A Revisit to Augmented Solow Model

Does Augmented Solow Model Explains Income Differences with Recent Economic Data?

A Research Paper presented by:

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Indonesia

in partial fulfilment of the requirements for obtaining the degree of

MASTER OF ARTS IN DEVELOPMENT STUDIES

Major:

ECD

Specialization:

Econometric Analysis of Development Policies

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The Hague, The Netherlands
December 2016

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List of Acronyms

GDP	Gross Domestic Product
IMF	International Monetary Fund
IQ	Intelligence Quotient
MRW	Mankiw Romer Weil
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
PPP	Purchase Power Parity
PWT	PENN World Table
R&D	Research and development
STATA	Stata is a general-purpose statistical software package created in 1985 by StataCorp.
UNCTAD	The United Nations Conference on Trade and Development
UNESCO	United Nations Educational, Scientific and Cultural Organization
WDI	World Development Index

Acknowledgements

For my family.

Irma Amelia, Hagia Sophia Oey.

For my parents

Papi Ito and Mami Reni.

Thank you for Nuffic NESO Indonesia and Dutch government for providing me a full scholarship to study at ISS-Erasmus University Rotterdam.

Prof. Bergeijk, you are one of the best academic supervisors I have ever met.

Abstract

In their landmark of study, Mankiw Romer and Weil (MRW) (1992) concluded that international differences in income per capita are best explained by using augmented Solow growth model. This paper attempts to replicate their job by using latest data, and with a touch of Asia countries as part of the samples. The initial results confirmed the findings by the original authors, however, the results with latest data update show a different pattern from the original paper. Some coefficients' magnitude become much stronger compared with what MRW and Textbook Solow Model suggested.

Relevance to Development Studies

Often criticized that most development projects trapped into one measurements only, the measurement of economic growth. Sometimes people overlook that development studies is a multidisciplinary study, and economic sector is one of the disciplines in development studies. This study revisited an influential literature and theory that explained economic growth in cross-country analysis. This study assessed the study with identical theory and methodology with latest data after 25 years of data changes since the study by Mankiw Romer Weil (MRW) (1992) published. Since the publication, the assumptions of economic data and the way economic data created are always changing.

Development economists are obsessed on how to increase someone's income and how to increase quality of life. The theory to explain income differences and economic growth used in this research paper is widely used in many studies, and policy decision making. Furthermore, the theory of Solow model and augmented Solow model influences the epistemology of development and how people see the economy. It is a model of capital accumulation in a pure production economy. It works by assessed that savings rate or investment rate has long run impact on income per capita.

The replication study aims to check on the robustness of the theory of exogenous growth theory by Solow, and further augmented Solow model by MRW. The study is influential and affects many academic researchers, as well as policy makers. By revisiting the study with latest data, this study will observe whether the original study is still valid and reliable. This study provides the readers a rich information about replication of a study, exogenous economic growth, and how data changes affect a result of a study.

Keywords

Growth theory, exogenous growth theory, replication, revisit, Asia, augmented Solow model, Solow model, convergence, divergence, macroeconomic, investment rate, population growth rate, human capital, physical capital, labour growth, working age population

Chapter 1 . Introduction

1.1. Solow Model and Augmented Solow Model

In a classic paper by Robert Solow (1956), he introduced a study of economic growth by assuming a standard neoclassical production function with decreasing returns to capital. His study if further taking rates of saving and population growth exogenously, moreover, he presented that rates of saving and population determine the steady-state level of income per capita. The conclusion of his study is straight forward, the higher the rate of savings or investments rate, the richer the country. The higher the rate of population growth, the poorer the country. Later, Mankiw Romer Weil (1992) in their influential paper took Robert Solow seriously, and tested the theory into empirical evidences. They built a prediction based on Solow model based on the data from 1960-1985.

MRW built few steps to test Solow model in their paper, starting from the original model, then adding human capital in the equation, testing the endogenous growth and convergence, lastly, they put interest rate differentials and capital movement. In their important conclusion of the study, they found out that Solow model provides consistent results with the empirical evidence for the first approximation. They also noted that more than half of the cross-country variation in income per capita was successfully explained by rate of saving and population growth. However, they also noted, while the first model correctly predicts the direction of the effects of savings and population growth, the magnitudes was still a puzzle. Their empirical evidence found out that the magnitude of the effect of savings and population growth on income are too large.

In their second model, they put human capital in the calculation, as well as physical capital. They used a proxy of human-capital accumulation as an additional independent variable in their regressions. Adding human capital lowers the magnitude of the effects of the rate of savings and population growth to almost the same with estimated augmented Solow model. MRW claimed that Augmented Solow model provides an almost complete description of why some countries are richer, and the others are poorer. Moreover, they also reported that their study show that Solow growth model is a complete theory of growth, and gives better answer to the question why some countries are poorer and some are richer, compared to endogenous growth theory.

This paper takes Robert Solow in his 1956 study and Mankiw Romer Weil in their 1992 study seriously. Testing on the robustness of the model and put it in the latest data is the goal of this paper. Later, in this research paper will use Asia sample to provide a little touch on how a different sample demographic change the statistical power and the results entirely.

1.2. Research Questions

The main research question of this research paper is:

"Does Augmented Solow Model Explains Income Differences with Recent Economic Data?"

This research paper also tried to answer below sub-questions:

1. Does Solow model and Augmented Solow model explain income differences in Asia countries?
2. Does the magnitude of investment rate and population rate show the same rate like the original study?
3. Do the cross-country samples in Non-oil, Intermediate and Asia have the tendency towards convergence?
4. Does the convergence rate in the original study by MRW similar with convergence rate in this study?

1.3. Study Limitation

In defining study limitation during the creation of this study, the limitation is divided into three groups. It includes study design limitations, impact limitations, and statistical/data limitations.

1.3.1. Study Design Limitation

This study used Solow Model as its basic theory. Solow model viewed as exogenous growth theory, and this study follows all the limitation created by exogenous growth theory. In addition, this study follows almost all of the assumptions made by MRW in their study and further discussed in Chapter 2 and

Chapter 3. One of the most important parts of the study is structural economic data changes since the study was created with using 1985 economic data.

1.3.2. Impact Limitation

In choosing the cross-country samples, MRW excluded more than 90 countries, including China, Vietnam, Middle eastern countries, Oceania countries, and smaller countries. Therefore, the impact of this study has a strong similarity in country demographics. Therefore, this study has strong population focus and population focus.

1.3.3. Statistical / Data Limitation

In mining the data, it is almost impossible to access completely updated identical data with what MRW had in 1992. Economic data is always changing, and the assumptions change all the time. Therefore, this study uses various different data sources in replicating the study by MRW in 1992. In providing the empirical results, this study used multilinear regression (OLS) and treated one country as one sample, despite the size of the economy and the influential level of the country. In other words, in this study countries with gigantic economy like USA, Canada and Japan are treated the same with countries with smaller economy like Burkina Faso, Ethiopia, or Bangladesh.

1.4. Why is this study important?

When we talk about development, one of the key factors in measuring development is economic sector. Currently, most of the economist measure development in economic sector by using Gross Domestic Product (GDP). In their paper, MRW used GDP and other macroeconomic variables. GDP itself is highly criticized by researchers, as Coyle (2015) mentioned "We tend to think about GDP as if it's a natural object. It's like a mountain, and we have methods of measuring it that are better or worse and more or less accurate. But there is a thing there to be measured. And that's not just true with the economy: There's no natural entity called GDP in the universe.". Moreover, measuring GDP can

be tricky, and one of the most important thing to remember is that GDP is an idea, not an object. How to measure GDP and other macroeconomic measurements may change over the time.

Along the history, how a country measure GDP may change its figure entirely. For example, in 1980s Italy counted black-market and many informal jobs into its GDP figure. Suddenly, in overnight Italy's economy was bigger than United Kingdom's economy. The event was famous as "Il Sorpasso". Another recent and famous example is the United States of America, in 2013 they changed the way they calculate their economy. A methodology that called by some economist as hedonic adjustment (quality adjusted index) made the US economy $500 billion bigger instantly. Therefore, this study becoming important to see, the fact that it has been more than 20 years since the original paper written. The way countries calculated their economy back then in 1960s until 1980s, and a comparison with latest data will be interesting to see.

In order to provide answer regarding the questions of this research, this research replicates the study from MRW (1992). MRW provides a framework on explain cross-country income variation, growth and convergence by using Solow model as the main theory. Variation in income output per person across countries have been used in recent years to produce doubt on growth theory. This study will test on growth frameworks elaborated by MRW, whether it explains income variation with latest data. In addition, by replicating MRW's paper, we will be able to test the methodology in explaining income and growth in different countries with latest data.

Chapter 2 . Academic Literatures

2.1. Growth theory

What constitutes economic growth? What causes one country is richer than another? Do natural resources abundances provide better economic growth? Do open economies grow more rapidly than closed economy? In terms of economy openness, world is now strongly biased with favouring trade liberalization, mostly due to availability of various studies showing that outward-oriented economies have consistent higher growth compared to inward-oriented countries. Another factor influenced was due to failures of import-substitution strategy, especially in 1980s. Rodrik (1999) asserts that "just as the advantages of import-substitution policies were overstated in an earlier era, today the benefits of openness are oversold routinely in the policy-relevant literature and in the publications of the World Bank and the IMF."

Trade openness and its effect on economic growth is considered arduous, and most of the studies show a mixed result on trade liberalization effect. Even though there are many studies available about positive correlation between trade flows and economic growth, but the effect of trade openness and growth is still questionable. In addition, empirical studies define trade openness in a various way as well. It is often a problem between researchers to define a standardized definition of trade openness.

There are various researches investigated what caused economic growth and income in one country is better or worse than the others. Many researchers tried to connect economic growth with trade (Yanikkaya, 2003; Makki and Somwaru, 2004; Rodriguez and Rodrik, D, 2001; Johnson, 2013), natural resources abundances (Papyrakis and Gerlagh, 2004; Sachs and Warner, 1995), institutions (Glaeser *et al*, 2004), population growth (Simon, 1986), and many other factors. It is still considered as a puzzle by researchers on what to caused economic growth, and why some countries had better economy compared to the others.

Previous studies with international trade theory already examined static gains and losses from trade restrictions. But, international trade theory explains lack of guidelines on the effect of international trade on economic growth and technical progress (Yanikkaya, 2003). However, new trade theory explains that gains from trade sourced from various basic causes. Those causes included comparative advantage differences, and economy-wide increasing return. A

study by Papyrakis and Gerlagh (2004) discusses about resources abundances, and innovation in relation with economic growth, which they assert that work effort, innovation, and production are negatively affected by resource abundances.

Different economic growth in East Asia, and Latin American countries have been a hot topic to discuss in regard to economic growth. East Asia focuses on high added value manufacturing products, and focuses on export-promotion policy, while Latin America focused on producing primary products and raw materials. East Asian countries had higher economic compared to Latin American countries. Therefore, many studies since the late 1970s examined the relationships between trade liberalization and economic growth.

New growth theory or endogenous growth theory has provided essential insights into understanding of the correlation between trade and growth (Romer, 1994). Since it incorporates technology, and research & development inside its equation, it explains why country with advanced technology trade to its partner. Further, innovation from R&D drives the increasing return from trading (Krugman, 1979), provides bigger market for countries with innovation, and explains about labor and capital mobility (Dollar, 1986). Moreover, trade allows developing countries to imitate new technologies from developed world, and access to intermediate goods, which is vital to their development process.

There have been arguments that developing countries receive more benefits by trading with developed world, and there will be convergence in the future. This explains by classical convergence empirical studies by using Solow-Swan model (Sala-i-martin, 1996), with main hypotheses that richer countries will have slower growth compared to poorer countries because of diminishing return of investment rate. Further, Mankiw, Romer, and Weil (1992) (MRW) made a linear model to introduce the logarithm of income per capita at the beginning of growth period as a measure of distance from a steady state. MRW work has inspired many studies regarding economic growth later (Brumm, 1996; Cohen, 1996; Islam, 1995; Lee *et al*, 1997; Nonneman and Vandhout, 1996; Sala-i-martin, 1996; Temple, 1998), including this study.

A key assumption made by MRW in the beginning is all countries started with the same rate of techological level. Technological rate set up by MRW does not country specific. Furthermore, the assumption of similar technology growth means that all variations in country growth must be elaborated by variation in

countries' distances from steady state and by the rate of decrease of returns to capital.

Poor countries experience a huge technology gap with developed countries, depends on their absorbing ability, they can grow faster if they have technology transfer. Some empirical paper and studies show that the key force to convergence is by technology transfer from developed countries to poor countries (Abramovitz, 1986; Baumol, 1986; Dowrick & Nguyen, 1989). Moreover, some studies also emphasized the importance of R&D in a country and the spillover effect of it (Fagerberg, 1994; Coe & Helpman, 1995). Rivera-batiz & Romer (1990) and Aghion & Howitt (1998) assert that country specific factors, such as market structure and R&D spending/policies affect long run technological growth. Therefore, Howitt (2000) incorporates international technological transfer in his endogenous growth study. Furthermore, he implies that short run growth rates influenced by technological catch-up, while in the long run growth rates are equalized between countries.

Classical convergence theory or exogenous growth theory may differ fundamentally with technological catch up theory or endogenous growth theory. However, in terms of estimating empirical questions, both are often using similar approaches. Both theories often contain log of initial GDP per capita. MRW showed that log of initial GDP per capita represents the distance a country from its steady state. Technology catch up model which presented by Stokey (1994) and Temple (1999) showed as the proxy of technology gap. They argue that conditional economic convergence as the effect of technology catching up.

Dowrick and Rogers (2002) exchanged investment data in MRW model to capital stock data. They claimed to be able to get a straight estimation of the output-capital elasticity and the indicated rate of classical convergence. They firstly tested they hypotheses of common technology in Sollow-Swan model, then test both classical and technological convergence. Furthermore, they test on the function of human capital in enabling faster technological transfer. They assert that systematic technological catch up and country-specific factors are important variables in explaining technological progress. In the long run, technological progress explains differences in income per capita accross countries.

Many studies already tried to replicate or revisit what MRW did (Canarella and Pollard, 2011; DelVecchio, 2007 and 2015; Temple, 1998; Nonneman and Vanhoudt, 1996; Ding and Knight, 2009). Some of the study tested Augmented

Solow Model with specific region, however until this study is written a revisit or replication with countries in Asia as the sample was not found. Ding and Knight (2009) tested Augmented Solow Model with China as the sample, whether the theory explains China's economy rapid growth. Some study critically contested the definition of human capital that MRW used (Ram, 2007; Knowles and Owen, 1995). Ram (2007) used IQ to define human capital instead of high school attendance, while Knowles and Owen (1995) used health capital and life expectancy for human capital proxy. From previous replications and revisits it is concluded that Solow Model and Augmented Solow Model are still influential until present time.

In his paper on testing the robustness of augmented Solow model, Temple (1998) asserts that cross-country growth analysis often put the countries in different level of analysis. He criticized that the model that MRW made was a crude estimation to the underlying data-generating process. In the regression, he used different cross-country samples and he put region in the equation, such as Africa, Latin America, East Asia. Which this study treats region as a sample instead of independent variable. Finally, he tested on the parameter heterogeneity and outliers on the data that MRW used. Furthermore, he found out in his robustness test that the model runs moderately well, except for OECD sample.

2.2. Neo Classical Growth Theory / Solow Model

Neo-classical growth theory has explained a reasonable job on explaining a broad patterns of economic changes across different geographic positions. The theory measure growth by looking through the lens of an aggregate production function. The aggregate production functions explain about the total output of an economy in relation to the aggregate amounts of capital, both human and physical, and labor. Some later theories include the simple measure of the level of technology in the economy as a whole.

In paper by Mankiw Romer Weil (1992), they took Robert Sollow seriously. Since this paper takes MRW seriously, therefore this paper uses also Sollow model in explaining growth. According to Sollow model, rates of population growth, technological progress and rates of savings are assumed to be similar or exogenous. Main two variables in explaining an output are capital and labor,

which are paid their marginal products. In MRW model, the adopt Cobb-Douglas production function, formally the equation is presented as:

$$Y(t) = K(t)^{\alpha}(A(t)L(t))^{1-\alpha} \qquad 0 < \alpha < 1.$$

Where, Y explains total output at time (t), K refers to total capital, L represents Labor, and A is the level of technology. The aggregate production function counts both physically exist and not exist, because it is a convenient construct. Production function is meant to be associated with people. In the original model, Labor and Technology is assumed to grow exogenously at the rate of *n* (rate of labor growth) and g (rate of technology growth):

$$L(t) = L(0)e^{nt}$$
$$A(t) = A(0)e^{gt}.$$

Sollow model uses *k* as the stock of capital per effective unit of labor, where *k* is equal to total capital (K) divided by level of technology (A) and total labor (L), *k*= K/AL. Furthermore, *y* is defined as the level of output per effective unit of labor, where *y* is equal to total output (Y) divided by level of technology (A) and total labor (L), *y* = Y/AL. The relationships of *k* are written as,

$$\dot{k}(t) = sy(t) - (n + g + \delta)k(t)$$
$$= sk(t)^{\alpha} - (n + g + \delta)k(t),$$

In the equation, d explains about rate of depreciation. The equation above suggests that *k* converge to a steady-state value *k** defined by $sk^{*\alpha} = (n+g+d)k^*$, or $k^* = [s/(n+g+d)]^{1/(1-\alpha)}$. In this equation, capital labor ratio is positively related to the rate of savings and negatively related to the rate of population growth.

Solow's central prediction was on the relationships on savings and population growth on real income. Therefore, we substitute and take log for equation $k^* = [s/(n+g+d)]^{1/(1-\alpha)}$ to production function $Y(t) = K(t)^{\alpha}(A(t)L(t))^{1-\alpha}$, $0<\alpha<1$. Long term income per capita explained as:

$$\ln\left[\frac{Y(t)}{L(t)}\right] = \ln A(0) + gt + \frac{\alpha}{1-\alpha}\ln(s) - \frac{\alpha}{1-\alpha}\ln(n+g+\delta).$$

In formulating the model, MRW assume that capital share in income (α) is about one-third, and assume savings rate as about 0.5 and elasticity (n+g+d) as -0.5. To answer their basic empirical specification, they used below equation:

$$\ln\left(\frac{Y}{L}\right) = a + \frac{\alpha}{1-\alpha}\ln(s) - \frac{\alpha}{1-\alpha}\ln(n+g+\delta) + \epsilon.$$

Some assumptions are made, such as time = 0 for simplicity, and the rates of saving and population growth are independent of country-specific factors shifting the production function.

In their next chapter of the study, they put human capital in the equation to test on the normalization of the magnitude. They write the equation of production function with human capital (H) as follows:

$$Y(t) = K(t)^{\alpha}H(t)^{\beta}(A(t)L(t))^{1-\alpha-\beta},$$

The evolution of the economy is explained by

$$\dot{k}(t) = s_k y(t) - (n + g + \delta)k(t),$$
$$\dot{h}(t) = s_h y(t) - (n + g + \delta)h(t),$$

Where, s_k explains the fraction of income invested in physical capital, and s_h explains the fraction invested in human capital. In the equation y = Y/AL, k = K/AL. and h = H/AL are quantities per effective unit of labour. They assume that same production function applies to physical capital, human capital, and consumption. In other words, they assume a perfect movement of capital from one form to another. Another assumption is $\alpha+\beta$ is less than 1, implies that there are decreasing returns to all capital. According to them, $\alpha+\beta = 1$ may cause no steady state of the model. For convergence and steady state, they define by:

$$k^* = \left(\frac{s_k^{1-\beta}s_h^{\beta}}{n + g + \delta}\right)^{1/(1-\alpha-\beta)}$$

$$h^* = \left(\frac{s_k^{\alpha}s_h^{1-\alpha}}{n + g + \delta}\right)^{1/(1-\alpha-\beta)}$$

Substituting above equation to the production function with human capital and put it in logarithmic form will explain how income per capita depends on population growth, accumulation of physical and human capital:

$$\ln\left[\frac{Y(t)}{L(t)}\right] = \ln A(0) + gt - \frac{\alpha + \beta}{1 - \alpha - \beta}\ln(n + g + \delta) + \frac{\alpha}{1 - \alpha - \beta}\ln(s_k) + \frac{\beta}{1 - \alpha - \beta}\ln(s_h).$$

The expected coefficients magnitude from the equation is about 1/3 for α and for β is between 1/3 to ½ based on the theory built by MRW and Textbook Solow model. Alternative approach to take account the role of human capital in determining income:

$$\ln\left[\frac{Y(t)}{L(t)}\right] = \ln A(0) + gt + \frac{\alpha}{1 - \alpha}\ln(s_k) - \frac{\alpha}{1 - \alpha}\ln(n + g + \delta) + \frac{\beta}{1 - \alpha}\ln(h^*).$$

This equation shows that human capital is part of the error term. Similar with Textbook Solow model, because saving rate/investment rate, and working age population growth rates influence h^*. MRW expected that human capital is positively correlated with saving/investment rate and negatively correlated with working age population growth. Similar with what MRW questioned in their paper, this paper also wants to know whether human capital linked more to rate of accumulation or to the level of human capital.

Chapter 3 . Methodology and Data

4.1. Methodology

This research paper is based on a replication of an influential paper in 1990s by Mankiw Romer Weil (1992) regarding growth theory and their analysis on the use of Solow model in explaining growth. A replication in research is an important component of academic processes (Brandt *et al.* 2014; Asendorpf *et al.*, 2013; Jasny, Chin, Chong, & Vignieri, 2011; Schmidt, 2009). According to them, replication paper includes repeating a study that considered important and influential by using the same methodology but with different subjects, time value and experimenters.

Researchers in creating a replication study applies the existing theory to a new situation with the aim of concluding generalizability to different subjects, time period, locations, or other variables in the same context of study. A replication study may be utilized as assurance that the results in previous study are reliable, valid, and robust. In terms of social science, replication study is a common tool to provide a solution for existing problems and solutions. The study by MRW (1992) is an influential and an important paper, this research paper will contribute to provide new information by applying the same methodology with the original paper.

An adequate data and information to provide replication for MRW's study is widely available and constantly updated by several organizations, i.e. The World Bank, University of California and University of Groningen, OECD, the United Nations, and many more. To provide a close replication, an original dataset source is used in this study as MRW used in their study in 1980s-1990s. This study will provide not only one dataset source, but two datasets to provide a thorough examination and replication of the study. This paper is not merely a replication to put new data to an existing methodology, but also a critical paper for the study by MRW. By replicating the study, a thorough examination to the paper is performed.

Replication study may result as a controversial discussion, or even a failure (Brandt *et al*, 2014). However, a failed replication of existing study is not merely a mistake of the researcher alone, it may be caused by several reasons. One of the reasons is a doubt on the accuracy of the entire original study, it may suggest that an important component of a popular theory is potentially erroneous. Also,

new findings may be less robust compared to the original study. Other reasons including misinterpretation of methodology, corrupted data, and so on.

A successful replication will give readers greater confidence in the accuracy of the predicted effects from the original paper. Moreover, a successful replication attempts help to estimate the magnitude of particular effect, and helps readers to understand the boundary of the existing study. Therefore, replications are crucial for theoretical development by confirmation or disconfirmation of results. The obvious goal to replicate a study is by testing the assumed underlying theoretical process from existing study. The testing includes checking the magnitude of the new results compared with existing results, and test the robustness of the data by recreating similar methodology as faithfully as possible.

According to Brandt *et al* (2014), the replication recipes in academic literature need to accurately replicate the original methodology of the original paper, and test the robustness of the effect of the new study outside the lab of origin. Moreover, they suggested that a replication fall into five steps:

1. "Carefully defining the effects and methods that the researcher intends to replicate;
2. Following as exactly as possible the methods of the original study (including participant recruitment, instructions, stimuli, measures, procedures, and analyses);
3. Having high statistical power;
4. Making complete details about the replication available, so that interested experts can fully evaluate the replication attempt (or attempt another replication themselves);
5. Evaluating replication results," (Brandt *et al*., 2014).

More than five steps they suggested, they also provided "36-questions guide to replication recipe". The framework of "36-questions guide to replication recipe" is used in this research paper to provide a solid replication study. The "36-questions guide to replication recipe" includes:

"The Nature of the Effect
1. Verbal description of the effect I am trying to replicate:
2. It is important to replicate this effect because:
3. The effect size of the effect I am trying to replicate is:
4. The confidence interval of the original effect is:

5. The sample size of the original effect is:
6. Where was the original study conducted? (e.g., lab, in the field, online)
7. What country/region was the original study conducted in?
8. What kind of sample did the original study use? (e.g., student, Mturk, representative)
9. Was the original study conducted with paper-and-pencil surveys, on a computer, or something else?
Designing the Replication Study
10. Are the original materials for the study available from the author?
a. If not, are the original materials for the study available elsewhere (e.g., previously published scales)?
b. If the original materials are not available from the author or elsewhere, how were the materials created for the replication attempt?
11. I know that assumptions (e.g., about the meaning of the stimuli) in the original study
will also hold in my replication because:
12. Location of the experimenter during data collection:
13. Experimenter knowledge of participant experimental condition:
14. Experimenter knowledge of overall hypotheses:
15. My target sample size is:
16. The rationale for my sample size is:
Documenting Differences between the Original and Replication Study
For each part of the study indicate whether the replication study is Exact, Close, or Conceptually Different
compared to the original study. Then, justify the rating.
17. The similarities/differences in the instructions are: [Exact | Close | Different]
18. The similarities/differences in the measures are: [Exact | Close | Different]
19. The similarities/differences in the stimuli are: [Exact | Close | Different]
20. The similarities/differences in the procedure are: [Exact | Close | Different]
21. The similarities/differences in the location (e.g., lab vs. online; alone vs. in groups) are: [Exact | Close | Different]

22. The similarities/differences in remuneration are: [Exact | Close | Different]
23. The similarities/differences between participant populations are: [Exact | Close | Different]
24. What differences between the original study and your study might be expected to influence the size and/or direction of the effect?
25. I have taken the following steps to test whether the differences listed in #24 will influence the outcome of my replication attempt:
Analysis and Replication Evaluation
26. My exclusion criteria are (e.g., handling outliers, removing participants from analysis):
27. My analysis plan is (justify differences from the original):
28. A successful replication is defined as:
Registering the Replication Attempt
29. The finalized materials, procedures, analysis plan etc of the replication are registered here:
Reporting the Replication
30. The effect size of the replication is:
31. The confidence interval of the replication effect size is:
32. The replication effect size [is/is not] (circle one) significantly different from the original effect size?
33. I judge the replication to be a(n) [success/informative failure to replicate/practical failure to
replicate/inconclusive] (circle one) because:
34. Interested experts can obtain my data and syntax here:
35. All of the analyses were reported in the report or are available here:
36. The limitations of my replication study are:" (Brandt et al, 2014)

The "36-questions guide to replication recipe" is a guidance to this research paper, and all of the 36 questions will be answered scattered in this research paper due to limitation of words. In replicating the work by MRW, not all parts in the paper will be examined and replicated. There are six chapters in the paper, including introduction, estimating textbook Solow model, adding human capital

accumulation to the Solow model, endogenous growth and convergence, interest rate differentials and capital movements, and conclusions. This research paper will replicate exogenous growth model (Solow model), augmented Solow model (adding human capital accumulation to the Solow model), and to test endogenous growth and convergence. The structure of this paper and the original paper are also different, the original paper provided step by step approach in testing the theory into calculation. The replication paper combine all of findings by MRW into one chapter, with some calculation testing outside the methodology used by the original paper.

In terms of calculation, this paper use ordinary least square (OLS) following the original paper by MRW. The software used to do econometrics calculation is STATA version 13.0. Data mining is done manually from the website from each sources, and explained further in the next chapter. Data crunching, merging and appending was done in Microsoft Excel 2013. Then, finished data is exported into STATA data file to be put in the regressions. All numbers are in the form of percentage not in the form of decimals. This approach was taken to provide correct results on the logarithm results.

3.2. Data

This research used secondary data provided in the internet. In their study, MRW (1992) used PENN World Table by Summers and Heston (1988). Since this research takes MRW seriously, it is essential for this research to use PENN World Table. This research uses PWT version 8.1 instead of 9.0 or 9.1 due to data error concern at the moment this paper was written. PWT version 8.1 provides observation from 1960 until 2011. Furthermore, a study by using of different datasets by van Bergeijk (1998) in testing MRW (1992) calculation has shown a slight difference in the empirical results. Therefore, to avoid measurement error by using only one dataset, another dataset from World Development Index (WDI) is used as comparison. The WDI dataset used is version December 2013, to provide an equal comparison with PWT 8.1.

The variable used by MRW in their paper includes list of 121 countries with population data, GDP growth data, investment rate, and human capital data. MRW noted that they provided a list of 121 countries due to lack of information from other countries at that time. The data is annual and cover the period of 1960-1985. They defined working age population as 15-64 years old, and human

capital as percentage of working age population in secondary school. Furthermore, the investment rate (I/Y) defined as share of all real government investment divided by real GDP, and income per capita as real GDP divided by working-age population in the same year. They also divided 121 countries into 3 groups, OECD countries, Non-Oil Countries, and Intermediate countries.

Original MRW data can be accessed in www.mrw.gdt (as of 03 Nov 2016). Compared to MRW, in constructing this research paper dataset, slight changes were made due to data unavailability or data structure changes. Below are the changes:

a. In calculating the dependent variable, GDP per capita PPP (Constant US$ 2005), it follows the definition of working age population as the denominator for both datasets. The number of working age population is taken from WDI, following the original paper of MRW. By using working age population as the denominator instead of total population, the nominal amount is higher compared to GDP per capita for total population. After divided total GDP PPP (constant 2005 US$) with working age population, then the results were put in logarithmic form.

b. In constructing population growth, data from World Development Index is used. It uses the exact definition of MRW, by using working age population 15-65 years old. PENN World Table only provide total population. In their paper, MRW also used working age population data from World Bank. The population growth calculation is "(population year x+1 – population year x) divided by population year x". Then, the results of population growth summed up, and divided by the number of observation.

c. The dummy variable of OECD in this paper is removed, while one more variable added, Asia. The dataset explains which countries are located geographically in Asia. In summary, there are three dummy variables, intermediate and non-oil countries follow the data from MRW, while Asia by using United Nation data. The reason of removal the OECD countries is due to small amount of countries in the observations. This paper aims for high statistical power. As MRW noted in their paper, OECD sample sometimes provide insignificant statistical power in the regression results.

d. Data for variable investment might be tricky, since MRW used data from PENN World Table for real investment divided by real GDP. While, in PWT version 8.1 dataset, the investment variable is not available. The only data variable in relation with government investment is government consumption data. However, government consumption also includes government investment. Therefore, this research uses investment data in the form Gross Fixed Capital Formation share in GDP. The data is originated from UNSTATS (unstats.un.org). The data is available since 1970 until 2014 when this research paper was written. There is a limitation of knowing investment data from 1960-1969. Investment data is calculated by averaging yearly data of the share of investment in GDP.

e. Another significant differences in dataset construction is variable SCHOOL for the augmented model. Variable SCHOOL refers to human capital. To fully implement the model, which human capital is one of the variables, they restrict human capital in the form of education. In their study, MRW uses proxy to define SCHOOL as the percentage of working age population in secondary school. They mined the data from UNESCO yearbook. It is debatable on how to define human capital, and to take education as the only variable. MRW also made a note on the variable they choose as "clearly imperfect: the age ranges in the two data series are not exactly the same, the variable does not include the input of teachers, and it completely ignores primary and higher education" (Mankiw *et al.* (pp. 419), 1992). Despite of the imperfection of SCHOOL definition, this research also uses education as the proxy to define human capital. SCHOOL defined in this research as percentage of enrollment in secondary education compared to total population. Both variables are taken from World Development Index by World Bank. The calculation for this independent variable is take an average of enrollment in secondary education divided by total population by year.

f. The assumption of 'g+d' is following the assumption made by MRW, 0.05. Therefore, the growth rate of depreciation and technology is counted exogenously at the rate of 0.05. In doing the regression the growth rate of labor, technology and population is summed up together, forming 0.05 plus population growth rate or (n+0.05). The number 0.05

might be too big for several countries, and also too small for several countries. If in their paper, MRW noted the changes of the assumption caused little effect on the empirical results, I would disagree. The assumption of 0.05 is due to the growth model explained as exogenous growth model.

After constructing all the dependent and independent variables, the average of each country were made according to the observation period. The first dataset is 1960-1985, this is to replicate the work done by MRW, to test on the study validity. Second dataset is 1960-2011, also a replication from MRW with extended observation year. Third and fourth dataset is made based on the fact that many countries started to have reliable economic data after 1991, especially in UNCTAD data. In addition, the study of MRW published in 1992, therefore 1992/1993 is the cutline for the years of observation. Hence, this study shows the differences before/after MRW published their paper. Furthermore, all data and STATA coding used in this research paper will be published publicly.

Chapter 4 . Results

This chapter is organized as follows:

4.1. First part is to check the which dataset to use in the replication model. In this sub-chapter is simply to replicate the exact MRW's first original regression for textbook Solow Model and Augmented Solow Model during 1960-1985 with latest dataset.

4.2. MRW's methodology is replicated to latest data. From original period 1960-1985, to full period 1960-2011. Next, period 1960-1992, and 1993-2011 to check the theory before/after the study published.

4.2.1. Replication of textbook Solow model with latest data and different time period

4.2.2. Replication of Augmented Solow model with latest data and different time period

4.3. Replication of convergence is divided into 4 parts:

4.3.1. Unconditional Convergence, just to check whether a group of cross-country moves into convergence or not. Latest data is compared with original study results.

4.3.2. Conditional Convergence with Textbook Solow Model, to check whether basic Solow Model can explain the convergence between a group of cross-country.

4.3.3. Conditional Convergence with Augmented Solow Model, by putting human capital in the equation. To check whether putting human capital in the equation provides better fit to the model.

4.3.4. Conditional Convergence with Augmented Solow Model – Restricted Regression, to check on the magnitude provided by the variables. Whether it changes over time or not.

4.4. Replicate all the methodologies with Asia samples

4.4.1. Replicate basic textbook Solow Model with Asia samples

4.4.2. Replicate Augmented Solow Model with Asia samples

4.4.3. Replicated Convergence with Asia samples:

4.4.3.1. Unconditional convergence

4.4.3.2. Conditional convergence textbook Solow Model

4.4.3.3. Conditional convergence augmented Solow model

4.4.3.4. Conditional convergence augmented Solow model, restricted regression

4.1. Dataset to Use

After more than 20 years since MRW published their paper, there have been massive changes in data sources, including the assumptions and methodologies from the data sources. Therefore, deciding to use which dataset in this study is essential. This study started with two datasets with similar variables. The first one is PENN World Table (PWT), which MRW used in their original paper. This research uses PWT version 8.1 to compare it to the second dataset. The second dataset is coming from the World Bank, World Development Indicator (WDI). In this research, WDI version December 2013 is used to provide an apple to apple comparison. It is important to note as well that, the data structure and assumptions for Penn World Table has been changed since MRW used this data for their study. It is impossible to get an identical dataset like the one that MRW used. The goals of this subchapter are to assess whether new datasets have the same trend like original study, and to pick which dataset to use in the replication.

A comparison of Textbook Solow Model between original paper by MRW (1992), PWT 8.1 and WDI December 2013 is provided below:

Table 1. Estimation of the Textbook Solow Model

Dependent Variable: Log GDP per working-age person in 1985

	Non-Oil			**Intermediate**		
	Original Paper	**PWT 8.1**	**WDI 2013**	**Original Paper**	**PWT 8.1**	**WDI 2013**
Observations	98	88	88	75	70	68
Constant	5.48	10.821	8.738	5.36	12.217	8.835
	(1.59)	(6.52)**	(5.79)**	(1.55)	(6.90)**	(5.49)**
ln(I/GDP)	1.42	1.374	2.077	1.31	1.055	2.026
	(0.14)	(5.49)**	(8.12)**	(0.17)	(3.50)**	(6.17)**
ln(n+g+d)	-1.97	-3.071	-3.128	-2.01	-3.182	-2.995
	(0.56)	(4.38)**	(5.00)**	(0.56)	(4.68)**	(5.40)**
R^2	N.A.	0.4	0.53	N.A.	0.38	0.55
Adj. R^2	0.59	0.38	0.53	0.59	0.36	0.53
Restricted Regression						
Constant	6.87	7.228	6.484	7.1	7.546	6.607
	(0.12)	(27.82)**	(24.80)**	(0.15)	(23.96)**	(21.01)**
ln(I/GDP) - ln(n+g+d)	1.48	1.615	2.246	1.43	1.492	2.305
	(0.12)	(7.03)**	(9.70)**	(0.14)	(5.64)**	(8.73)**
R^2	N.A.	0.37	0.52	N.A.	0.32	0.54
Adj. R^2	0.59	0.36	0.51	0.59	0.31	0.53
Implied α	**0.60**	**0.62**	**0.69**	**0.59**	**0.59**	**0.69**

Note: * p<0.05; ** p<0.01; number in parentheses is standard error; the original paper does not provide information about p value/t test and R-squared.

In estimating the original Solow's textbook model, both dataset explains similar trend with strong statistical results as well. However, WDI 2013 shows higher value on the R^2 and Adj. R^2, both in Non-oil samples and Intermediate Samples. It demonstrates that using WDI 2013 produces higher statistical accuracy on the regression compared to the data. Furthermore, table 1 shows a similar trend with the original paper, with all coefficients are significantly different from 0 because its p-value is 0.000, which is smaller than 0.01. Every unit increase of investment in percentage, we expect Log GDP per working age person in 1985 increase by 1.374 percent for Non-Oil PWT 8.1, and 2.077 percent for Non-Oil WDI 2013. Also, population gives a negative effect on GDP per working age person, every unit increase of population in percentage, we can expect a decrease of -3.071 percent in GDP per working age person by using PWT 8.1 for Non-oil countries, and a decrease of 3.128 percent by using WDI for Non-oil countries.

The results of this study and the original paper are both support the Solow model, there are three aspects to support this view. Firstly, the coefficients on saving and population growth are both showing the predicted sign. All variables in this study are highly significant, while there are only two out of three variables in the original paper show high significance. Secondly, the restriction that the coefficients on ln(s) and ln(n+g+d) are equal in magnitude and opposite in sign is not rejected in any of the equation. Thirdly, differences value in saving and population growth account for a large fraction of the cross-country variation in income per capita.

As MRW mentioned in their paper, a Solow model itself is not completely successful. The impacts of investment/capital and labor force growth are much larger than the model predicts. Especially for implied α, the results both for replication results show higher value compared to the study by MRW. The magnitude impact by using WDI 2013 dataset gives a much higher results on the value of α, which confirms the finding of MRW that the empirical results show a bigger magnitude effect compared to the theory. Important to see that, all variables here show a highly significant value statistically, compared to the original paper by MRW. However, the magnitude also becoming bigger for all variables. It is a pity that in their original paper, MRW did not completely provide statistically fitness measurements or model fitness measurements in their paper.

In order to manage a bigger magnitude in estimating the impact of Investment rate in textbook Solow model, MRW came out with Augmented Solow Model. The origin of augmented Solow model by MRW was to improve the value of α by putting another form of capital, human capital. By having a improved value of α, the model will fit or close with textbook Solow model. Therefore, to provide further analysis on which dataset in this paper should use, a test on augmented Solow model on the dataset is also provided below in Table 2:

Table 2. Estimation of the Augmented Solow Model

Dependent Variable: Log GDP per working-age person in 1985

	Non-Oil			**Intermediate**		
	Original Paper	**PWT 8.1**	**WDI 2013**	**Original Paper**	**PWT 8.1**	**WDI 2013**
Observations	98	86	86	75	68	66
Constant	6.89	10.736	9.364	7.81	11.399	9.031
	(1.17)	(7.94)**	(7.77)**	(1.19)	(7.29)**	(6.43)**
ln(I/GDP)	0.69	0.836	1.41	0.7	0.609	1.43
	(0.13)	(3.89)**	(6.43)**	(0.15)	(2.21)*	(4.66)**
ln(n+g+d)	-1.73	-2.379	-2.583	-1.5	-2.366	-2.427
	(0.41)	(4.08)**	(5.10)**	(0.4)	(3.80)**	(4.84)**
ln(SCHOOL)	0.66	0.581	0.559	0.73	0.663	0.603
	(0.07)	(7.06)**	(7.52)**	(0.1)	(5.05)**	(5.11)**
R^2	N.A.	0.62	0.72	N.A.	0.55	0.68
Adj. R^2	0.78	0.60	0.71	0.77	0.53	0.66
Restricted Regression						
Constant	7.86	8.752	8.072	7.97	9.123	8.162
	(0.14)	(30.08)**	(27.87)**	(0.15)	(23.87)**	(20.68)**
ln(I/GDP) - ln(n+g+d)	0.73	0.947	1.494	0.71	0.774	1.523
	(0.12)	(4.66)**	(7.26)**	(0.14)	(3.04)**	(5.66)**
ln(SCHOOL) - ln(n+g+d)	0.67	0.6	0.567	0.74	0.717	0.617
	(0.07)	(7.33)**	(7.66)**	(0.09)	(5.64)**	(5.34)**
R^2	N.A.	0.61	0.71	N.A.	0.54	0.67
Adj. R^2	0.78	0.59	0.71	0.77	0.52	0.66
Implied α	**0.31**	**0.37**	**0.49**	**0.29**	**0.31**	**0.48**
Implied β	**0.28**	**0.24**	**0.19**	**0.30**	**0.29**	**0.19**

Note: * p<0.05; ** p<0.01; number in parentheses is standard error; the original paper does not provide information about p value/t test and R-squared.

From table 2, we can see a similar trend with table 1. WDI 2013 dataset provides a higher statistical accuracy on the regression line compared to the dataset. Both models show that WDI 2013 provide higher value of R-squared. Therefore, this study use WDI 2013 in replicating the works of MRW. However, while adding human capital in the equation decreases the "anomaly" of the high

estimation results of capital/investment, and a little bit of population/labor estimation. By using WDI dataset, the estimation results for Investment/Capital and labor are exceedingly high compared to the theory and the original paper.

The implied value of α is showing the same trend of stronger value compared to the original paper. Interesting to see that in the original paper, MRW put SCHOOL variable to reduce the magnitude of α. The replication results show a similar trend, but the effect of putting human capital in the calculation to reduce α magnitude is not as impactful as the original paper by MRW. Especially for WDI 2013, the value of α is still exceedingly high after putting human capital in the equation, and left β value weaker compared to the original paper and the theory Solow model.

In deciding which dataset to use in the replication, statistical fit is the highest priority in the decision process. Even though, WDI 2013 provides a greater magnitude compared to PWT 8.1, and move further from original textbook Solow Model, it provides better statistical fitness into the model. Therefore, for replication parts, WDI 2013 is used. However, for convergence test, PWT 8.1 is used, due to dataset availability. WDI 2013 dataset ranges only from 1970s, and PWT 8.1 ranges from 1960.

4.2. Replication of Solow Model and Augmented Solow Model with recent economic data

4.2.1. Replication of textbook Solow model

In their study, MRW divided the countries into 3 groups, Non-oil, Intermediate and OECD. This study does not use OECD samples. Below is the summary of number of countries in each samples in MRW study:

Non- Oil	Intermediate	OECD	Total Countries
98 Countries	75 Countries	22 Countries	121 Countries

In their study MRW excluded many countries in the calculation. Some are oil producer countries, and countries without complete economic data. They assume that the GDP information in oil producer countries is misleading because

of oil extraction does not provide added value. Therefore, number of countries in this chapter follows the definition by MRW. However, few number of countries reduced due to various reasons. Along the years, some countries in the observation were expanded, disappeared, united, and/or separated. It is almost impossible to track all original countries in MRW's study to be included in this study.

In this study, from the original period of textbook Solow Model 1960-1985, expanded to 2011. There are four groups in this study, first group is the original study 1960-1985, then 1960-2011, 1960-1992, 1993-2011. The first regression (1960-1985) is the original textbook Solow model as presented in table 3:

Table 3. Estimation of the Textbook Solow Model 1960-1985, 1960-2011, 1960-1992, 1993-2011

Dependent Variable: Log GDP per working-age person in the end of the period

	Non-Oil				**Intermediate**			
	1960-1985	**1960-2011**	**1960-1992**	**1993-2011**	**1960-1985**	**1960-2011**	**1960-1992**	**1993-2011**
Observations	88	90	90	91	68	70	70	70
Constant	8.738	10.381	8.801	15.385	8.835	10.628	9.488	15.619
	(5.79)**	(5.71)**	(5.38)**	(10.01)**	(5.49)**	(5.24)**	(5.90)**	(8.30)**
ln(I/GDP)	2.077	2.9	2.389	1.699	2.026	2.555	2.244	1.267
	(8.12)**	(7.98)**	(8.44)**	(4.99)**	(6.17)**	(5.50)**	(6.97)**	(2.77)**
ln(n+g+d)	-3.128	-5.11	-3.629	-5.851	-2.995	-4.615	-3.65	-5.22
	(5.00)**	(8.11)**	(5.45)**	(11.96)**	(5.40)**	(7.52)**	(6.44)**	(9.12)**
R^2	0.53	0.65	0.56	0.69	0.55	0.61	0.62	0.6
Adj. R^2	0.52	0.64	0.55	0.68	0.53	0.60	0.60	0.58
Restricted Regression								
Constant	6.484	5.374	6.135	5.729	6.607	5.724	6.297	6.25
	(24.80)**	(16.33)**	(21.93)**	(16.75)**	(21.01)**	(13.95)**	(20.33)**	(13.38)**
ln(I/GDP) - ln(n+g+d)	2.246	3.535	2.61	3.168	2.305	3.348	2.632	2.853
	(9.70)**	(12.01)**	(10.35)**	(10.48)**	(8.73)**	(9.63)**	(9.96)**	(7.31)**
R^2	0.52	0.62	0.55	0.55	0.54	0.58	0.59	0.44
Adj. R^2	0.52	0.62	0.54	0.54	0.53	0.57	0.58	0.43
Implied α	**0.69**	**0.78**	**0.72**	**0.76**	**0.69**	**0.77**	**0.72**	**0.74**

Note: * $p<0.05$; ** $p<0.01$; number in parentheses is standard error;

From the regression results in table 3 with various periods, we can see a solid and steady trend in the regressions. In four different time period, all variables show statistically significant with $p<0.01$. From table 3 we can conclude that the results support Solow Model and MRW's works with different time period. Recent years, the constant of the equation increases, showing a bigger amount of GDP per capita. The value implied α in the replication with latest data show-

ing a bigger value, and go further from MRW original paper and original textbook Solow model (one-third). Implied α was calculated by (value of ln(I/GDP) - ln(n+g+d)) divided by (1+ ln(I/GDP) - ln(n+g+d)).

The magnitude of population has been bigger in recent years, showing a stronger impact of population growth to GDP per capita. Table 3 shows that population growth is stronger compared to economic / production growth. This finding fits with a classic essay by Malthus (1888), which he wrote that population grows at exponential rate, while food production grows at arithmetic rate. A strong population growth can be problematic if it outperforms increases in food production. He also wrote the connection between population growth and its relationships with happiness and income. Furthermore, Gamble (2014) asserts that the remarkable success of western economies in the past 200 years is therefore associated with strong population growth. However, population growth can be problematic if it outpaces increases in productivity. Another study by Berry (2014) claimed that GDP per capita and living standards stagnate because of a strong growth in population. However, he noticed that GDP growth would have been lower without population growth as well.

Berry (2014) divided his study of population growth and economic growth in the United Kingdom into several periods. In mid until late of 1960s, he noted that population growth matches with high economic growth. While in 1970s, population growth matches with lower economic growth. Ten years after that in 1980s until mid-1990s, population growth supports relatively high economic growth. However, after year 2000, population grows at extremely fast rate, in contrast the economy experienced severe recession and stagnation until the recovery in 2013. His study shows the relationships between population growth and economic growth in the United Kingdom alone, however his study also matches with the results of the regression in this paper.

4.2.2. Replication of augmented Solow model

Capital estimation results in the replication of textbook Solow model is still showing an exceedingly high value in this replication along different time periods. The value is even higher for period 1960-2011, but lower during 1993-2011. The share of capital in textbook Solow model is estimated to be between 1/3

and 0.4. Moreover, population/labour growth shows the similar high value estimation as capital estimation results. Also, they noticed that their original regression provided not statistically significant for OECD samples, but a statistically significant results for the other samples. Therefore, the replication of augmented Solow Model by MRW in Table 4 is interesting to see. Is it true that putting human capital in the equation will normalize the estimation of capital/investment as MRW claimed in their paper?

Table 4. Estimation of the Augmented Solow Model 1960-1985, 1960-2011, 1960-1992, 1993-2011

Dependent Variable: Log GDP per working-age person								
	Non-Oil				**Intermediate**			
	1960-1985	1960-2011	1960-1992	1993-2011	1960-1985	1960-2011	1960-1992	1993-2011
Observations	88	90	90	90	66	70	70	69
Constant	9.364	9.692	9.491	14.006	9.031	9.768	9.717	14.173
	(7.77)**	(7.10)**	(7.12)**	(9.72)**	(6.43)**	(6.31)**	(6.82)**	(8.13)**
ln(I/GDP)	1.41	1.815	1.644	1.413	1.43	1.667	1.737	1.081
	(6.43)**	(6.01)**	(6.46)**	(4.26)**	(4.66)**	(4.44)**	(5.66)**	(2.51)*
ln(n+g+d)	-2.583	-3.49	-3.058	-4.911	-2.427	-3.27	-3.194	-4.424
	(5.10)**	(6.82)**	(5.59)**	(9.57)**	(4.84)**	(6.49)**	(6.25)**	(7.80)**
ln(SCHOOL)	0.559	0.75	0.578	0.32	0.603	0.761	0.443	0.326
	(7.52)**	(8.28)**	(6.78)**	(3.48)**	(5.11)**	(7.05)**	(4.43)**	(2.96)**
R^2	0.72	0.81	0.72	0.75	0.68	0.78	0.7	0.66
Adj. R^2	0.71	0.79	0.70	0.73	0.66	0.76	0.69	0.64
Restricted Regression								
Constant	8.072	7.7	7.725	7.081	8.162	7.86	7.474	7.347
	(27.87)**	(21.71)**	(23.96)**	(17.68)**	(20.68)**	(19.06)**	(20.14)**	(14.98)**
ln(I/GDP) - ln(n+g+d)	1.494	2.014	1.777	2.198	1.523	1.926	1.985	2.052
	(7.26)**	(7.35)**	(7.51)**	(6.69)**	(5.66)**	(6.08)**	(7.35)**	(5.16)**
ln(SCHOOL) - ln(n+g+d)	0.567	0.784	0.59	0.486	0.617	0.798	0.467	0.461
	(7.66)**	(8.89)**	(6.92)**	(5.04)**	(5.34)**	(7.62)**	(4.65)**	(3.96)**
R^2	0.71	0.8	0.71	0.67	0.67	0.77	0.69	0.58
Adj. R^2	0.70	0.79	0.70	0.66	0.66	0.77	0.68	0.56
Implied α	**0.49**	**0.53**	**0.53**	**0.59**	**0.49**	**0.52**	**0.58**	**0.58**
Implied β	**0.19**	**0.21**	**0.18**	**0.13**	**0.19**	**0.21**	**0.14**	**0.13**

* p<0.05; ** p<0.01; number in parentheses is standard error;

In the replication by using WDI 2013 with latest dataset, putting variable human capital (SCHOOL) in the equation successfully reduced the estimation results for capital / investments / savings variable, and population / labor variables. We can see a decrease of magnitude from the value of implied α compared with the value in Table 3. It is captivating to see, that the magnitude for all vari-

ables are generally stronger compared to the original study and the theory. Especially for the value of α and β, the values are not even close to one-third for all values. Even though, the equation shows a strong statistical fitness, but the implied value of α and β gives much stronger magnitude compared to the original paper by MRW and textbook Solow Model in Table 2.

The findings here are contradicting with the conclusion of MRW in their paper. In their original paper, they claimed that augmented Solow model normalize the magnitude of investment/savings rate to one-third, similar with what textbook Solow model suggested. However, the findings for all regression constantly reject the one-third magnitude.

4.3. Replication of Convergence

This sub-chapter replicates the next part of MRW study regarding testing of convergence. In testing convergence, MRW emphasized that Solow model does not predict convergence, but it provides a prediction that income per capita in a given country converges to country's steady state value. MRW called Solow model convergence as conditional convergence, where they calculate convergence rate as λ. According to the theory by MRW, convergence rate formula used in the calculation (lambda / λ) = -ln (1 +coefficient of "ln (GDP/capita beginning year)") / years (t). To define t (years), simply deduct the last year of observation to the beginning year of observation. In testing of convergence, dataset PWT 8.1. is used due to data availability reason. In WDI 2013 dataset, GDP data recorded since 1970-1980s in most countries. Therefore, the use of PWT 8.1. is essential to provide the amount of income in 1960.

In testing convergence, MRW did three steps. First step was testing the convergence unconditionally, just based on income in beginning year of observations compared with average economic growth. Then they tested convergence with textbook Solow model. Last step to check convergence with augmented Solow model. They claimed that Augmented Solow model provides better accuracy in predicting convergence compared to other methodologies. However, there is a problem appeared in testing convergence by looking at the original data provided by MRW in their appendix. Since this study recalculate everything on what MRW reported in their paper, a slight mistake found in their independent variable (average growth of GDP). If we take a look, the way they calculated average

growth of GDP is "(GDP in last year of observation – GDP in beginning year of observation) divided by 25 years". This study does not replicate the way MRW calculated their independent variable (average growth of GDP).

4.3.1. Unconditional Convergence

This part replicated MRW methodology in testing unconditional convergence. They argue that unconditional convergence methodology provides failures in previous studies in explaining incomes of different countries to converge. They measure convergence by looking at adjusted R-square value. Where, it ranges between 0 to 1. If the value closer to zero, it means group of countries do not converge their income, when the value closer to one, it means group of countries have a strong tendency towards converging their income.

Below is unconditional convergence replication with different time period:

Table 5. Test for unconditional convergence

Dependent Variable: Log difference GDP per working-age person End year and Beginning year

	Non Oil					**Intermediate**				
	Original Paper (1960-1985)	PWT 8.1 (1960-1985	PWT 8.1 (1960-2011)	PWT 8.1 (1960-1992)	PWT 8.1 (1993-2011	Original Paper (1960-1985)	PWT 8.1 (1960-1985)	PWT 8.1 (1960-2011)	PWT 8.1 (1960-1992)	PWT 8.1 (1993-2011
Observations	98	86	86	86	90	75	71	71	71	71
Constant	-0.266	-0.174	0.367	-0.205	0.355	0.587	0.296	0.986	0.285	0.419
	(0.380)	(0.45)	(0.64)	(0.43)	(1.81)	(0.433)	(0.67)	(1.49)	(0.51)	(1.87)
ln(GDP/capita beginning year)	0.0943	0.0777	0.062	0.091	-0.002	-0.0042	0.029	-0.003	0.04	-0.009
	(0.0496)	(1.72)	(0.92)	(1.61)	(0.11)	(0.054)	(0.57)	(0.03)	(0.62)	(0.37)
Adj. R^2	**0.03**	**0.022**	**-0.002**	**0.02**	**-0.01**	**-0.01**	**-0.0097**	**-0.0145**	**-0.0089**	**-0.0124**
t (years)	25	25	51	32	18	25	25	51	32	18
implied λ	**-0.0036**	**-0.003**	**-0.001**	**-0.002**	**0.0001**	**0.00016**	**-0.001**	**0.00005**	**-0.0012**	**0.000502**

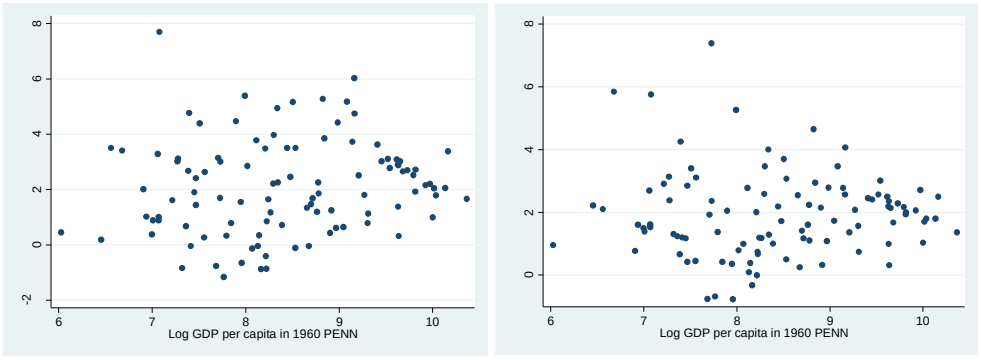
* p<0.05; ** p<0.01. Standard errors are in parenteheses. ln(GDP/capita beginning year) is GDP per working-age person in the beginning year of each regression. Original paper does not provide p value/t test.

In looking at convergence, MRW focused on the value of adjusted R^2, the bigger the value, the stronger the tendency towards convergence. While, a negative value means divergence. Interesting to see that, in testing convergence MRW does not look at each variables' p-value/t-stat. The only statistical measurements matter in here is adjusted R^2. The results in table 5 show similar trend with MRW's findings, where there is no tendency for poorer countries to grow faster on average than richer countries. Both group of countries are showing

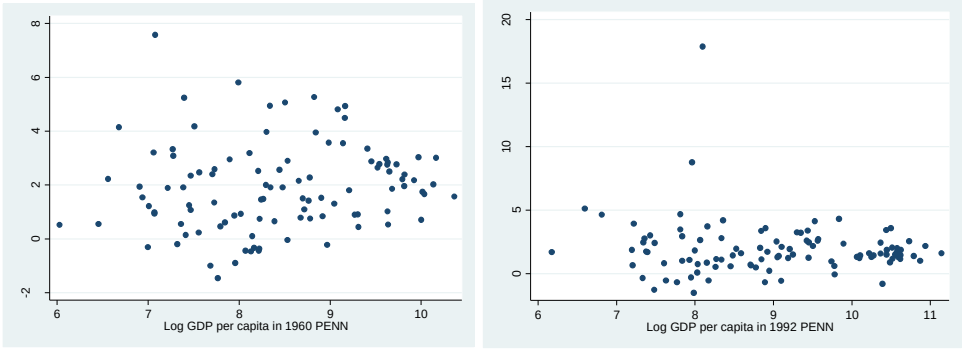
similar results, even, some results showing divergence by showing negative value. Divergence shows that poor countries stay poor, and rich countries go richer left poor countries behind.

Figure 1 provides a picture on the regression in table 5. MRW just simply made a regression on GDP growth and Log of GDP per capita in the beginning of observation. Contrary with table 5, there is no country restrictions in graph 2. In this graph there is no evidence that countries started poor tend to grow faster compared to rich countries. Except for year 1993-2011, we can see a slight tendency.

Figure 1. Growth Rate for all countries Versus Log output per working age population in the beginning of observation.



1960-1985 1960-2011



1960-1992 1993-2011

4.3.2. Conditional Convergence, Textbook Solow Model

After claiming that unconditional convergence methodology brought failure in testing convergence, MRW put the rates of investment and population

growth to the right hand side of the equation to check on the conditional convergence. A methodology that they claimed "successful" to explain convergence, where unconditional convergence does not provide results of tendency towards convergence in many previous studies (De Long, 1988; Romer, 1987). Another weakness from MRW paper in testing convergence is the definition of convergence by adjusted R^2, they did not provide guidance on the value of adjusted R^2. Their paper claimed that the value of adjusted R^2 0.46 for OECD countries show a strong tendency of convergence.

Table 6 show a similar result with MRW's paper. Following the definition of MRW of convergence (0.46 = significant tendency toward convergence), the replication results for this equation are showing strong evidence of convergence for Non-oil and Intermediate samples.

Table 6. Test for Conditional convergence - Basic Solow Model

Dependent Variable: Log difference GDP per working-age person End year and Beginning year

	Non Oil					**Intermediate**				
	Original Paper (1960-1985)	PWT 8.1 (1960-1985)	PWT 8.1 (1960-2011)	PWT 8.1 (1960-1992)	PWT 8.1 (1993-2011	Original Paper (1960-1985)	PWT 8.1 (1960-1985)	PWT 8.1 (1960-2011)	PWT 8.1 (1960-1992)	PWT 8.1 (1993-2011)
Observations	98	85	86	86	90	75	70	71	71	71
Constant	1.93	-0.657	0.721	-0.301	-0.133	2.23	-0.241	0.901	0.206	0.023
	(0.83)	(0.82)	(0.48)	(0.32)	(0.22)	(0.86)	(0.21)	(0.47)	(0.17)	(0.04)
ln(GDP/capita beginning year)	-0.141	-0.027	-0.163	-0.054	-0.067	-0.228	-0.062	-0.189	-0.093	-0.061
	(0.052)	(0.44)	(2.07)*	(0.71)	(2.33)*	(0.057)	(0.89)	(3.34)**	(1.09)	(2.01)*
ln(I/GDP)	0.647	0.607	1.408	0.81	0.553	0.644	0.605	1.39	0.807	0.462
	(0.087)	(2.79)**	(3.31)**	(2.72)**	(5.48)**	(0.104)	(2.00)*	(2.75)**	(2.12)*	(4.17)**
ln(n+g+d)	-0.299	-0.233	-1.392	-0.567	-0.312	-0.464	-0.241	-1.327	-0.634	-0.28
	(0.304)	(0.78)	(3.34)**	(1.56)	(1.60)	(0.307)	(0.21)	(3.02)**	(1.67)	(1.41)
Adj. R^2	**0.38**	**0.3**	**0.43**	**0.34**	**0.26**	**0.35**	**0.26**	**0.42**	**0.31**	**0.22**
t (years)	25	25	51	32	18	25	25	51	32	18
implied λ	**0.00606**	**0.00109**	**0.00349**	**0.00173**	**0.00385**	**0.0104**	**0.00256**	**0.00411**	**0.00305**	**0.0035**

* p<0.05; ** p<0.01. Standard errors are in parenteheses. ln(GDP/capita beginning year) is GDP per working-age person in the beginning year of each regression. Original Paper does not provide p value information

The results of initial income becoming significantly negative, and putting the rate of investment and population growth rates improves substantially the statistically fit of the regression. Not all variables are statistically significant, only period 1960-2011 provides a significant value statistically for all variables. Also, period 1960-2011 provides higher tendency towards convergence. It shows that by using textbook Solow model in testing convergence for a period of 51 years we can see a tendency towards convergence.

4.3.3. Conditional Convergence, Augmented Solow Model

In their next regression, MRW put variable SCHOOL in the regression to explain convergence. Similar with their idea on putting human capital in the equation, they felt that human capital improved the convergence test results.

The results for table 11 shows that putting MRW's methodology with adding SCHOOL variable in the equation improves the fit of the regression, especially for period 1960-2011 for both Non-oil and Intermediate samples. Period 1960-2011 shows a higher value of convergence as well compared to other periods, it means that for a longer period of year, there is a tendency towards convergence for cross-country samples. This finding is similar with textbook Solow (Solow, 1956), which he mentioned that in the long run poorer countries grow faster than richer countries, and in the end they go into convergence. However, since the value of coefficient on the initial level of income lowers, it affects the rate of convergence as well. The original study provides a higher value of convergence rate by almost 10 times faster compared to the replication. In other words, the study of MRW suggested a much faster convergence rate compared to this replication.

Table 7. Test for Conditional convergence - Augmented Solow Model

Dependent Variable: Log difference GDP per working-age person End year and Beginning year

	Non Oil					**Intermediate**				
	Original Paper (1960-1985)	PWT 8.1 (1960-1985	PWT 8.1 (1960-2011)	PWT 8.1 (1960-1992)	PWT 8.1 (1993-2011	Original Paper (1960-1985)	PWT 8.1 (1960-1985)	PWT 8.1 (1960-2011)	PWT 8.1 (1960-1992)	PWT 8.1 (1993-2011
Observations	98	83	86	86	90	75	68	71	71	71
Constant	3.04	0.333	1.884	1.074	-0.089	3.69	0.317	1.488	0.971	0.042
	(0.83)	(0.35)	(1.07)	(1.02)	(0.14)	(0.91)	(0.25)	(0.71)	(0.73)	(0.07)
ln(GDP/capita beginning year)	-0.289	-0.116	-0.311	-0.171	-0.077	-0.366	-0.125	-0.3	-0.173	-0.068
	(0.062)	(1.65)	(3.42)**	(2.21)*	(2.42)*	(0.067)	(1.62)	(3.03)**	(2.00)*	(2.04)*
ln(I/GDP)	0.524	0.542	1.132	0.694	0.534	0.538	0.529	1.18	0.706	0.45
	(0.087)	(2.45)*	(3.07)**	(2.56)*	(5.31)**	(0.102)	(1.69)	(2.53)*	(1.99)	(4.12)**
ln(n+g+d)	-0.505	-0.302	-1.16	-0.683	-0.282	-0.551	-0.237	-1.067	-0.633	-0.259
	(0.288)	(0.98)	(2.63)*	(1.89)	(1.39)	(0.288)	(0.72)	(2.26)*	(1.61)	(1.27)
ln(SCHOOL)	0.233	0.154	0.393	0.234	0.031	0.271	0.176	0.38	0.225	0.025
	(0.060)	(3.09)**	(4.40)**	(3.98)**	(1.09)	(0.081)	(2.47)*	(3.82)**	(3.15)**	(0.77)
Adj. R^2	**0.46**	**0.38**	**0.55**	**0.46**	**0.27**	**0.43**	**0.33**	**0.51**	**0.41**	**0.23**
t (years)	25	25	51	32	18	25	25	51	32	18
implied λ	**0.0136**	**0.0049**	**0.0073**	**0.0059**	**0.0045**	**0.0182**	**0.0053**	**0.0070**	**0.0059**	**0.0039**

* p<0.05; ** p<0.01. Standard errors are in parenteheses. ln(GDP/capita beginning year) is GDP per working-age person in the beginning year of each regression. Original Paper does not provide p value information

4.3.4. Conditional Convergence, Augmented Solow Model – Restricted Regression

This chapter presents estimates of below equation in MRW paper:

$$\ln(y(t)) - \ln(y(0)) = (1 - e^{-\lambda t}) \frac{\alpha}{1-\alpha-\beta} \ln(s_k) + (1 - e^{-\lambda t}) \frac{\beta}{1-\alpha-\beta} \ln(s_h) - (1 - e^{-\lambda t}) \frac{\alpha+\beta}{1-\alpha-\beta} \ln(n+g+\delta) - (1 - e^{-\lambda t}) \ln(y(0)).$$

By imposing the restriction on ln (Sk), Ln (Sh), and Ln (n+g+d) sum to zero. In their original paper, the restriction was not rejected and provided only small impact to the results. However, in the findings of this replication, some coefficients are highly impacted by the restriction, for Intermediate sample period 1960-2011, the initial income is positive and the value is more than one. The value is statistically strong as well, which MRW have not provided any solution for this kind of findings.

Table 8. Test for Conditional convergence - Augmented Solow Model, Restricted Regression

Dependent Variable: Log difference GDP per working-age person End year and Beginning year

	Non Oil					**Intermediate**				
	Original Paper (1960-1985)	PWT 8.1 (1960-1985	PWT 8.1 (1960-2011)	PWT 8.1 (1960-1992)	PWT 8.1 (1993-2011	Original Paper (1960-1985)	PWT 8.1 (1960-1985)	PWT 8.1 (1960-2011)	PWT 8.1 (1960-1992)	PWT 8.1 (1993-2011
Observations	98	83	86	86	90	75	68	71	71	71
Constant	2.46	1.296	2.77	1.675	0.651	3.09	1.493	-0.321	1.732	0.604
	(0.48)	(2.44)*	(3.64)**	(2.81)**	(2.46)*	(0.53)	(2.40)*	(3.33)**	(2.58)*	(2.19)*
ln(GDP/capita beginning year)	-0.299	-0.133	-0.325	-0.182	-0.095	-0.372	-0.147	1.096	-0.189	-0.079
	(0.061)	(1.86)	(3.69)**	(2.27)*	(3.33)**	(0.067)	(1.88)	(2.97)**	(2.09)*	(2.53)*
ln(I/GDP) - ln(n+g+d)	0.5	0.503	1.077	0.667	0.498	0.506	0.467	0.358	0.666	0.413
	(0.082)	(2.43)*	(3.46)**	(2.66)**	(5.15)**	(0.095)	(1.77)	(3.28)**	(2.13)*	(3.95)**
ln(SCHOOL) - ln(n+g+d)	0.238	0.155	0.383	0.234	0.024	0.266	0.167	2.71	0.221	0.019
	(0.060)	(3.05)**	(4.10)**	(4.01)**	(0.77)	(0.080)	(2.19)*	(3.13)**	(3.12)**	(0.57)
Adj. R^2	**0.46**	**0.37**	**0.54**	**0.45**	**0.26**	**0.44**	**0.31**	**0.51**	**0.4**	**0.22**
t (years)	25	25	51	32	18	25	25	51	32	18
implied λ	**0.0142**	**0.0057**	**0.0077**	**0.0063**	**0.0055**	**0.0186**	**0.0064**	**0.0145**	**0.0065**	**0.0046**
implied α	**0.48**	**0.64**	**0.60**	**0.62**	**0.81**	**0.44**	**0.60**	**0.18**	**0.62**	**0.81**
implied β	**0.23**	**0.20**	**0.21**	**0.22**	**0.04**	**0.23**	**0.21**	**1.37**	**0.21**	**0.04**

* p<0.05; ** p<0.01. Standard errors are in parenteheses. ln(GDP/capita beginning year) is GDP per working-age person in the beginning year of each regression. Original Paper does not provide p value information

The value of α ranges from 0.44-0.48 for original paper, and 0.60-0.81 for replication, except for intermediate sample 1960-2011. The estimates of β are mostly lies on 0.20ish, except for recent years where the value drops, and rate of investment explains convergence compared to human capital. Intermediate sample period. As a conclusion, the results of applying Augmented Solow Model changes over time. Some time periods have stronger rate of investments, and some time periods have faster rate of convergence.

In their original paper, they noted that the value of $\lambda = 0.02$ means almost half of the departure from steady state in 1945 would have remained by the end of the samples in 1985. But in replication, the value shows not much differences. It shows that convergence rate changes over time. The regression results in the period 1960-2011, 1960-1992, 1993-2011 show a stronger statistical power for all coefficients compared to the original period 1960-1985.

4.4. Replicate MRW study with Asia sample

This sub-chapter aims to replicate further on the methodology that MRW did in their study. MRW picked their cross-country samples by Nonoil, Intermediate, and OECD. This study is also interested on geographical location of cross-country samples. The motivation to do this sub-chapter is to see whether geographical location or neighbouring countries provide similar trend with the study by MRW and its replication in previous sub-chapter in chapter 4. In addition, testing the methodology with different countries might show robustness of the theory. Some cross-country sample can be small, but it is arguable, since MRW used only 22 countries in their OECD cross-country sample.

In replicating the identical methodology, there are 47 Asia countries in the dataset. Unfortunately, from a total of 47 Asia countries in the dataset, original MRW's study used only 18 Asia countries in Non-Oil category, and 17 Asia Countries in Intermediate category. The reason for MRW to pick only limited amount of Asia countries seemed to be "acceptable", there was missing or incomplete economic data at that time, some of Asia countries are oil producers, and some Asia countries did not get the independence yet, just got their independence or not formed yet. By the time the original paper was written, the world was experiencing cold war between Uni Soviet and the United States of America. After the end of cold war, many new countries formed in Asia and in

East Europe. Therefore, when the work is replicated, then the results might not be showing a strong result statistically. In addition, some countries that are excluded by MRW in their study might be included in this study, such as, oil producer countries.

This study does not put Asia or region in the right hand side of the equation, unlike Temple (1998) did. Because, this study is a replication for what MRW did. A replication means replicate the identical methodology with the original study and test its robustness. Based on this understanding, this study replicates the methodology of MRW without changing it.

4.4.1. Replicate basic textbook Solow Model with Asia sample

Table 9 replicated textbook Solow model with Asia sample. Compared to OECD sample (22 countries), Asia sample (30-39 countries) has more number of countries. Contrary with MRW concluded, and textbook Solow model, income differences in Asia do not explained by investment rate, and population growth. With exact year when MRW study made (1960-1985), Asia give a positive result on population growth. The fact is conflicting with what textbook Solow model mention, and what MRW did.

Table 9. Estimation of the Textbook Solow Model with Asia Countries sample 1960-1985, 1960-2011, 1960-1992, 1993-2011

Dependent Variable: Log GDP per working-age person				
	Asia			
	1960-1985	1960-2011	1960-1992	1993-2011
Observations	30	39	35	39
Constant	-1.465	2.831	-0.977	5.971
	(0.60)	(1.19)	(0.39)	(2.37)*
ln(I/GDP)	0.365	1.332	0.787	0.853
	(0.89)	(2.28)*	(1.87)	(1.38)
ln(n+g+d)	4.44	1.214	3.683	0.396
	(4.42)**	(1.40)	(3.42)**	(0.51)
R-Squared	0.43	0.18	0.34	0.057
Adj. R-Squared	0.39	0.14	0.29	0.0041
Restricted Regression				
Constant	9.336	8.818	8.775	9.051
	(16.99)**	(14.04)**	(15.89)**	(15.33)**
ln(I/GDP) - ln(n+g+d)	-0.292	0.6	0.279	0.362
	(0.58)	(1.09)	(0.58)	(0.75)
R^2	0.01	0.03	0.01	0.01
Adj. R^2	-0.02	0.005	-0.02	-0.012
Implied α	**-0.41242938**	**0.375**	**0.2181392**	**0.26578561**

* p<0.05; ** p<0.01; number in parentheses are standard error; the original paper does not provide information about p value/t test.

It is arguable that some of Asian countries are biggest oil producers in the world, such as Saudi Arabia, China, United Arab Emirates, Iran, and Iraq. In fact, United states of America and Canada are part of the biggest oil producer countries in the world. But, MRW put USA and Canada in their study as samples in all categories, Non-oil, Intermediate and OECD. Nevertheless, some important production intensive countries that MRW excluded in their study are included China, Dubai, and Vietnam. In total, they excluded about 90 countries from their study, including Oceania countries, Middle East Countries, East Europe countries, Asia countries, and smaller countries.

The regression results in Table 9 becoming stimulating to see. It included all middle east countries, China and Vietnam in the regression. It is arguable that the production condition in those countries was different at the original was made. Therefore, this study interested to see the value of regression of recent year between year 1993-2011. Still, textbook Solow model does not explain income differences in Asia for all time periods. However, the implied α is close with what textbook Solow model suggested, despite the statistical power.

4.4.2. Replicate basic Augmented Solow Model with Asia sample

MRW did augmented Solow model to weaken the value of investment in explaining income differences. Since the regression results with textbook Solow model provided a weak result, it is expected that augmented Solow model to provide weak results as well. For Asia sample, augmented Solow model does not provide explanation on income differences between countries.

Similar with the results in table 9, population show a strong statistical results in Asia sample, and positive sign. The sign of population growth rate was expected to be negative. In addition, restricted regression provided that the composition of investment rate and education rate do not comply with what MRW and Solow model suggested. From total two regressions with textbook Solow model and Augmented Solow model, it seems that the theory only works in some specific selected countries.

Table 10. Estimation of the Augmented Solow Model with Asia Countries sample 1960-1985, 1960-2011, 1960-1992, 1993-2011				
Dependent Variable: Log GDP per working-age person				
	Asia			
	1960-1985	1960-2011	1960-1992	1993-2011
Observations	30	37	34	37
Constant	-1.403	0.47	-0.871	3.688
	(0.71)	(0.24)	(0.47)	(1.55)
ln(I/GDP)	0.282	1.438	0.675	1.147
	(0.69)	(2.29)*	(1.52)	(1.94)
ln(n+g+d)	4.438	2.01	3.731	0.872
	(4.50)**	(3.00)**	(3.78)**	(1.26)
ln(SCHOOL)	0.288	0.274	0.174	0.209
	(1.44)	(0.91)	(0.76)	(0.77)
R-Squared	0.47	0.33	0.35	0.13
Adj. R-Squared	0.41	0.27	0.29	0.05
Restricted Regression				
Constant	9.629	9.198	8.957	9.096
	(13.18)**	(10.44)**	(11.80)**	(13.13)**
ln(I/GDP) - ln(n+g+d)	-0.355	0.389	0.214	0.322
	(0.69)	(0.60)	(0.40)	(0.60)
ln(SCHOOL) - ln(n+g+d)	0.164	0.233	0.091	0.093
	(0.62)	(0.69)	(0.37)	(0.32)
R^2	0.03	0.05	0.01	0.02
Adj. R^2	-0.04	-0.01	-0.05	-0.04
Implied α	**-0.44**	**0.24**	**0.16**	**0.23**
Implied β	**0.20**	**0.14**	**0.07**	**0.07**
* p<0.05; ** p<0.01; number in parentheses are standard error; the original paper does not provide information about p value/t test.				

4.4.3. Testing Convergence with Asia Sample

This sub-chapter test the convergence with the same methodology like MRW did in their original paper. Despite of cross-country sample issue explained earlier in this chapter, unconditional convergence should not be problematic. It checks purely on income in the beginning of observation compared with the economic growth.

4.4.3.1. Unconditional Convergence with Asia sample

Unconditional convergence provided a failure in Non-oil and Intermediate samples. This paper test unconditional convergence with Asia sample. There are

a total of 19 Asia countries in 3 regressions, and 43 Asia countries in 1 regression. From unconditional convergence results we can notice that Asia countries does not have the tendency towards convergence before 1992/1993. It is important to remember that in convergence test MRW gave their attention only at adjusted R^2, not on the significant level of coefficients.

Table 11. Test for unconditional convergence Asia Countries				
Dependent Variable: Log difference GDP per working-age person End year and Beginning year				
	Asia			
	PWT 8.1 (1960-1985	PWT 8.1 (1960-2011)	PWT 8.1 (1960-1992)	PWT 8.1 (1993-2011)
Observations	19	19	19	43
Constant	0.152	3.067	0.916	1.743
	(0.16)	(1.88)	(0.71)	(4.31)**
ln(GDP/capita beginning year)	0.07	-0.203	0	-0.138
	(0.61)	(1.02)	(0.00)	(3.13)**
Adjusted R^2	**-0.0361**	**0.0021**	**-0.0588**	**0.1734**
t (years)	25	51	32	18
implied λ	**-0.002706346**	**0.004449031**	**0**	**0.00825**
* p<0.05; ** p<0.01. Standard errors are in parentehese. ln(GDP/capita beginning year) is GDP per working-age person in the beginning year of each regression.				

Findings in Table 11 confirms that after 1992/1993 Asia has a slight tendency towards convergence, after 1992/1993. The rate of convergence is also much higher compared to the rate of convergence in Nonoil/Intermediate sample. The coefficients are showing strong statistical power as well. However, the initial income per capita in period 1960-1985 when MRW did their study showed a positive sign. Compared with regression results in period 1993-2011 when MRW already published their study. These findings confirm that Asia countries did not have supportive evidence on convergence when MRW published their paper. It may be the results why MRW excluded so many Asian countries in their samples, Non-Oil, Intermediate, and OECD.

4.4.3.2. Conditional Convergence Textbook Solow Model with Asia sample

When we restrict the regression into Asia countries, there is a stronger tendency towards convergence compared to Non-oil/Intermediate samples. Contrary with unconditional convergence results, after 1992/1993 Asia samples provides a different trend of the degree of convergence. All four period provides a strong tendency towards convergence, but after year 1992/1993 the tendency of convergence is lower compared to before 1992/1993.

Table 12. Test for Conditional convergence Asia Countries - Basic solow Model

Dependent Variable: Log difference GDP per working-age person End year and Beginning year

	Asia			
	PWT 8.1 (1960-1985)	PWT 8.1 (1960-2011)	PWT 8.1 (1960-1992)	PWT 8.1 (1993-2011)
Observations	19	19	19	39
Constant	0.912	3.049	2.531	1.615
	(0.52)	(0.86)	(1.23)	(1.77)
ln(I/GDP)	0.889	2.094	1.434	0.276
	(2.55)*	(3.40)**	(3.22)**	(1.06)
ln(n+g+d)	-1.111	-2.814	-2.292	-0.358
	(1.47)	(2.54)*	(3.33)**	-1.61
ln(GDP/capita beginning year)	-0.089	-0.33	-0.185	-0.14
	(0.71)	(2.13)	(1.18)	(2.91)**
Adjusted R^2	**0.29**	**0.59**	**0.43**	**0.32**
t (years)	25	51	32	18
implied λ	**0.00373**	**0.00785**	**0.00639**	**0.00838**

* p<0.05; ** p<0.01. Standard errors are in parentehese. ln(GDP/capita beginning year) is GDP per working-age person in the beginning year of each regression.

The rate of convergence after 1992/1993 period shows a faster convergence rate. During 1960-2011 there is a significant tendency of Asian countries towards convergence. The convergence rate increased after MRW published their paper as shown by the empirical results.

4.4.3.3. Conditional Convergence Augmented Solow Model with Asia sample

For Asia sample, the equation of augmented Solow model, restricted regression provides mixed results. All results show a strong tendency for convergence, however the rate of convergence becoming a little bit faster in recent years compared to 1960-1985 period. Again, statistically augmented Solow model does not

explain income differences in Asia countries, but it gives us a view that Asia countries have a strong tendency to converge with rate of convergence between 0.0058 – 0.0087.

Table 13. Test for Conditional convergence - Augmented Solow Model – Asia Sample				
Dependent Variable: Log difference GDP per working-age person End year and Beginning year				
	Asia			
	PWT 8.1 (1960-1985)	PWT 8.1 (1960-2011)	PWT 8.1 (1960-1992)	PWT 8.1 (1993-2011)
Observations	19	19	19	37
Constant	2.535	2.691	3.928	1.315
	(1.23)	(0.63)	(1.35)	(1.47)
ln(GDP/capita beginning year)	-0.135	-0.304	-0.242	-0.14
	(1.17)	(1.39)	(1.46)	(2.68)*
ln(I/GDP)	0.51	2.185	1.111	0.395
	(1.16)	(3.06)**	(1.81)	(1.45)
ln(n+g+d)	-1.354	-2.767	-2.498	-0.282
	(1.55)	(2.34)*	(2.41)*	(1.52)
ln(SCHOOL)	0.447	-0.154	0.41	-0.145
	(1.91)	(0.27)	(1.13)	(2.00)
Adj. R^2	**0.47**	**0.59**	**0.49**	**0.42**
t (years)	25	51	32	18
implied λ	**0.0058**	**0.0071**	**0.0087**	**0.0084**
* p<0.05; ** p<0.01. Standard errors are in parentehese. ln(GDP/capita beginning year) is GDP per working-age person in the beginning year of each regression. Original Paper does not provide p value information				

Contrary with the original paper, augmented Solow model test in Asia sample does not provide higher tendency of convergence and higher rate of convergence. The initial income per capita per worker also showing a negative coefficients compared with textbook Solow model convergence test. Adding variable SCHOOL in the regression improve the statistical performance of the regression.

4.4.4.4. Conditional Convergence Augmented Solow Model with Asia sample, restricted regression

It's an unfortunate that not all countries in Asia has complete economic data from 1960, that caused only 19 samples for 3 regressions. But for the period after MRW published their paper in 1992/1993, there are 37 countries in the sample. It gives a sufficient number of observations. The regression show that augmented Solow model does not explain income differences in Asia countries.

Asia countries have strong tendency towards convergence, but with slower convergence rate compared to Non-oil and Intermediate samples. The regression results after 1992/1993 period shows a better fitness, however a failure in estimating the value of α and β.

Table 14. Test for Conditional convergence - Augmented Solow Model for Asia Countries sample - Restricted Regression				
Dependent Variable: Log difference GDP per working-age person End year and Beginning year				
	Asia			
	PWT 8.1 (1960-1985)	PWT 8.1 (1960-2011)	PWT 8.1 (1960-1992)	PWT 8.1 (1993-2011)
Observations	19	19	19	37
Constant	1.8	1.254	2.101	1.254
	(2.01)	(0.52)	(1.30)	(2.46)*
ln(GDP/capita beginning year)	-0.149	-0.331	-0.281	-0.141
	(1.38)	(1.47)	(1.75)	(2.86)**
ln(I/GDP) - ln(n+g+d)	0.537	2.337	1.235	0.406
	(1.32)	(4.36)**	(2.26)*	(2.03)
ln(SCHOOL) - ln(n+g+d)	0.441	-0.145	0.397	-0.143
	(1.98)	(0.26)	(1.13)	(2.15)*
Adj. R^2	0.46	0.58	0.48	0.42
t (years)	25	51	32	18
implied λ	**0.0065**	**0.0079**	**0.0103**	**0.0084**
implied α	**0.48**	**0.93**	**0.65**	**1.00**
implied β	**0.39**	**-0.06**	**0.21**	**-0.35**
*** p<0.05; ** p<0.01. Standard errors are in parentehese. ln(GDP/capita beginning year) is GDP per working-age person in the beginning year of each regression. Original Paper does not provide p value information**				

Chapter 5 . Conclusions

The replication of MRW study in 1992 shows mixed results with the conclusion of the study. This study agrees that international differences in income per working age people are better understood by using augmented Solow growth model instead of original textbook Solow Model. Augmented Solow model improves the model and the statistical strengths, however not to the correct magnitude as the original paper suggested. Moreover, the model is a results of the combination of physical capital, human capital, labour. Also the used for investment in the form of capitals, physical capital, human capital and consumption. The model assumes that there is a perfect mobility between form of capitals. Contrary with the original paper, replication results with different time periods do not support $Y = K^{1/3}H^{1/3}L^{1/3}$ in most results.

Important to note that the regression results in all replications improved in terms of statistical strengths, as all coefficients are statistically strong. In their original paper, MRW noted that some coefficients are not statistically strong. Moreover, this replication paper has several empirical results. First, elasticity of income in relation to the stock of physical capital to capital's share in income changes over time. Unlike the original paper stated, both are substantially not different. In this paper show that there are substantial externalities to the accumulation of physical capital, as shown by bigger magnitude of investment / savings rate (implied α) in the empirical results compared to the original study and textbook Solow model.

Second, all variables related to accumulation of physical capital on the impact to income per capita show significant values statistically. Human capital also show a statistically significant value towards income per capita. Therefore, higher investment / savings rate and higher investment on human capital raises factor productivity as measured in the original paper by MRW. Contrary with the effect of adding of human capital lower the magnitude of savings / investment rate towards one-third, in this replication the effect of adding human capital is not significant to reduce the magnitude of savings / investment rate. The replication by using PWT 8.1 showed a closer result with the original paper, but with weaker statistical strength.

Third, regarding population growth, as MRW concluded, the magnitude of population growth is bigger compared to Textbook Solow model. According to

the theory, augmented Solow model has lower magnitude of population growth compared to Textbook Solow Model. The trend is also shown in this replication paper. However, the magnitude is smaller than the study by MRW. The coefficient value and magnitude changes over the time and different cross country group, but with similar negative effect to income per capita.

Fourth, in terms of convergence, again this replication shows a mixed results compared to the original paper. In the first unconditional replication, Non-oil and Intermediate samples show a tendency of no convergence. In replicating convergence with Basic Solow Model and Augmented Solow model, the results are mixed in terms of the magnitude. In addition, convergence rate for most empirical results are slower than textbook Solow model, and the study by MRW suggests. Textbook Solow model noted that the economy reaches halfway to steady state in about 17 years, and 35 years in MRW paper. However, this paper tells a different result, the convergence rate in this paper is even slower. This paper also contrast with MRW results for the tendency of augmented Solow model to provide higher rate of convergence and higher tendency towards convergence. In many samples, using augmented Solow model in convergence does not increase the rate of convergence and increase the tendency of group of countries to converge.

Contrary on what Temple (1998) did in his robustness test with augmented Solow model, this study show that the value of α is constantly much stronger than the textbook Solow model and Augmented Solow model. In his study, Temple (1998) set new cross-country samples instead of using similar definition on cross-country samples used by MRW. His study showed a lower level of α and β in recreating augmented Solow model for all of his cross-country sample. He noticed that many countries are excluded from the cross-country sample, which he tested with different countries compositions.

This study may have resulted in debate on the validity of textbook Solow model or augmented Solow model on the study by MRW. The term of savings rate / investment rate in defining income differences should be tested further. In addition, the methodology that MRW used in creating cross-country analysis, and the way they picked the countries in the sample are debatable. Asia sample showed that by the time MRW did their study, economic data in Asia countries did not provide any evidence to support Solow model or Augmented Solow model. However, after they published their paper in 1992, with period of study

1993-2011 the results show a better statistical power compared to previous period. This study highly criticized how MRW picked their cross-country samples and urge further study to test Solow model and augmented Solow model with different specifications of cross-country samples.

This study is not final, and left many unanswered questions. For further study, it is recommended to relook again on the countries sample that MRW used. Further study may attempt different geographical locations, and different methodology in picking the countries as samples. A new method on how to consider the economy size of a country is also important. We cannot treat the economy of a small country with superpower countries equally. Moreover, in further study of replicating augmented Solow model, other forms of human capital can substitute current form to check on the effect to the magnitude. An assumption of level of technological growth rate, and rate of depreciation can be examined further.

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