinear programming approach is developed to normalize test scores from different test programs so that normalized test scores are on a common scale. These normalized test scores form a dataset of education quality of countries of broader growth experiences. Then, cross-country growth regressions using equation (5) directly use these normalized test scores to investigate the correlation between education quality and TFP growth.

The nonlinear programming approach developed by Gustafsson (2013) is applied to normalizing test scores around 2000 and test scores around 2006 separately. In contrast with Gustafsson (2013), the simple average of test scores across subjects and different years is not used to measure a country's overall education quality. Instead, we only use math scores. Doing so allows us to directly identify the correlation between math improvement and TFP growth. Moreover, education quality of the particular year is measured by its respective math score around the same year. Since our regression is implemented for two sub-periods, we conduct a nonlinear programming approach to normalizing scores of test programs around 2000 and scores of test programs around 2007 separately.

Suppose there are n different test programs containing math scores. We want to find transformed coefficients (α_m, β_m), m = 1, …, n-1 for test programs excluding PISA. Transformed coefficients are not needed for PISA because the scale of PISA is used as a common scale. Transformed coefficients are used to normalize test scores of a particular test program: $T_{im} = \alpha_m + \beta_m * O_{im}$, where O_{im} represents the original test score for the country i and the test program m and T_{im} represents the respected transformed test score.

The transformed coefficients (α_m, β_m) are found by using nonlinear optimization. The objective function is $minz = f(\alpha_1, \beta_{1,\dots,} \alpha_{n-1}, \beta_{n-1}) = \sum_{j=1}^{k} \bar{D}_j W_j$. The variable k is the number of pairs of any two test programs. $D_{ij} = (T_{i,m=c} - T_{i,m=d})^2$. $\bar{D}_j$ is the simple average of D_{ij} of common countries in a pair of two test programs. W_j are constant weights. Details of constructing objective function could be found in Appendix A. Overall, the objective function is constructed in the way that z measures how normalized test scores of common countries in various test programs differ. Then, a nonlinear programming approach is conducted to find transformed coefficients (a_m, β_m) so that the difference z is minimized.

If we only use PISA test scores to measure education quality, the regression using equation (5) could only be performed for 38 countries. By conducting the nonlinear programming approach, we could transform math test scores from three test programs (PISA 2000, TIMSS 2003, and SACMEQ 2000) to normalized test scores around 2000. We could also transform test scores form three test programs (PISA 2006, TIMSS 2007, and SERCE 2006) to normalized test scores around 2006. These normalized test scores are used to measure education quality. By having normalized test scores of SACMEQ 2000 and SERCE 2006, we could investigate the correlation between education quality and TFP growth for countries with broader growth experiences (including more African countries and Latin American countries).

4. Results and Discussion

Base regression results of investigating GDP growth are reported in Table 1. Table 1 shows that determinants of GDP growth during 1965-1990 are nearly the same as determinants of GDP growth during 1990-2014. During 1965-1990, government consumption is negatively correlated with GDP growth at 5% level. During 1990-2014, government consumption is negatively correlated with GDP growth at around 10% level. For both periods, rule of law index has positive correlation with GDP growth at 1% level. For both periods, voice and accountability index has negative correlation GDP growth at 1% level. In contrast with the conditional convergence implied by Neoclassical growth models, the initial level of log real GDP per capita has none correlation with the subsequent GDP growth during 1965-1990 by controlling structural parameters. Moreover, the initial level of log real GDP per capita has positive correlation with the subsequent GDP growth during 1990-2014 at 10% significance level by controlling structural parameters. The coefficient illustrates that if GDP per capita increases by 1 percent, GDP growth rate has 0.31% increase. Overall, the coefficients in Table 1 illustrates the relative consistency between empirical study and growth models during the period 1965-1990 and the recent period 1990-2014. However, the coefficients also indicate that conditional convergence implied by Solow Model is not supported because regression results do not show the initial level of log real GDP per capita does not has negative correlation with GDP growth. Also, the negative correlation between voice and accountability index and GDP growth need further research.

Moreover, in contrast with previous research, the initial level of male schooling has negative correlation with GDP growth, while the initial level of female schooling has positive correlation with GDP growth. These results support using instrumental variable estimation to uncover the correlation between the initial level of schooling and GDP growth.

Table 2 describes what happens when the instrumental variable (children ratio) for the initial level of female schooling is used. Instrumental variable estimation uncovers the correlation between the initial level of schooling and GDP growth during the period 1990-2014. Instrumental variable estimates (IV estimates) shows that the initial level of male schooling is strongly and significantly correlated with GDP growth during 1990-2014 at around 1% significance level. One year increase in the initial level of male schooling (measured by years of secondary and higher schooling) correlates with 3.66% increase in GDP growth. It also indicates strong and significant negative correlation between female schooling and GDP growth. One year increase in the initial level of female schooling (measured by years of secondary and higher schooling) correlates with 3.84% decrease in GDP growth at around 1% significance level. Comparing IV estimates with OLS estimates in Table 2 indicates OLS estimates underestimates the positive correlation between the initial level of male schooling and subsequent GDP growth. This result is consistent with the hypothesis that OLS estimates of the correlation between the level of schooling and GDP growth has the endogeneity problem. However, it should be noted that the standard error of IV estimate (0.018) is larger than that of OLS estimate (0.003). The positive correlation between male schooling and GDP growth is not very precise.

Regression results of investigating the correlation between determinants of GDP growth and TFP growth under the period 2000-2014 are reported in Table 3. If GDP per capita increases by 1 percent, TFP growth has 0.12% increase. One year increase in the initial level of male schooling correlates with 0.38% increase in TFP growth. If fertility rate increases by 1 percent, TFP growth has 2.49% decrease. If log life expectancy increases by 1 percent, TFP growth has

3.44% decrease. However, voice and accountability index has negative correlation with TFP growth. All results are statistically significant at 1%.

In addition, Table 3 demonstrates that a 1 year increase in the initial level of male schooling produces a 0.38% increase instead of 0.17% in TFP growth when math scores are added to the regression. The standard error of this correlation coefficient remains 0.003, which indicates that the estimate remains precise. Thus, the initial level of male schooling is no longer significantly correlated with TFP growth. However, education quality is positively correlated with TFP growth at 1% level. Thus, the positive association between math scores and TFP growth dwarfs its positive association with the initial level of male schooling significantly.

Results of cross-country growth regressions show the relative consistency between empirical study and growth models. Nevertheless, the lack of a good-as-random assignment mechanism for variables affecting human capital and physical capital makes us wary to push a strongly causal interpretation of the coefficients. Thus, further researches are needed to test the insensitivity of regression results to alternate samples and specifications. Also, a case study exploring how policy reforms affect GDP growth (or TFP growth) could be conducted to identify the channel through which human capital and physical capital affect growth rates. The regression results indicate the negative correlation between voice and accountability index and GDP growth, and the negative correlation between voice and accountability index and TFP growth. Voice and accountability index is used to measure democracy. These regression results contradict the argument of growth literature that democracy promotes GDP growth and TFP growth. This contradiction suggests that voice and accountability index may not be measured correctly. More researches on how democracy affects GDP growth and TFP growth are needed. The regression results indicate the positive correlation between education quality and TFP growth. Education quality is measured in terms of student achievement. Other variables directly measuring education quality such as student-teacher ratio are ideal for us to explore how education quality affects GDP growth.

5. Conclusion

Cross-country growth regressions are used to investigate GDP growth and TFP growth. Regression results are almost consistent with growth models. However, the initial level of log real GDP per capita has the positive correlation with subsequent GDP growth during 1990-

2014. This positive correlation questions whether conditional convergence has indeed taken place now. The regression results indicate the positive correlation between initial level of real GDP per capita and TFP growth, the negative correlation between fertility rate and TFP growth, and the negative correlation between life expectancy and TFP growth at 1% significance level. These results suggest economic conditions and demographic variables might affect TFP growth. In addition, a nonlinear programming approach is applied to normalizing math scores countries achieve in various test programs so that normalized scores are comparable. By adding these normalized scores to growth regressions, we find that the positive correlation between the initial level of schooling and the subsequent TFP growth is no longer significant. This suggests that education quantity may not positively affects TFP growth. More study is needed to investigate how education quality affects TFP growth.

Appendix A: Constructing an objective function to normalize test scores

Gustafsson (2013) developed an nonlinear programming approach to normalizing test scores. This nonlinear programing approach does not require test programs to have U.S. as a participant. A list of test programs could be used for normalizing test scores as long as any two sub-sets of these test programs are directly or indirectly joined by at least two countries. This less strict requirement allows the inclusion of additional reginal test programs.

We adopt Gustafsson's approach to construct the objective function for normalizing test scores. The objective function is $minz = f(\alpha_1, \beta_{1,...,} \alpha_{n-1}, \beta_{n-1}) = \sum_{j=1}^{k} \overline{D_J} W_j$. The construction of the objective function is described as follows. The variable k is the number of pairs of any two test programs. Gustafsson firstly assumes that the relationship between the original score and the normalized score is linear. Thus, the first equation is $T_{im} = \alpha_m + \beta_m * O_{im}$, where O_{im} represents the original test score for the country i and the test program m and T_{im} represents the respected transformed test score. The second equation is $D_{ij} = (T_{i,m=c} - T_{i,m=d})^2$. D_{ij} measures the difference between the transformed score for the country i in test program c and the transformed score for the country i in test program d. $\overline{D_J}$ is the simple average of D_{ij} of bridge countries connecting two test programs in the pair j.

If the objective function is just $min\text{z} = \sum_{j=1}^{k} \overline{D_J}$, the function assumes that every pair of two test programs carries equal weight. Doing so makes countries repeatedly across many programs carry too much weight in the nonlinear programming solution. Thus, Gustafsson subjectively builds the weight system W_j (j = 1,2, …k) to assign an equal weight to each country. Details of building the weight system could be found by his paper (2013). Thus, $z = \sum_{j=1}^{k} \overline{D_J} W_j$, where W_j are constant weights.

A nonlinear programming approach is conducted to finding transformed coefficients (a_m, β_m) so that z is minimized. Then (a_m, β_m) are used to normalize test scores of different test programs so that normalized test scores are on a common scale.

Tables

Table 1 – Investigate GDP growth

Table 1- Base Regression - Investigate determinants of GDP growth		
	1965-1990	1990-2014
Variable	Coefficient	Coefficient
Initial level of log real GDP per capita	-0.0006	0.0031
	(0.002)	(0.002)
Initial level of male schooling	-0.0041	-0.0040
	(0.005)	(0.003)
Initial level of female schooling	-0.0035	0.0042
	(0.005)	(0.002)
Log average life expectancy	-0.0091	0.0004
	(0.007)	(0.006)
Average ratio of government consumption to real GDP	-0.0011	-0.0005
	(0.000)	(0.000)
Rule of law index	0.0034	0.0084
	(0.003)	(0.003)
Voice and accountability index	-0.0134	-0.0127
	(0.005)	(0.003)
Adjusted R^2	0.741	0.714
Observations	154	241

Table 2 – The correlation between years of schooling and GDP growth

Table 2- Uncover the correlation between years of schooling and GDP growth during 2000-2014		
	IV estimates	OLS estimates
Variable	Coefficient	Coefficient
Initial level of male schooling	0.0366	-0.004
	(0.018)	(0.003)
Initial level of female schooling	-0.0384	0.0042
	(0.019)	(0.002)

Table 3 – Investigate TFP growth

Table 3- Investigate TFP growth during 2000-2014		
Variable	Coefficient	Coefficient
Initial level of log real GDP per capita	0.012	0.0095
	(0.004)	0.004
Initial level of male schooling	0.0038	0.0017
	(0.001)	(0.001)
Log average fertility rate	-0.0249	-0.0155
	0.006	(0.007)
Log average life expectancy	-0.0344	-0.0363
	0.012	0.012
Initial level of math test scores		0.0001
		(0.000)
Voice and accountability index	-0.0093	-0.008
	(0.004)	(0.004)
Adjusted R^2	0.324	0.351
Observations	186	186

Table 4 – Endogeneity of the initial level of female schooling

Table 4- Test for endogeneity of the initial level of female schooling	
	1990-2014
Variable	Coefficient
Residuals	0.0434
	(0.019)
Initial level of log real GDP per capita	-0.0006
	(0.002)
Initial level of male schooling	-0.0041
	(0.005)
Initial level of female schooling	-0.0035
	(0.005)
Log average life expectancy	-0.0091
	(0.007)
Average ratio of government consumption to real GDP	-0.0011
	(0.000)
Rule of law index	0.0034
	(0.003)
Voice and accountability index	-0.0134
	(0.005)
Adjusted R^2	0.724
Observations	186

Table 5 – The correlation between female schooling and its instrumental variable

Table 5- The correlation between female schooling and children ratio	
	1990-2014
Variable	Coefficient
Initial level of log real GDP per capita	-0.0457
	(0.036)
Initial level of male schooling	0.9363
	0.024
Children ratio	-0.0283
	(0.010)
Log average life expectancy	0.2048
	(0.112)
Average ratio of government consumption to real GDP	0.0111
	(0.006)
Rule of law index	-0.1247
	(0.060)
Voice and accountability index	0.079
	(0.061)
Adjusted R^2	0.977
Observations	186

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