An Empirical Investigation of the Unified Growth Theory

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[1] The author declares that the text and work presented in this Master thesis is original and that no sources other than those mentioned in the text and its references have been used in writing the Master thesis.

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Abstract:

The Unified Growth Theory is a new theory dealing with macroeconomic development. It combines elements from endogenous, intergenerational and infinite-horizons models, to explain the history of economic development. Can the growth theory be used to classify the stage of economic development of nations? We will try, comparing the developing trends of GDP per capita growth and population growth of 33 nations with the outcome of a baseline simulation. We find that countries can either be classified in the transitional stage, of the Modern Growth Regime. We will also use patent statistics to see if it is a good proxy for the technological progress rate. We find that although it does clarify differences between countries, it shows to be a good proxy for countries with a big manufacturing sector. For countries with a big tertiary sector, it falls short of the intended purpose. To test the validity of the theory, a regression is performed on the countries in the two different stages. The results of these regressions is that, although the predicted influence of population growth on economic growth is present, the relationship isn't robust when different control variables are added.

Content

1. Introduction:

In macro-economics, growth theories are used to analyze, explain and predict the growth paths of national economies. Over the years, different growth theories were developed to explain economic growth. This ranges from the exogenous models to endogenous models and from the overlapping generations models to the infinite horizon models. In 2000, Oded Galor and David Weil introduced a new model, the Unified Growth Theory (Galor & Weil, 2000). In this study, the validity of this model will be tested with a selection of countries.

The Unified Growth Theory explains the development of nations in a different way than older macro-economic theories. First there were exogenous growth theories, which took some parameters as a given. These were, among others, technological progress and population growth rate. The endogenous theories expanded on the exogenous theories, by explaining how long run economic growth was affected by micro-economic foundations. Only, there was a problem with these theories. They did not explain the development of national and the world economy, when one looked at the empirical evidence.

The Unified Growth Theory was developed, to explain the observed track many Western European economies have taken.

The main hypotheses of this model are as follows:

- In the initial phase, a country is in a Malthusian regime, with a low population growth, almost no GDP growth, and a low technological growth rate. Over time, there is an interaction between population growth and technological growth rate, which makes them both rise.
- After the technological progress rate hits a certain point, the economy goes into a transitional phase, where the birth rate & technological progress rate rises quickly, and GDP growth rate also rises, but income doesn’t rise, because birthrate rises more quickly. Human capital accumulation is nonexistent in this phase.
- After the transitional phase, there is a demand for human capital, and its ratio will rise quickly. GDP per capita growth rate will rise monotonically in technological

leader states, while the income per capita growth rate in technological follower states will rise even faster than in the leader states, before dropping down to the level of the leader states. This way, the technological followers will catch up to the leader states.

Furthermore, according to the theory, there will be three clubs of countries: the ones that are still in the Malthusian state, the countries that are in a stable economic growth and the countries that are in the transitional phase.

The structure of the thesis will be as follows: First, we expand on the background of the basic Unified Growth Theory. We explain the basic propositions of the model, the hypotheses that come from these propositions, and the proof Oded Galor and other authors have found for these hypotheses. Furthermore, other research papers on the same subject will be discussed.

Next, we try to prove the basic model of the UGT and to put a selection of countries in one of the groups stated in the hypotheses. For the first part of the analysis, historical GDP growth rate data and population growth rate, taken from the Maddison database, will be used. The second part of the analysis will focus its attention on the technological progress rate. We will use the patent applications by residents to mimic the technological progress rate, and to see if this works. Finally, the two parts of the analysis will be tested. For this, different regressions are formed. The robustness will be tested with control variables.

- Can the Unified Growth Theory effectively be used to classify the state of development of a countries economy?
- In which stage can one classify the developing countries?
- Do the up and coming countries (China, Russia, Brazil and India) show the parameters of the transition stage, or the Modern Growth Regime?
- Is there a good proxy for the technological progress rate, and if so, what is it?

Lastly, I will deduct conclusions from the analysis, and give some indications for future research.

2. Literature research

Research on economic development is very abundant. Articles about the Unified Growth Theory though, are only a small part of the literature. This is mainly, because the theory is quite new. The first article about the theory, written by Oded Galor and David Weil, was published in 2000 (Galor & Weil, 2000). Many subsequent articles and papers build on this paper. In this section, we first get into the different growth models, to discuss the evolution of the field. Next, we discuss the different variations developed since the publication of the original Unified Growth Theory. Also, we discuss the factors that could influence the take-off from stagnation to growth.

2.1 Growth Models

2.1.1 Theoretical models

In macroeconomics, different growth models can be uncovered. When one looks at the growth models in a timeline, there seems to be an evolution over time. The modern growth models start with the Solow Growth Model (Solow, 1956). The model is based on the neo-classical framework. Solow developed a simple growth model, where the economic growth rate and technological progress are exogenous. Although it explained the economic development of the United States of America, other key predictions of the model are not consistently supported by empirical evidence.

Next, there are there Infinite-horizon and overlapping-generation models, as developed by Ramsey, Cass, Koopmans, and Diamond (Diamond, 1965; Cass, 1965; Ramsey, 1928; Koopmans, 1965). Both models look a lot like the Solow model, as in, these models also use exogenous parameters. The difference between the two models and the Solow Model is that the evolution of capital stock is derived from the interaction between maximizing households and firms. Because of this, the savings rate has been endogenized. The infinite-horizon model, or Ramsey-Cass-Koopmans Model, differs from the overlapping-generations model, or Diamond Model, in the fact that the latter assumes the entry of new households into the economy.

Endogenous growth models were developed as an answer to the shortcomings of the exogenous growth models, namely the fact that some parameters were given exogenously. These models, as developed by Paul Romer, Gene Grossman and Elhanan Helpman, or Philippe Aghion and Peter Howitt, use microeconomic foundations (Romer P. , 1986; Grossman & Helpman, 1991; Aghion & Howitt, 1992). Household will maximize utility, while companies maximize profits. Furthermore, technological progress has become endogenous, by creating a R&D sector, where a fraction of labor and capital, normally used for production, is used. This sector will create new ideas, giving a specific technological progress.

Last in this line of growth models is the Unified Growth Theory, as developed by Galor and Weil (Galor & Weil, 2000). One can actually see this theory as a combination of the overlapping-generation model and endogenous growth theories. A big difference is that the original Unified Growth model does not take physical capital stock and –accumulation into account. Instead, it focuses its scope on human capital accumulation and technological progress. A more detailed explanation of the model is given in the section; "Model Description".

2.1.2 Empirical Research

According to the Unified Growth Theory, there are three factors influencing economic growth per capita: population growth, the technological progress rate and human capital. But this is not the only paper on economic development. Another article is the paper by Robert Barro, where the author used a neoclassical growth model to determine which variables have a positive influence on economic growth (Barro R. J., 1996a). He found that for a given starting level of real per capita GDP the most influential variables were a higher initial schooling and life expectancy, lower fertility, lower government consumption, better maintenance of the rule of law, lower inflation, and improvements in the terms of trade. This is a positive result for the Unified Growth Theory, since two of the three important variables of the Unified Growth Theory are also significant in the analysis of Barro. Initial schooling is directly related to the accumulation of human capital, while lower fertility is related to the population growth.

Technological progress is not named in the article by Barro, but this is an important variable in the Unified Growth Theory. However, it is also a difficult variable to quantify. Zvi Grilliches explained a similar difficulty (Grilliches, 1979). In his article, he stated that the whole of productivity growth is mostly explained with either a case study or a production function. The problem is that the latter researchers try to explain all of TFP growth with a variable based on R&D inputs, which actually only accounts for a part of TFP growth. He concludes with the recommendation that a research should be done into patents, if they actually measure anything, and if it could be used for measuring production growth.

Zvi Grilliches addresses the potential use of patent statistics as an economic indicator for technological change (Grilliches, 1990). He surveys a number of studies relating patent statistics and their use to illuminate the innovation process and technological change. He found that patent data could be used to describe inventive input and output, especially when R&D data isn't readily available. There are some drawbacks with this variable. There are dangers of too much variance and skewness when being used in some specific fields. Also there is the danger of the patent statistics being lagged due to bureaucratic reasons. However, the author believes it is still a good resource for measuring economic change.

2.2 Unified Growth Theory

2.2.1 Variations of the Unified Growth Theory

There are a number of papers dedicated to the Unified Growth Theory. Either to empirical prove the theory set out by Galor and Weil (Galor & Weil, 2000), or to research different versions of the same theory. Strülik and Weisdorf devised their own theory, based on the unified growth theory, but they hold more strictly to the preventive check hypothesis, as developed by Thomas Malthus, which states that fertility rates vary inversely with the price of food (Strülik & Weisdorf, 2008a). The biggest difference between this model and the standard unified growth theory is that instead of focusing on the accumulation of human capital and choosing the number and quality of children, they selected productivity and fertility as the driving forces behind the transition from the Malthusian era to the Modern Growth era.

They used a two sector framework, agriculture and industry. The assumptions were that agricultural productivity and growth income makes food prices lower, and therefore raising children relatively less expensive. However Industrial productivity and income growth raises the price of foods, and make raising children relatively more expensive. Their hypothesis was there would be an agricultural revolution first, greatly improving the productivity of the sector, an adjacent development was that since food prices would drop because of the aforementioned increase in productivity, and with that, there would be an increase in the fertility rate. The agricultural revolution would be followed up by an industrial revolution, letting the fertility rate and the population growth drop again. All the events occur endogenously. They predict that after these two revolutions, the country would be on a balanced growth path with zero population growth, and no exponential economic growth.

This hypothesis was also tested with data collected for Germany, England, France and Sweden. They did find a negative correlation between the crude birth rate and the relative price of food, for all four countries. According to the authors, this is especially good in the case of France, where earlier attempts to explain the growth path of the country did not fit the standard theory as well as the model developed by the authors. Furthermore, the authors believe this model is able to complement the standard model, as well as older endogenous growth models.

Strülik and Weisdorf wrote another article, where they tried to make a model which predicted the initial negative and later positive relationship between child mortality and the net population growth (Strülik & Weisdorf, 2008b). This model showed the interaction between technological progress, mortality, fertility and economic growth in the transitional process. For this model, they primarily used the model they developed in the aforementioned article, while adding different elements from own work (Strülik & Weisdorf, 2008a; Strulik, 2008; Weisdorf, 2008) .

This is an important article, in the sense that it explains the increase in the population, not as people having more children, but as the death rate going down, allowing for people to live longer, and thereby increasing the population. In evidence acquired by the authors, the birth rate for England shows an increase from 34 births per 1000 persons in 1771, to 41 births in 1821. But after that, the birth rate falls to the original level about 10 years later. The Crude death rate, however, falls from 35 deaths per 1000 persons in 1731 to 22 deaths per 1000 persons in 1831, making the decrease in death much higher than the increase in births.

The model they developed, shows to be robust despite when the model is modified. For example, while in the original model, there is no growth in the steady state, it is possible to change this to a constant positive growth, when one also changes the no population growth to a positive population growth. The qualitative results of the model will not be affected in this case.

2.2.2 Empirical Research

Initiating Factors

Besides writing the article that is the basis for this thesis, Oded Galor, among others, also researched the initiating factors behind this growth model. In 2002, together with Omer Moav, he wrote about the influence of natural selection on this model (Galor & Moav, 2002). The idea was, that the traits mankind developed in the struggle for survival, aided in the take-off from Malthusian stagnation towards modern economic growth.

The model has four characteristics: First, there is a Malthusian world, with the typical characteristics stated in the Unified Growth Theory. Second, it incorporates the following traits of the Darwinian Evolution theory; variety, intergenerational transmission of genetic traits, and natural selection. As a third element, the human evolution links to the economic growth process. The fourth and last element links the rise in rate of technological progress to the demographic transition, sustainable economic growth and the rate of return to human capital (Galor & Moav, 2002, pp. 1137-1141).

Instead of natural selection, a second historical explanation could be that the initial technological level of civilizations is a basis for the wealth of nations today. This premise is researched by Comin, Easterly and Gong (Comin, Easterly, & Gong, 2010). They try to answer the question if the level of sophistication of a country of area in 1000 B.C. could be a significant influence on the national economic development today. They do this by creating a simple model, where the cost adopting new technologies is dependent on the current stock of technologies. The authors have also collected a dataset spanning from 1000 B.C. until 1500 A.D., and divided this into two periods; from 1000 B.C. until 0 A.D., and from 0 A.D. until 1500 A.D.

This dataset is constructed as follows: The authors took an existing dataset, namely that of the Atlas of Cultural Evolution, and used the data to code each country. If a country had a certain kind of technology, it got code 1, if not, it got code 0. After that, the sum of all possible technologies was averaged, giving a technology rate on interval [0,1].

The results of the model give strong evidence that the level of technology in 100 B.C. has a strong association with the wealth of nations today. The results are also robust. When dummies for continents or geographic locations are added, the outcome does not change. According to the authors, this could be because a certain technology level can support a larger population, who can create more non-rival ideas, raising the technology level. This creates a virtuous circle, holding up until today and probably beyond. The authors also insist that this is only part of the complete explanation for historical economic development, since other factors are also conducing to (the absence of) economic development. This model alone does not explain difference in development between England and China, for example.

Another factor that could contribute to the difference in the course of economic development is the degree of geographic isolation of a country. This is researched by Quamrul Ashraf, Oded Galor and Ömer Özak (Ashraf, Galor, & Özak, 2009). They tried to find if the geographic isolation of a country, before there were reliable methods of transport by sea or air, had an influence on the economic development of that country. Although one might think that a low degree of isolation has a beneficial influence (through diffusion of technology), China was highly isolated in that time, and it did not seem to be bad for the development of that country.

The authors used the data of the "Old World", that is, Europe, Northern Africa and Asia. For countries in this geographical area, the degree of isolation is calculated by averaging the time required to travel from the capital of that country to every specific point on earth. The limiting factors are that only land routes are to be used, and difficulties on route (mountains, gorges, etc.) would increase the time required to travel. The results are that even though isolation has a negative effect on technology diffusion and trade, there is a beneficial effect of isolation on contemporary economic development. There is also evidence that the degree of isolation have had an effect on the variations in economic development today.

Parametric Model

Most articles regarding the Unified Growth Theory are purely qualitative. This is purely because it is a complex model. It is an article by Nils-Petter Lagerhöf that tries to quantify this model (Lagerlöf, 2006). He states that the main problem for this theory is the fact that it tries to explain everything in a single model. Because of all the endogenous variables that are influenced by multiple different parameters, has this model become a four-dimensional, nonlinear system of difference equations. Galor and Weil tried to analyze this, using two-dimensional diagrams with some variables held constant. In this article, the author tries to analyze this model by simulating it. To do this, he transforms the base equations of the model into parametric form. Next, he assigns values for the baseline simulation. These values are either taken from a different article, or stylized data from statistical databases.

The evidence found from this simulation is that the simulation does replicate the growth path as they are observed in real life. Moreover, the population growth rates replicate the observed data on population growth even more than in the original article by Galor and Weil. The original article does not show the oscillation that population growth had in history, while the simulation does. A possible explanation for this oscillation is that population expands when resources per capita are abundant, eventually generating a Malthusian backlash causing a decline in population, after which the cycle starts over again (Lagerlöf, 2006, p. 139).

Trade

O’Rourke and Williamson researched the wage/land rent ratios from 1500 A.D. onwards (O' Rourke & Williamson, 2005). They stated that the increase in living standards is not only because of the Industrial Revolution, but also because of the opening of trade. This lowers the transport costs, associated with trade. Since food prices in the overseas areas were cheaper, it became cheaper to import food and export manufactured goods. This lowered the land rents in England, while raising the wages of laborers. The wage/land rent ratio (w/r) in turn rises. This does not comply with the Malthusian w/r, which due to the slowly increasing population and quasi-fixed land should go down.

The great difference with the Unified Growth Theory is that this paper is more practical, whereas the article by Galor is theoretical. Trade really took off after the Industrial

Revolution, and cannot be swept under the rug as unimportant to economic growth. This is also stated by O'Rourke and Williamson, who say that the take-off of trade was one of the most important factors for European countries to escape the Malthusian era.

Galor and Mountford have tried to fit trade in the Unified Growth Theory (Galor & Mountford, 2008). Although the original Unified Growth Theory does not take trade into account, the authors believe that trade plays a pivotal role in explaining why the gap between developed and less developed countries have widened. The authors call this widening "The Great Divergence" (Galor & Mountford, 2008, p. 1143). They developed a theory based on the Unified Growth Theory. This model tries to show the twofold effect international trade has on the economic transition from stagnation to growth. This twofold effect is that expedited the economic transition in technologically advanced nations, while delaying the transition in technologically less developed countries. The expedition is caused by the fact that because of international trade, the economy will specialize in technologically advanced products, thereby demanding more skilled labor to make the products and machinery. In technologically less developed countries, the economy is pushed towards the less technological specialization, thereby reducing the demand for skilled labor and reducing the investment in the quality of the population. This pushes the country back in the economic development from stagnation towards modern economic growth. Trade will also influence the population growth because of this effect. In the less developed country, the increased gains from trade will spur the population growth, as it does in the Malthusian epoch of the standard Unified Growth Theory. In the developed countries, population growth will decline, as it does in the Modern Growth Regime.

This theory is tested by performing a cross country regression with trade as a share of GDP and the log of GDP per capita as the two most important independent variables. The most important dependent variables are the total fertility rate and the education rate. The results of this study are that there is evidence of validity in this theory, especially on the part of fertility. The authors state that the regression on education rate is also robust, however, with an average R^2 of 0.08, there is not a lot of correlation. The results show that trade has a positive effect on fertility and a negative effect on education in non-OECD countries, while the situation is reversed with the OECD countries.

The Effect of Human Capital

An effect of the Unified Growth Theory, as proposed by Galor, states that the level of human capital goes up after the adoption of the Modern Growth Regime. This is because of the higher level of technological progress, which calls for a higher educated population. However, Boucekkine et al. have another explanation for the increase in human capital (Boucekkine, de la Croix, & Licandro, 2002). They state that the level of education received depends on the accumulation of human capital over the years, and the survival law. They explained that people choose the time they receive education, they work and retire. This is dependent on the longevity of their lives. The older they get, the longer they will enjoy education.

Boucekkine et al. used an OLG model, where the accumulation of human capital depended on the vintage human capital. The authors also researched the effect of exogenous changes in demographics on the growth. Although they found that positive changes in the possibility of survival always induces a longer schooling period and a later retirement, it does not necessarily mean a higher growth per capita. There are two effects that influence the growth per capita: first, the mixed influence of life expectancy. At low levels of longevity, this is a positive effect. But after some threshold, it becomes a negative effect. Second, we have the negative influence of the ageing of the workforce. Also, the population growth will be large enough to maximize the growth per capita. This implies that there are enough students and pensioners.

3. Model description:

3.1 Introduction

The Unified Growth Theory has been developed in response to the inadequacy of previous endogenous growth models to provide explanation for the historical global and national data on economic growth. Together with David Weil, Oded Galor developed a unified model that could explain the historical data (Galor & Weil, 2000). The model characterizes three different regimes in this model: The "Malthusian Regime", the "Post-Malthusian Regime", and the "Modern Growth Regime" (Galor & Weil, 2000, p. 806). The model looks at the differences between these regimes, using the behavior of income per capita and the relationship between the level of income per capita and the growth rate of the population.

They characterize the Malthusian Regime as an era where technological progress and population growth are very slow, especially by modern standards. The income per capita (and because of the almost stagnant population growth, GDP as well) is constant. The relationship between income per capita and population growth is positive, i.e. as the population grows so will the income per capita.

The Modern Growth Regime is somewhat the opposite of the Malthusian Regime. This regime is characterized by a steady growth in income per capita and technological progress. Population growth and income per capita have a negative relation, a slow population growth results in a higher level of output and thus income per capita.

The Post-Malthusian Regime, or transition period, is characterized by a rise in income per capita, though not as fast as in the later period. Population growth goes up as well, since the Malthusian relationship between population growth and income per capita was still in place.

Next, the three stages of the theory will be explained. The conditional dynamical system of the economy is described using education and the effective resources per worker. This shows how the economy goes to the steady state equilibriums.

The model itself is an overlapping-generations economy. Activity extends over an infinite discrete time. In every period it produces a single homogenous good for which it uses land (which is fixed over time) and efficiency inputs of labor, which depends on households' decision in the preceding period regarding the number and level of human capital of their children (Galor & Weil, 2000, p. 811).

The next subsections will explain the basic form of the theory, and are taken from the article of Galor and Weil (Galor & Weil, 2000, pp. 811-825).

3.2 Production

Production occurs according to a constant- returns-to-scale technology that is subject to endogenous technological progress. The output produced at time t, Y_t, is

$$(1) \quad Y_t = H_t^{\alpha}(A_t X)^{1-\alpha}$$

where X and H_t are the quantities of land and efficiency units of labor employed in production at time t, $\alpha \in (0,1)$, and $A_t > 0$ represents the endogenously determined technological level at time t. The multiplicative form in which technology (A_t) and land (X) appear in the production function implies that the relevant factor for the output produced is the product of the two, which we define as "effective resources." Output per worker produced at time t, y_t, is

$$(2) \; y_t = h_t^{\alpha} x_t^{(1-\alpha)} \equiv y(h_t, x_t),$$

where $y_h(h_t, x_t) > 0$ and $y_x(h_t, x_t) > 0 \; \forall \; (h_t, x_t) \gg 0, h_t \equiv H_t/L_t$ is the number of efficiency units of labor per worker and $x_t \equiv (A_t X)/L_t$ is the amount of effective resources per worker at time t.

3.3 Preferences

The consumers have specific preferences in the different periods in time. Individuals live for two periods, and have a single parent. The first period, the authors call it the childhood period $(t-1)$, every individuals consumes a portion of the allocated time of the parent. The higher the parent wants the quality of the child to be, the bigger the portion of time the child will consume.

In the second period, the parenthood phase, the individuals have to divide one unit of time between performing labor and raising a child. They will choose an optimal number and quality of children and use the remaining time to work. The preferences take the form of the following function, and are defined over consumption above a subsistence level $\tilde{c} > 0$, and over the potential aggregate income of their children:

$$(3)\ u^t = (c_t)^{(1-\gamma)}(w_{t+1}n_t h_{t+1})^{\gamma},$$

Where n_t is the number of children of individual t, h_{t+1} is the level of human capital, or education, of each child, and w_{t+1} is the wage per efficiency unit of labor at $t+1$ (Galor & Weil, 2000, p. 812).

Further assumptions are that time is the only input needed for both the quantity as the quality of the children. The fraction of time needed for an individual of generation t to raise a child with education level e_{t+1} is defined as $\tau^q + \tau^e e_{t+1}$, where τ^q is the time needed to raise a child, no matters what quality of education it has, and $\tau^e e_{t+1}$ is the time needed to get the child to a get a unit of education for each child. Potential income for an individual is defined as $z_t \equiv w_t h_t$, where $w_t$is the wage per efficiency unit of output, h_t. We can then define the budget constraint for an individual as:

$$(4)\ \ w_t h_t n_t(\tau^q + \tau^e e_{t+1}) + c_t \leq w_t h_t.$$

The level of an individual's level of human capital is determined by the level of education and the rate of technological progress:

$$(5)\ \ \ h_{t+1} = h(e_{t+1}, g_{t+1}),$$

where the level of education is an increasing, strictly concave function, and the level of technological progress is a decreasing strictly convex function. Also, education will alleviate the effects of technological progress. Although the number of efficiency units of labor per individual may diminish because the technological progress moves from one state to another, the effective number of efficiency units of labor, i.e. the product of the individual's level of human capital and the economy's technological state (reflected in the wage per efficiency unit of labor), will be higher.

After optimizing the given equations, and proving some propositions, the authors found the following dynamical system, which is defined by the evolution of the output per worker, the level of human capital per worker and the effective resource per worker.

There are two different systems, or regimes. In the first regime, the consumption constraint is binding, whereas in the second regime, it isn't. From one of the propositions, it follows, that when the consumption constraint is binding, an increase in the number of effective resources per worker will increase the number of children, but not the quality of the children. When the consumption constraint is non-binding, an increase in effective resources will not change the number or quality of children.

3.4 Visualizations

To visualize parts of the theory, we will look at two groups of graphs; one group depicting the evolution of education and technological growth, and the other group depicting the conditional dynamical system. We will explain the graphs for each stage. The former group will show how the increase in technological progress will influence the need for human capital, while the latter will show the choice of the individuals for more income or better educated offspring. The common denominator is the education graph, which is shown as a curve in the former group, while the intersections with the technology curve are shown as loci in the latter. This also shows how the choices of individuals and the need for technological progress are intertwined.

3.4.1 Evolution of technology and education

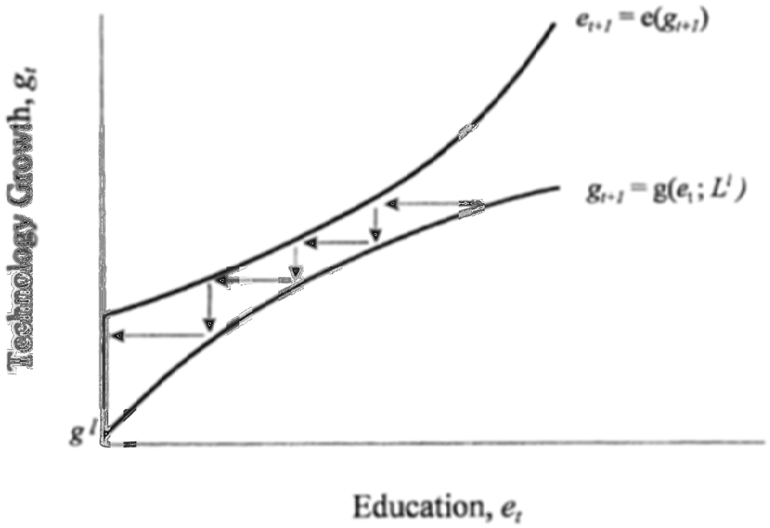

Figure 1: The Evolution of Technology Growth and Education for a Small Population (Galor & Weil, 2000, p. 818)

When there is a small population, like there was before the agricultural revolution in western countries, the evolution of education and technology growth rates show as in Figure 3. There you can see that there is only one stable point, point (0, g^l). This coincides with the notion that due to a low technological progress, there isn't a need for human capital.

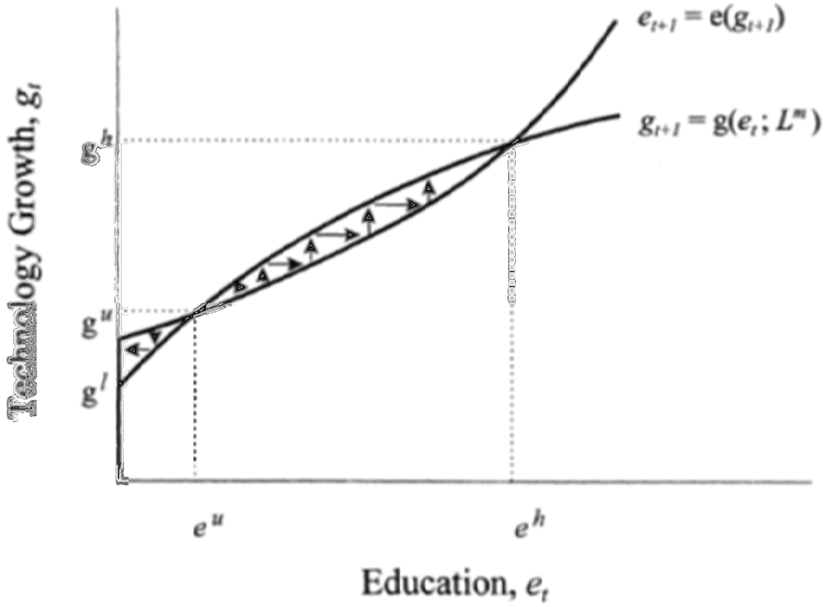

Figure 2: The Evolution of Technology Growth and Education for a Medium Population (Galor & Weil, 2000, p. 819)

When a country is in the transitional phase of the model, the evolutions of education and technological growth rates look as in Figure 2, where one can see two stable steady state equilibriums: (*0,* g^l) and (e^h,g^h). The evolution of technology has shifted upwards. Unless there are external shocks to the economy, the evolution of education and technology progress rate will go to the lower equilibrium, (*0,* g^l). Also, the equilibriums will rise with the size in population. This shows that human capital isn't that important until late in the transitional stage.

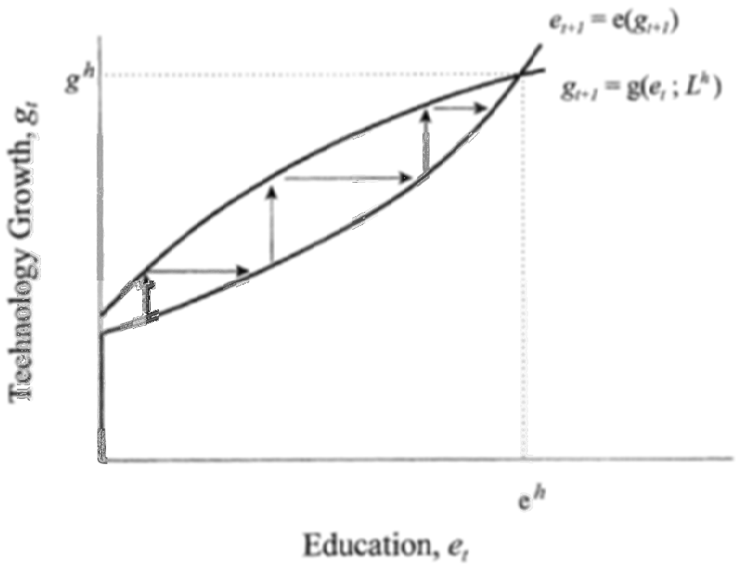

Figure 3: The Evolution of Technology Growth and Education for a Large Population (Galor & Weil, 2000, p. 820)

When the size of the population is large, Figure 3 shows the evolution of technology change and education. There is one stable steady state equilibrium, (e^h,g^h). In this stage, accumulation of human capital has become an important part of the development of the economy. It needs educated people to come up with new ideas to propagate a high technological progress rate, and to maintain the exploits that come from a high technological progress (e.g. machinery, computer systems).

3.4.2 The Conditional Dynamical Systems

With the first part explained, it is now time to look at the choice process for an individual.

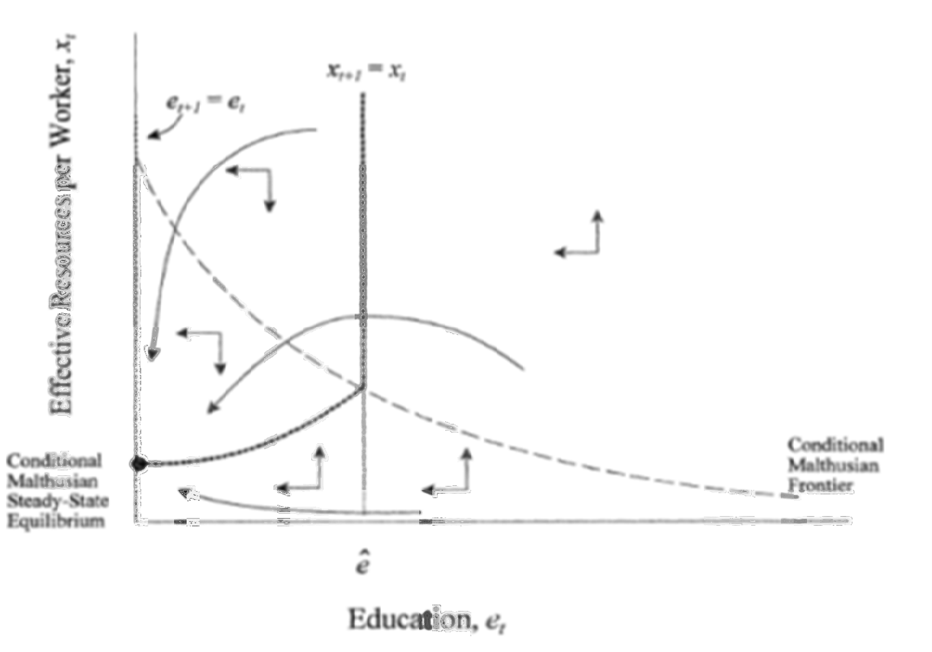

Figure 4: The Conditional Dynamical System for a Small Population (Galor & Weil, 2000, p. 822)

Here, we have the conditional dynamical system for a small population. Visible as the dotted lines are the $e_{t+1} = e_t$ line, this is the set of values (e_t, x_t) where education is constant over time; and the $x_{t+1} = x_t$ line, this is the set of pairs (e_t, x_t) for a given g_t, where the effective resources are constant over time. One can also see the Malthusian Frontier. Under this curve, the consumption constraint is binding. The intersection between these two lines, also called the EE and XX locus, will be the point of the stable steady state equilibrium. Since the EE-locus lies on the $e_t = 0$ line, and intersects the XX-locus at$(0, x_t)$, this is the point where the equilibrium will be. In the figure one can also see the paths one can take to get to the equilibrium. An individual will think it is more important to spend money on consumption goods than on education, partly because income will barely go over the subsistence level, partly because there is no need to from a technological point of view.

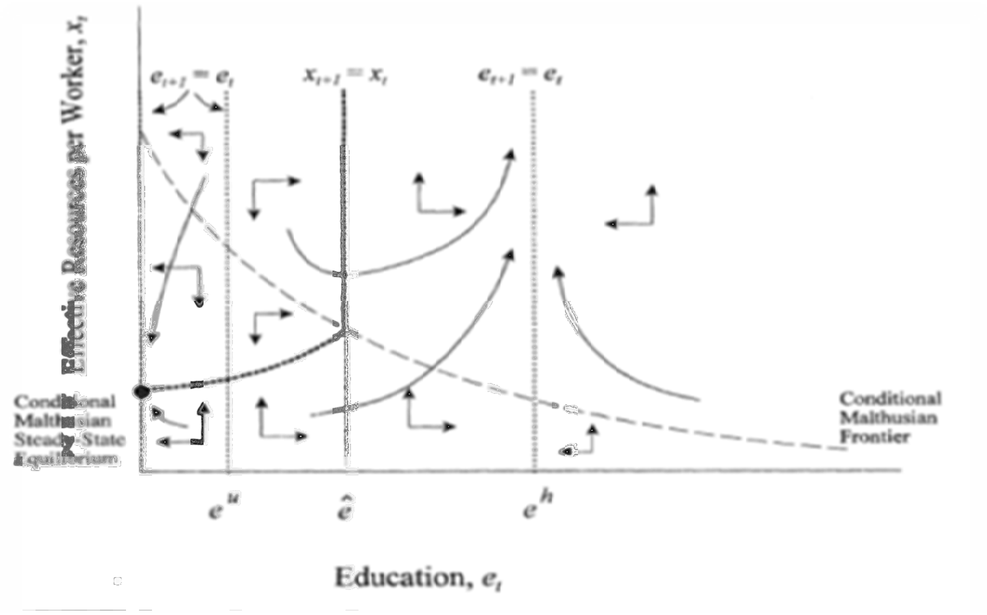

Figure 5: The Conditional Dynamical System for a Medium Population (Galor & Weil, 2000, p. 823)

In Figure 5, the evolution of education and effective resources per worker is shown when the country is in transition. Again, we have the Conditional Malthusian Steady-State equilibrium. But extra equilibriums have become present. This is equivalent with the presence of multiple equilibriums in Figure 2. The same explanation as with Figure 2 holds here, that is, in absence of an external shock, the evolution of both variables will go to the Malthusian Steady-State equilibrium.

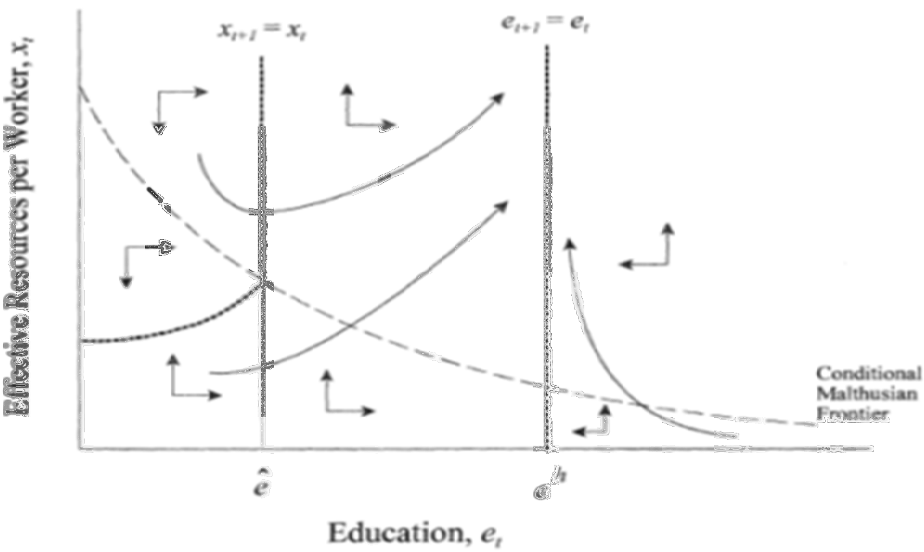

Figure 2: The Conditional Dynamical System for a Large Population (Galor & Weil, 2000, p. 824)

Finally, we have the evolution of education and effective resources per worker for a large population. The Malthusian Steady-State Equilibrium has disappeared, and as in Figure 6, there is an equilibrium at the education level e_h. Since the education locus is leading now, the choice will be made to spend money on education, instead of just consumption.

In this scenario, the economy will finally cross over the Malthusian Frontier and enters the Modern Growth Regime, where the consumption constraint is no longer binding.

3.5 Main Hypotheses

With the basis of the theory explained, we now look at the different stages in development. The different hypotheses for the different stages are listed, and the intuition behind each stage will be explained.

3.5.1 Malthusian Regime

- The main hypothesis for this stage is that there is little population growth, little technological progress and a near zero growth of income per capita. Moreover, population growth and income per capita have a positive interaction. If income per capita grows, population growth will rise as well.

One can now make the scenario for the Malthusian Regime of Unified Growth Theory. Consider a non- or slightly developed country, with a low population, a small rate of technological change and no education, since the parents have no incentive to provide it to their offspring. This state is depicted in Figure 3 and Figure 6. For a given rate of technological change, both education and effective resources per worker are constant, and following from equation (2) and (6), so is the output per worker. The effects of external shocks will be extinguished through the nature of the Malthusian economy. For example, an increase in income would be spent on the rearing of more children, instead of using the extra income increasing the quality of the existing children. Population growth is very small, and intertwined with the rise in the rate of technological progress.

3.5.2 Transitional stage

- This stage can be characterized by increased growth in per capita income, population growth and technological progress. The positive relationship between income and population growth remains in this stage.

Over time, the growth in population and rate of technological change will shift the steady-state equilibrium in Figure 3 and 6 upwards, while output per individual stays constant at subsistence level. After a certain period, the curve for the rate of technological change in Figure 3 will have shifted upwards to such a level, that the curves of rate of technological change and education will have taken the shape of Figure 4. In this system, there are multiple steady-state equilibriums, one of which will still be the Malthusian Equilibrium, with the characteristics stated above. Equilibrium is characterized by a higher level of education and rate of technological progress, an increasing amount of income per capita, and a moderate population growth. However, since a Malthusian Equilibrium still exists, an absence of large shocks will cause the economy to remain in this steady-state. A large shock could indeed make the economy jump from the Malthusian state to the Modern Growth Regime.

3.5.3 Modern Growth Regime

- The main hypothesis is that in this stage, the income per capita grows steadily at a high percentage, certainly compared to the Malthusian and transitional stages. Population growth and income per capita have a negative relationship in this stage.

The evolution of education and standard of living are more complicated. This is because of the two effects of technological progress on the evolution of population. It induces parents to make their children higher educated, lowering the population growth. But by increasing the potential income, technological progress will also increase the fraction of time parents use to rear their children. The theory states that the second effect initially dominates the choice of the parents, thereby increasing the population growth. However, after the economy transverses the Malthusian Frontier, the first effect will become the dominant effect. This is because further improvements in technology will no longer have a time-changing effect on the raising of children, whereas the high rate of technological progress will increase the amount of education given to each child. At this point, the tie between population growth and technological progress will sever, decreasing population growth and increasing the rate of technological change. However, it is not possible to say how much the population growth will decrease, and whether it will still have a positive relationship with the rate of technological progress. There are different scenarios possible concerning the population growth and technological progress, the theory does not make firm predictions about both. It could be the case that population growth in the Modern Growth Regime is 0, making this Regime a steady state. But population could also be either positive or negative, with subsequent changes in the level of education and technology.

4. Classification Analysis

4.1 Methodology

Next, we will review the data of a selection of countries, to see where they are on the road to the Modern Economic Growth Regime. Because there are three distinctive periods in the hypothesis, each with their own set of parameter values, we can collect data from a databank and see which path they seem to have. If we can line up the found data with a specific period of development, it could be stated that that country would be in that stage of development.

Furthermore, we can make suggestions what actions a country has to take, to get the country in the next stage. With some countries, there will be some interesting questions. For example; did the one-child policy in China actually help them traverse the transitional stage more quickly? Does the riches in oil push some countries in the Modern Growth Regime, or will those countries have a problem as soon as the oil fields dry?

The selection of the countries will be as follows: First, to get a baseline, we will retrieve data for a selection of developed nations, particularly from Western Europe, as well as the United States of America, Japan and Hong Kong. The last three countries are not mentioned in the original article by Galor (Galor & Weil, 2000), but can be counted as important, developed economies. We sort the data and show the graphical evolution of the different variables.

Next, there will be a selection of different underdeveloped and up and coming countries. This includes the BRIC-countries (Brazil, Russia, China and India), other well to do and up and coming Asian countries (The remaining three Tigers: South Korea, Singapore and Taiwan), and a selection of other countries. Of the African countries, we will review South Africa, Ghana, Senegal, Kenya, Sudan and Nigeria. For Northern Africa and the Middle East, we will review Algeria, Saudi Arabia, Egypt, Jordan, the United Arab Emirates and Syria. For South America, I chose Peru, Chile, Honduras, Mexico and Colombia. I also want to add Pakistan, Bangladesh, Indonesia and Thailand to the selection of Asian countries.

The research will focus itself onto three different variables; GDP growth per capita, population growth and patents filed by residents. The first two variables are self-explanatory, since the Unified Growth Theory is based on those variables. I decided to use the patents filed by residents, since I feel that this is a good proxy for the rate of technological progress. Patents are individual, so no two persons can file the same patent at a different time. Technological progress is characterized by new ideas and processes, and since patents protect these new ideas, it stands to reason that patents will be a good proxy for technological progress. I only use the patents filed by residents, so not to contaminate the data with patents of the same product or process in different countries.

4.2 Data

As data source, I will use the Historical Database by Maddison (Maddison, 2009). This particular data source has data for GDP per capita and population from 0 AD until 2008, although annual data is only available from 1870 onwards. This means that we can obtain data for 6 familial generations or 7.5 cultural generations. The duration of a familial generation is 25.2 years and the average duration of a cultural generation is 18 years. From the dataset we can calculate the GDP growth rate per year and the population growth rate per year. The GDP per capita is shown in 1990 Geary-Khamis dollar. The population growth is calculated with the data on population from 1870 onwards. Both variables are then averaged for a 20-year time period. This period is chosen, because this in between a familial and a cultural generation, and hacks the data into 7 even periods. When there wasn't yearly data, the average growth rate was calculated for that period.

There are some limitations, when using the Maddison database. First off, data for the Russian Federation is scarce for the period <1990. There is no data on GDP per capita or population in that period, except for one data point in 1973. This limitation is present in both the databases of Maddison and the World Bank. This will mean that we cannot really give an indication for Russia on where on the path of development this country is. In a lesser extent, this limitation is also present for the bulk of the African countries and some of the Arab and Asian countries. For these countries we miss either GDP per capita data or both variables for the pre-1950 period. This will make our research less accurate, but we do have enough data for 3 periods. Another downside is that we do not have any data on patent applications by residents for Taiwan. This means that we cannot get an indication of the technological progress rate in Taiwan. But I will leave Taiwan in the selection on the basis that we have enough data of the other 2 variables to give a good estimation where Taiwan is on the path to economic development. However, Taiwan will be one of the countries that will be scrapped after this section of research.

The results of the test will be discussed individually where needed, but for space, we will show the graphical results in groups of four or five countries. The division of the groups will be; developed countries, the BRIC countries, the Asian Tigers, a Latin American group, a group for the African countries with the data starting in 1950, A North African and Middle Eastern group, and two other groups. One group contains Indonesia, Thailand, Ghana and South Africa. The Other group contains Bangladesh, Pakistan, Saudi Arabia and the United Arab Emirates.

This part of the research is all about the trends in GDP per capita growth rates and the population growth rates. Using the premises outlined by the Unified Growth Theory, each country will be classified in one of the three stages; the Malthusian, transitional or Modern Growth stage. To understand what we are looking for, we will use the outcome of the baseline simulation, done by Nils Lagerlöf (Lagerlöf, 2006):

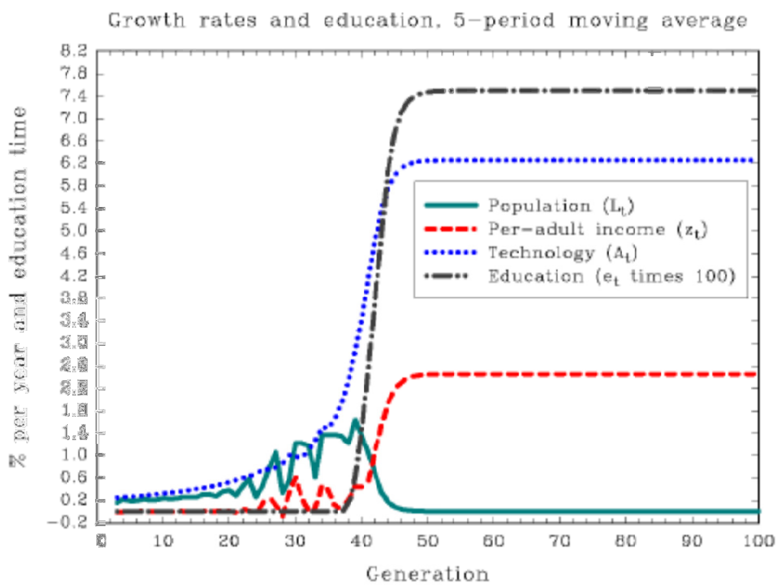

Figure 3: Simulation of parametric UGT model (Lagerlöf, 2006, p. 130)

Here we must focus on the path of the green and the red dotted lines. If we can match up the growth paths of these lines with the trend lines of our graphs, we can estimate where along the line these countries are in terms of economic development.

4.3 Results

4.3.1 Developed Economies:

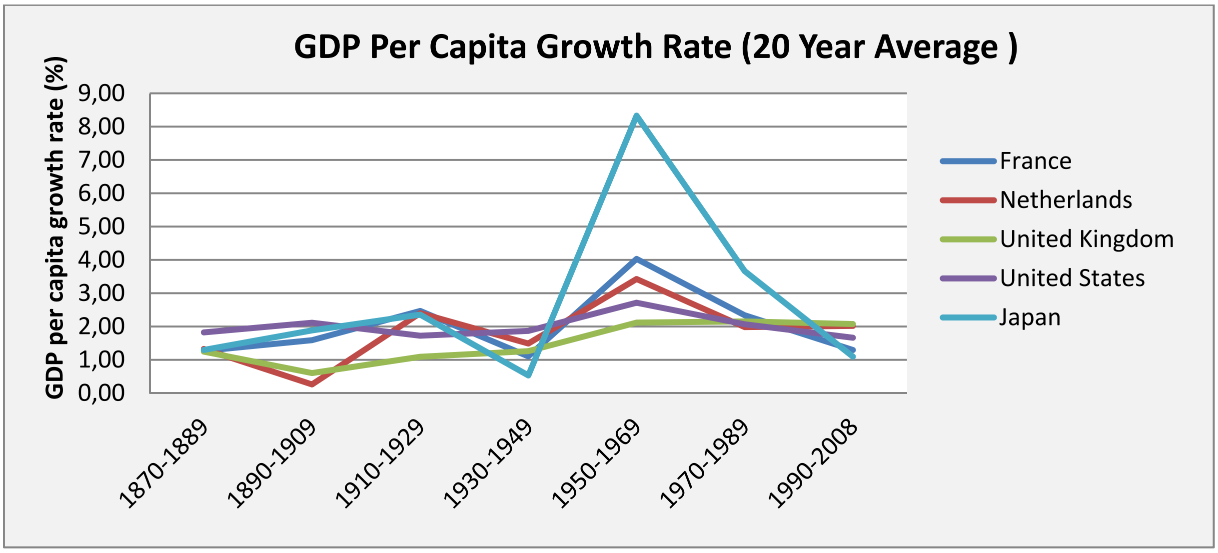

Figure 4: GDP per Capita Growth Rate for Developed Countries

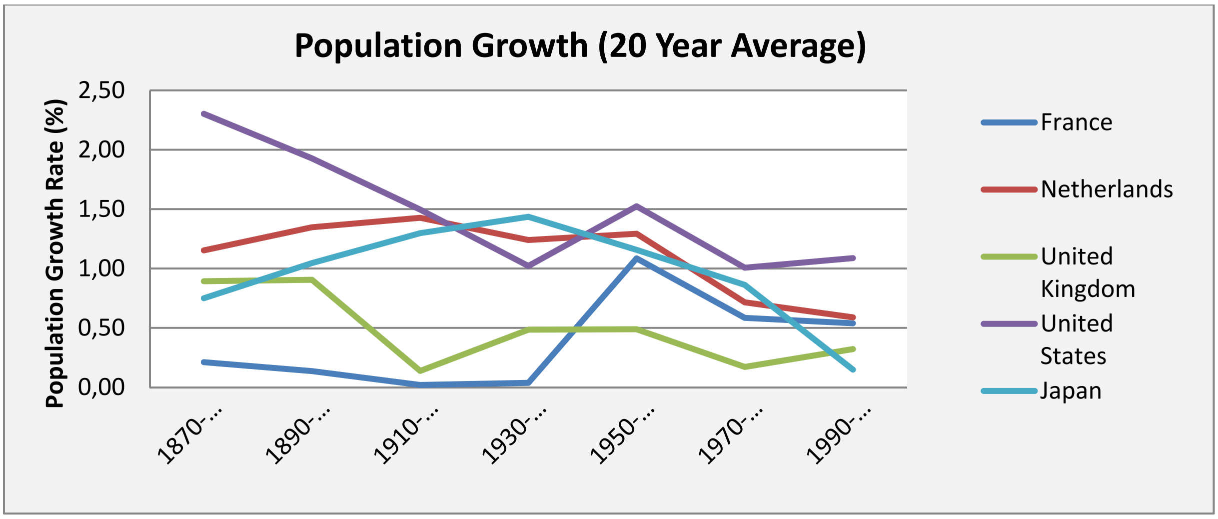

Figure 5: Population Growth Rate for Developed Countries

Let us start with the United Kingdom, since this country is also used in the empirical studies by other authors. At the start of our measurement in the year 1870, the United Kingdom was at the end of the transitional phase of economic development, according to Weisdorf and Strülik (Strülik & Weisdorf, 2008b). They calculated a Net Reproduction Rate (NRR) of around 1.5% in 1870, and in 1921 the NRR dropped to 0.7% (Strülik & Weisdorf, 2008b, p. 4). Since their NRR does not include immigration and emigration, their numbers differ from mine.

However, if we look at the trend of the population growth, we can clearly see that there is a downward trend. This is in line with the expectations of the model. If we look at the GDP per capita growth rate, we can see a slow but steady increase for the United Kingdom. More important, we can also see that the trend line is very stable, no big increases or decreases. We must remember that the points in the graphs are 20-year averages of the GDP per capita growth rates, so an economic downturn, like a recession, is averaged out with the subsequent economic upturn.

When we look at the Netherlands, the United States and France, we can see that for the GDP per capita growth rate, the countries show a similar path. All show either a slight increase in the growth rate or a stable path. These growth paths support the notion of a Modern Economic Growth.

Looking at population growth, we see that although the countries take a different path, the population growth rate of France and the Netherlands are practically the same level. In the United States, the population growth is on a downward trend, but higher than the other countries in this graph.

Japan is the odd duck out in this graph. Although we generally view this country as a developed nation, it does show the signs of a technological follower. The high GDP per capita growth rates in the period 1950-1989 are signs of this. Technological followers can achieve higher growth rates than technological leaders because they can implement existing technology relatively cheap, not incurring the costs of developing this technology. Technological followers have a relative advantage over technological leaders in this aspect. The speed with which it has moved towards the technological leaders is impressive. It has overcome the gap within 60 years, and it even shows the signs of a near 0% population growth, as Galor predicted would happen in the Modern Growth Regime. Off course, we cannot be sure if that will happen, at least not until some decades in the future.

4.3.2 BRIC-countries:

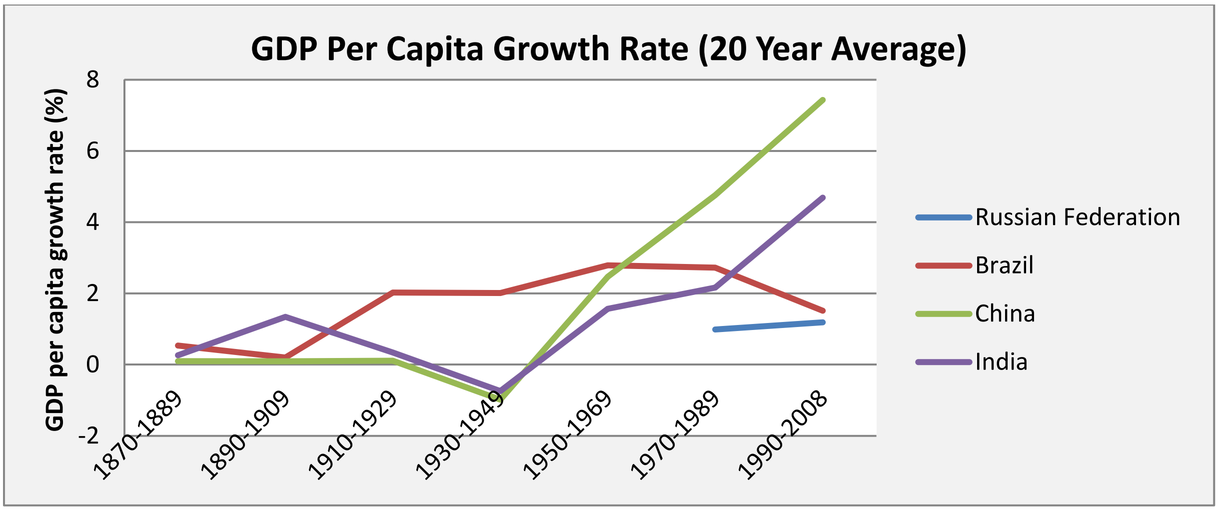

Figure 6: GDP per Capita Growth Rate for the BRIC Countries

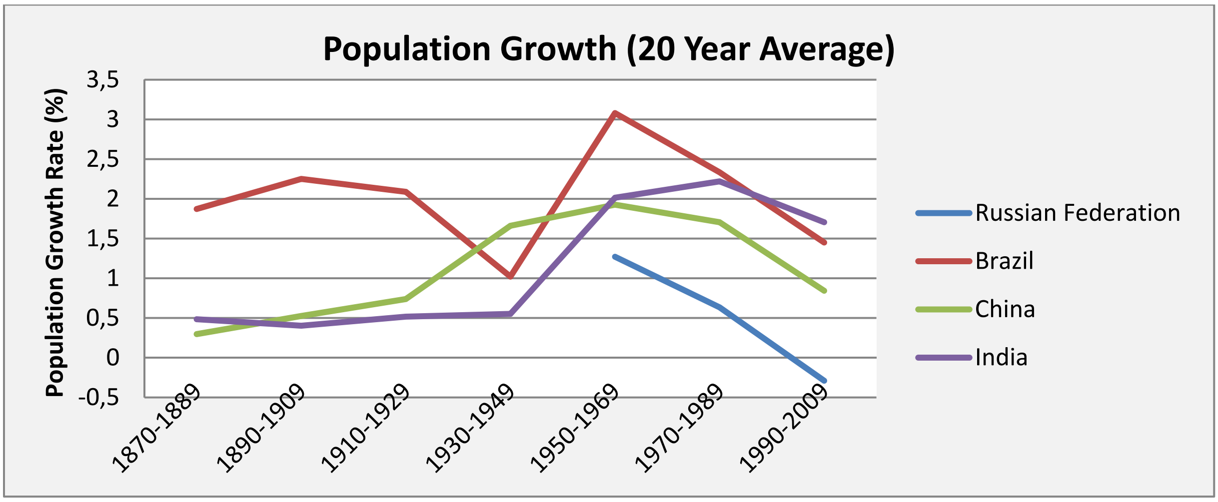

Figure 7: Population Growth Rate for the BRIC Countries

Let us look at the BRIC countries now. China and India have similar slopes for both the population growth rate and the GDP per capita growth rate. China seems to be the better of the two, with a population growth rate that has lowered to levels seen in the developed countries. But on average, it still shows a growing trend. So we have to look at the next 20 years, that is, the next generation, to be sure that China will become a country with a developed economy. To that end, we could use the prediction that is given in the Maddison historical database. It states that the predicted level of population in China in the year 2030 will be 1.461 billion. This would result in an average growth rate of 0.44%. This result puts the economy of China in a developed state. However, a big reason for the low population growth rate in China is the One Child policy. This policy, which started in 1979, has been stated to have prevented at least 250 million births in the period 1980-2000 (2000). To put this in perspective; if the policy wasn't implemented, China would have at least 170 million more inhabitants in the year 2000, than it had in 2010.

The average GDP per capita growth rate is high and has risen rapidly over the course of 80 years. This is mostly because of the low initial GDP per capita in the period 1930-1949. The lowest point of the GDP per capita in that period was GK$ 448, while it has risen to GK$ 6725 in 2008. And while this is an impressive growth, China does need to raise the GDP per capita even more, to really be counted as a highly developed economy. Even more important, if China would keep this growth rate up, it would be the country with one off the highest GDP per capita in less than 20 years. It cannot keep up this growth rate for too long. So I predict a decline in the growth rate to a more sustainable level in the coming periods. So for now, I would classify China in the early stage of Modern Economic Growth. China shows the signs of a technological follower state, with the high GDP per capita growth rates. These rates are necessary to play catch-up with the technological leader states, as explained the previous subsection.

While India has the same general shape as China, there are some differences between the two. First off, India shows a much higher population growth rate, with the average of the last 20 years being 1.7%. Also, the general trend for the last 140 years is highly positive. One can see that the transitional stage for India has started around 1950. When one looks at the GDP per capita growth rate, there is a difference to the transitional stage as stated by the theory. The theory states that the GDP per capita doesn't grow in the transitional stage, due to the growth in the population. However, it seems like GDP per capita does rise in the last 80 years. Again, this can be evidence of the fact that India is actually in the early stage of a Modern Growth regime. The difference is that the population still chooses to have relative many children. This could be because of cultural reasons. In India, it is usual that the children support the parents when they get older.

Brazil has both a fluctuating population growth and GDP per capita growth rate. The latter is more constant than the former. The large difference between Brazil and the aforementioned countries gives evidence for the notion that Brazil is actually in the transitional stage.

For Russia, an informed decision cannot be made, since there are too little datapoints.

4.3.3 Asian Tigers:

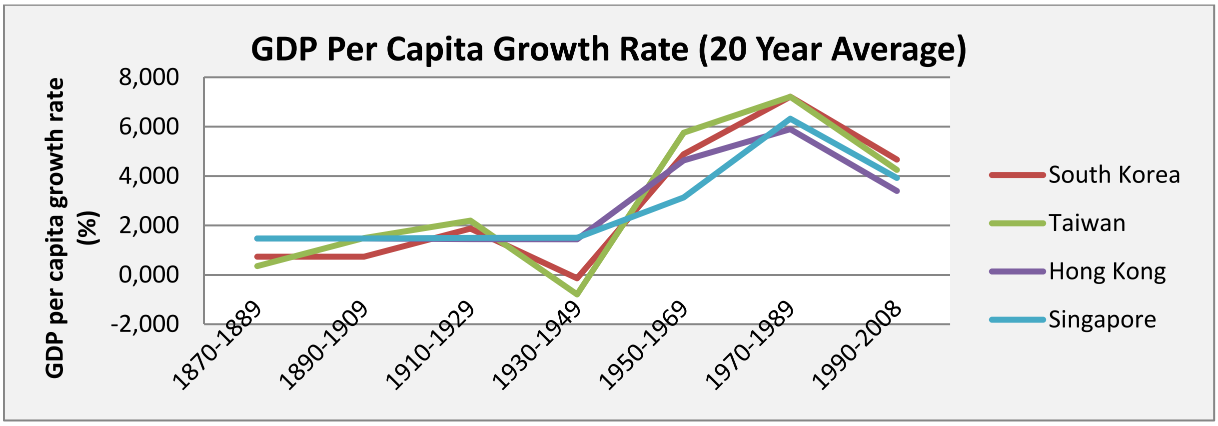

Figure 8: GDP per Capita Growth Rate for the Asian Tigers

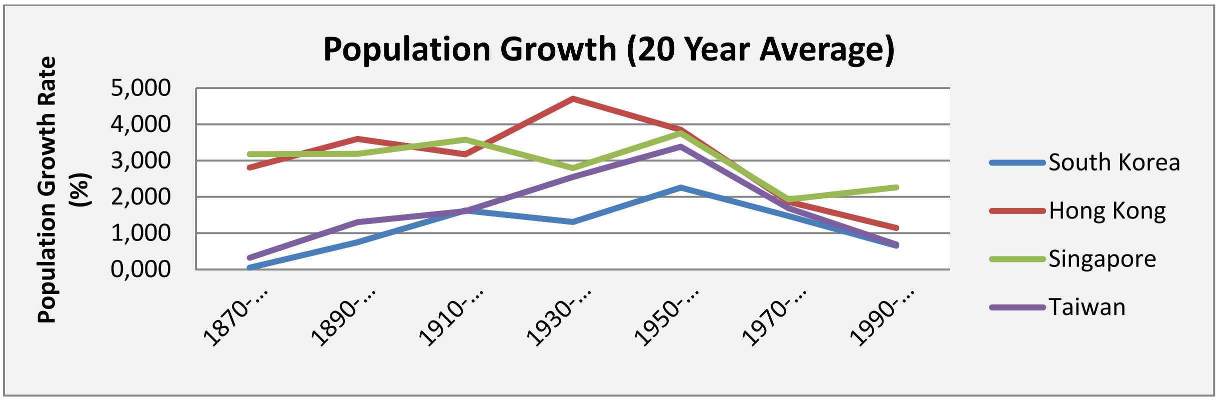

Figure 9: Population Growth Rate for the Asian Tigers

Since all of the countries show the same general growth paths, these countries will be discussed as a group. All countries look like technological followers in the Modern Growth Regime. The catch-up occurred in the period 1950-1989, after which the growth rates started their descent towards the level of that of the technological leading nations. The same can be said for the population growth rates. These follow the path, as predicted by the model.

What the graph of the GDP per capita growth rate doesn't show, is the relative volatility of the growth rates. Although the averages show a stable path, within those 20 years averages there are a lot of variations. For example, Hong Kong has experienced a top growth rate of 9.18%, as well as a low point of -5.67%. We do not see the same variation in the GDP per capita growth rates with the 'established' countries. So if there is improvement to be made, besides finishing the catch-up with the technological leading nations, it is to reduce the volatility of the growth rate.

4.3.4 African countries:

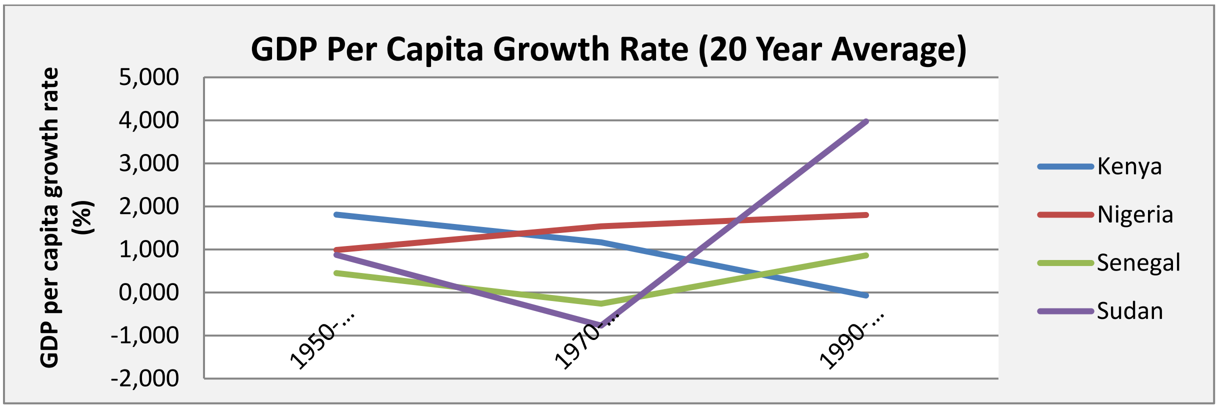

Figure 10: GDP per Capita Growth Rate for African Countries

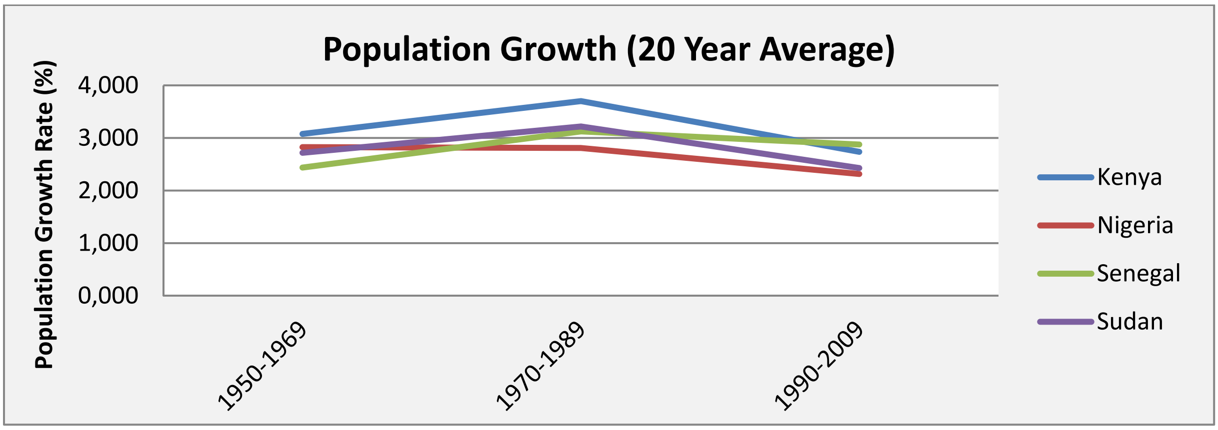

Figure 11: Population Growth Rate for the African Countries

The African countries show us a whole other picture than the previous three groups. Since we do not have the full 7 time periods, we cannot give a certain indication of the stage these countries are in, but the graphs show the impression that at least three of the countries are in the transitional stage of the Unified Growth Theory. To recall, this stage is highlighted by the facts that the GDP per capita id relatively low, while the population growth is relatively high. Also important to remember, is that without a positive external shock, these countries will remain in a Malthusian state. Kenya, Nigeria and Senegal all show these characteristics, where Nigeria could be a small case of doubt, with its GDP growth rate of 1.8%. However, the other two countries have the definite characteristics of countries in transition.

Sudan has a relatively high GDP per capita growth rate in the last 20 years; this is mainly because of oil production and export. This has also sparked the revival of light industry. However, population growth hasn't fallen that far. I would classify this country at the end of the transitional stage, and the beginning of the Modern Growth Regime. Since Nigeria has the same characteristics as Sudan, one could not be blamed to classify Nigeria in the same region of economic development. However, I feel that since Nigeria is a technological follower, its growth rate should be higher to gain up on the technological leaders. And since we have no signs that this is happening, one should group Nigeria at the end of the transitional stage.

4.3.5 Muslim countries:

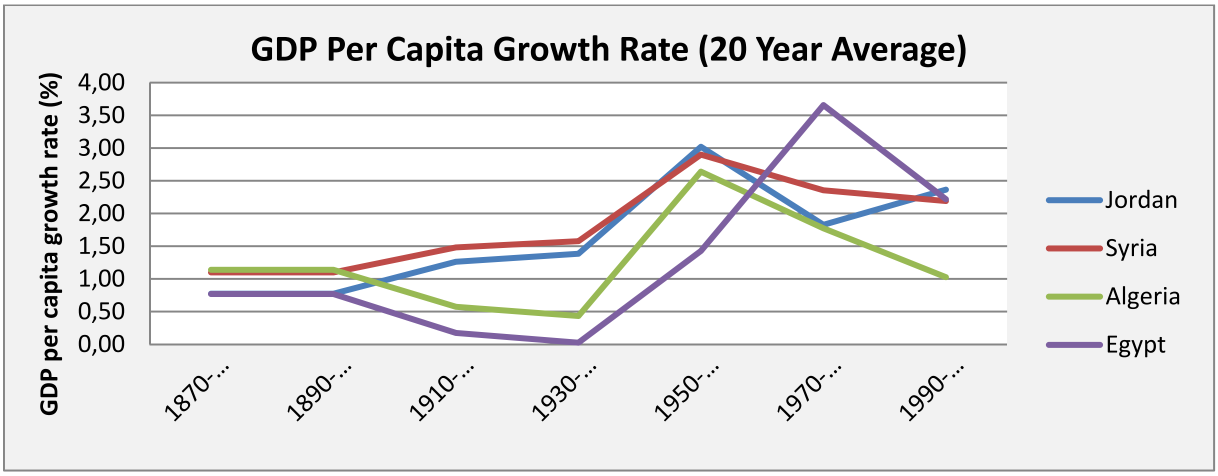

Figure 12: GDP per Capita Growth Rate for Muslim Countries (1)

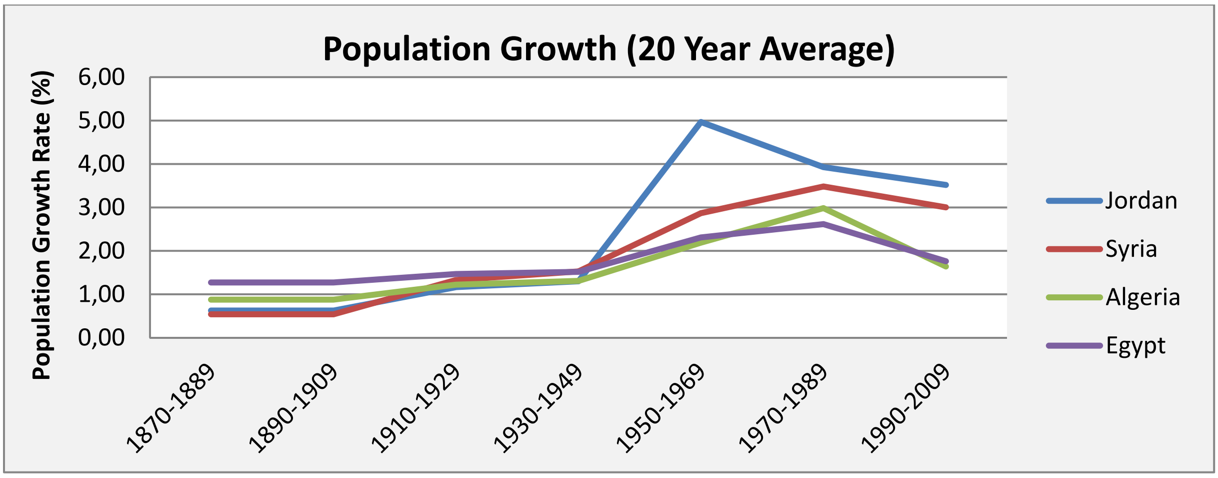

Figure 13: Population Growth Rate for the Muslim Countries (1)

This is the first of two groups of countries, where the predominantly religion is Islam. First off, we see a lot of fluctuations in the course of the per capita growth rate. The population growth rates do show a positive relationship with the GDP per capita growth rate, suggesting that these countries are in the transitional stage.

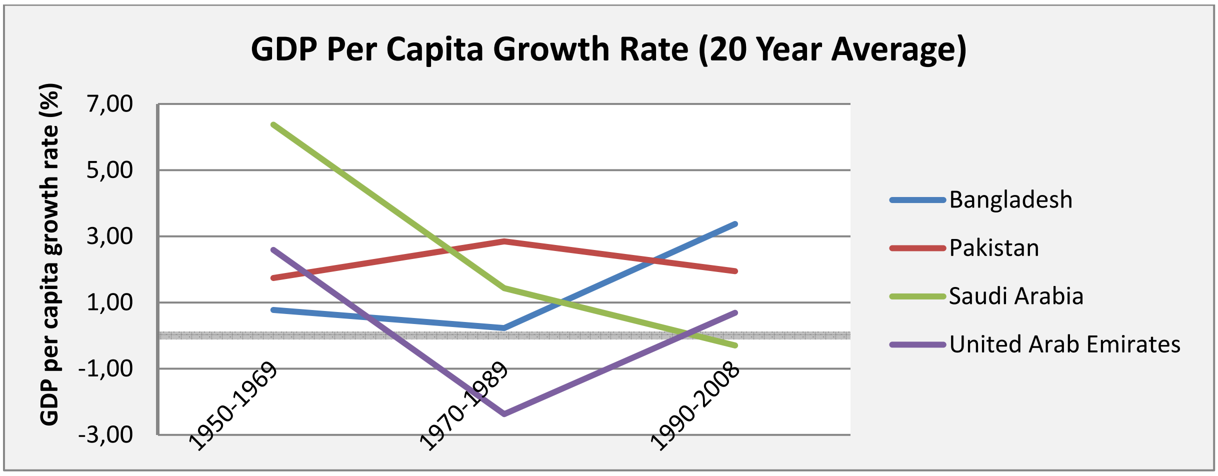

Figure 14: GDP per Capita Growth Rate for Muslim Countries (2)

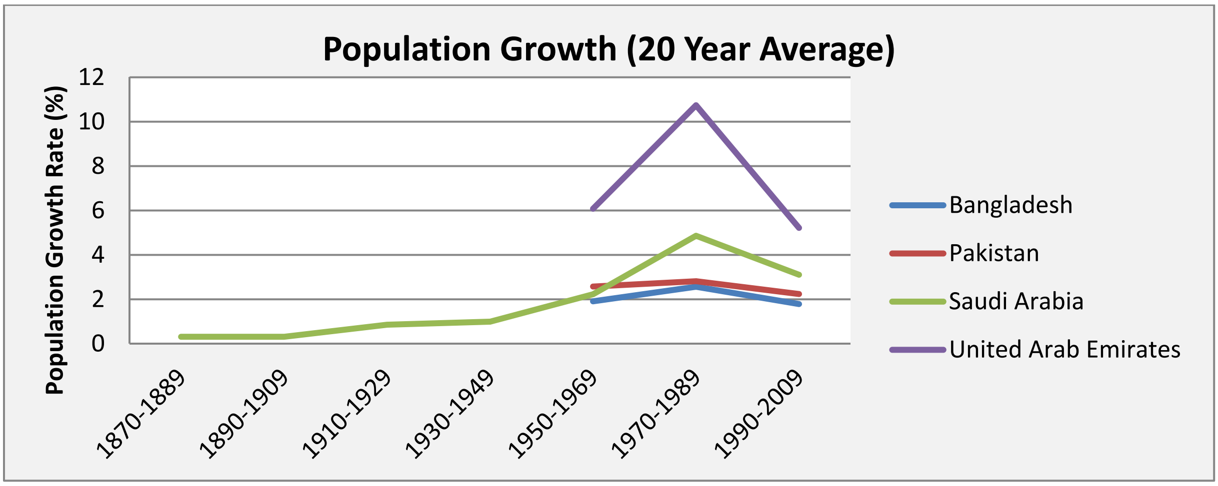

Figure 15: Population Growth Rate for the Muslim Countries (2)

This is the second of the two groups. Again, we cannot be as sure about these countries as with most of the other groups, since we only have data on three generations. The United Arab Emirates seems to be in a transitional stage, mainly because of the negative relationship between the population growth and the GDP growth rate. However, in real life, the UAE is known to have a highly developed economy. So, the graphs do not show the actual state of the economy. This could be because the GDP is highly affected by the earnings coming from the export of oil products. A lower price for oil thus greatly reduces the GDP. Saudi Arabia has the same problem. Its economy depends for a large part on the export of oil. This skews the results. Also, it is true for both countries that, while the average rate is high, population growth is steadily going down in the last 20 years. The 2009 growth rates for the UAE and Saudi Arabia have been 3.82% and 1.91%, respectively. The 20 year averages are 5.22% and 3.10% respectively. With the planned diversification of both economies, the economic dependence on oil exports should diminish in the future.

Pakistan and Bangladesh seem to be in a similar situation, although Pakistan has a slight edge over Bangladesh, because of the higher initial GDP per capita. Because of the high population growth rate and the erratic behavior of the GDP per capita growth, these countries are in the transitional stage.

4.3.6 Up and coming economies:

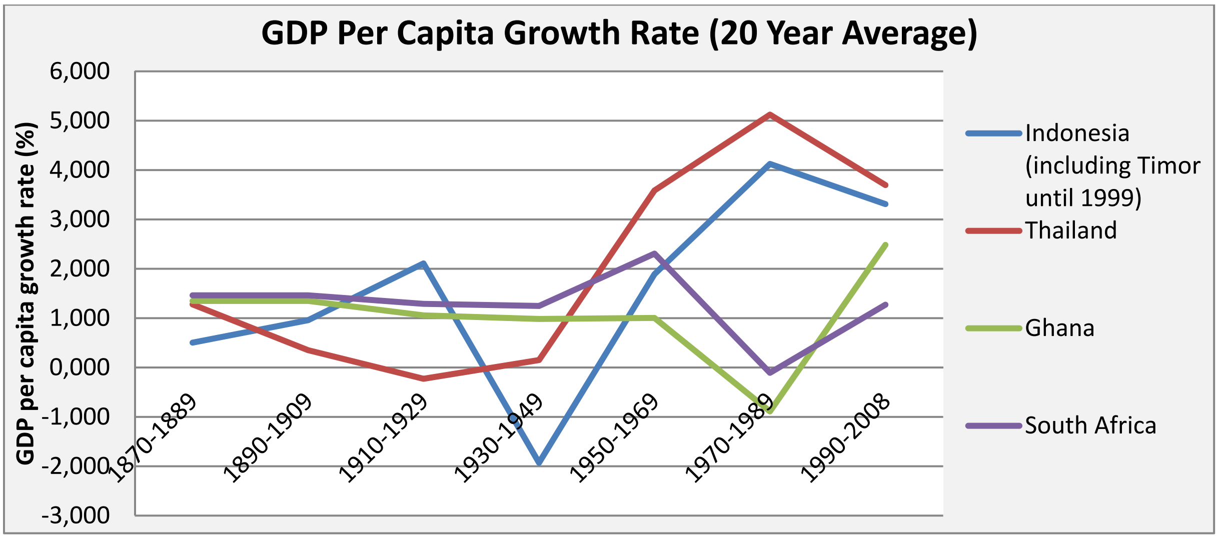

Figure 16: GDP per Capita Growth Rate for Up and Coming Nations

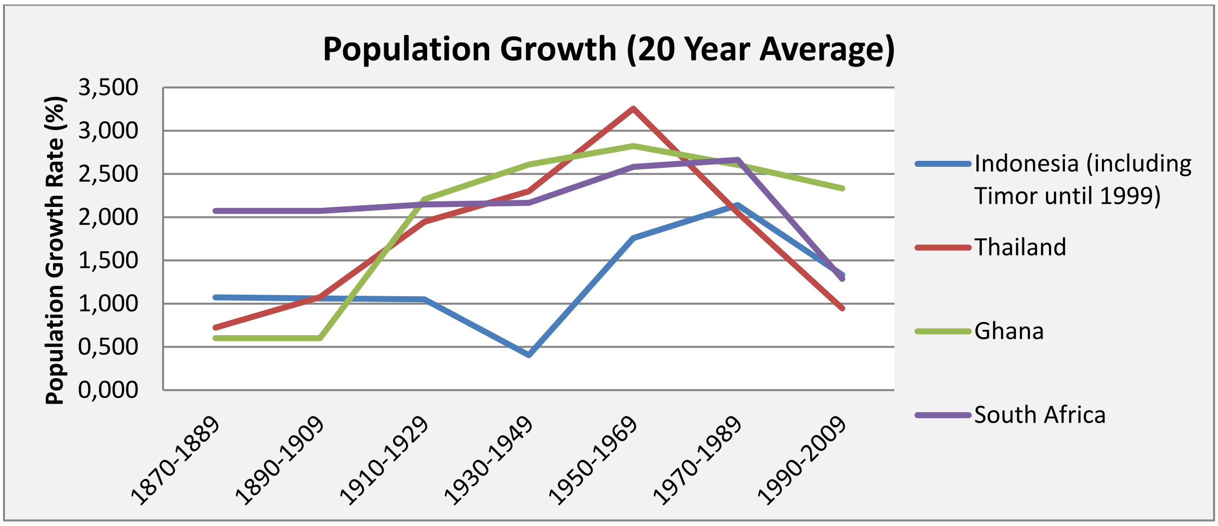

Figure 17: Population Growth Rate for Up and Coming Nations

Indonesia shows a positive relationship between GDP per capita growth rate and population growth. Also, the growth rates are significantly higher than 0%. For this, we can qualify this country in the transitional phase.

Thailand shows a similar in the GDP per capita growth path and population growth, at least for the last 40 years. Again, we could classify this country as being in the transitional phase of the Unified Growth Theory.

Ghana is on the way back from a negative external shock. This external shock was induced by the mismanagement of the economy in the 1970's. Since then, a recovery program has put the economy back on the right track. Also, population growth is steadily going down, another sign that the country is on the right track, as far as the Unified Growth Theory is concerned. However, it is still in the transitional stage.

South Africa is the last country in this group. This country is in the Modern Growth Regime for a while now, and the only negative external shock was in the 1980's, when international sanctions against the Apartheid regime crippled the economy.

4.3.7 Latin American countries:

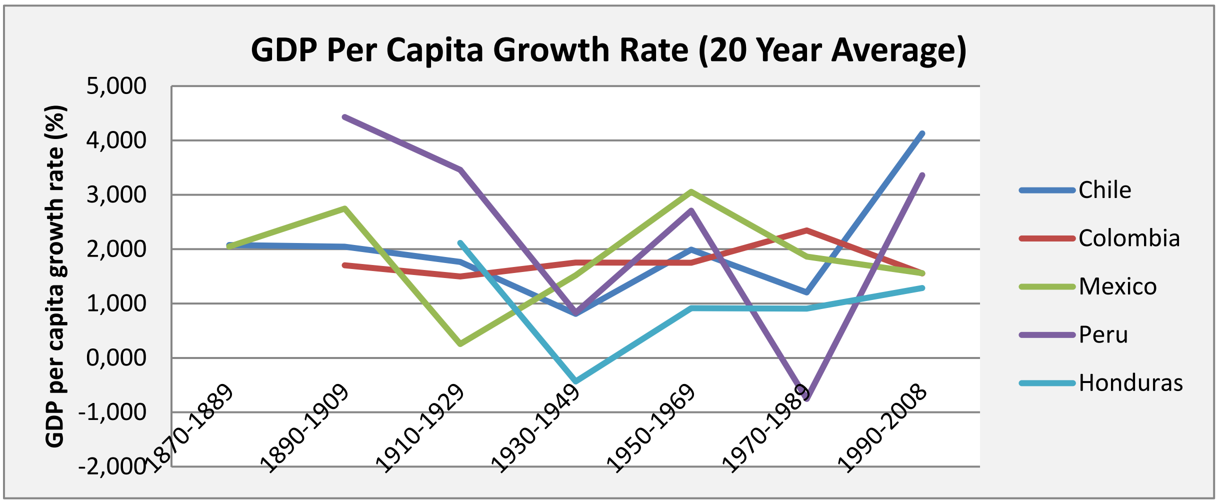

Figure 18: GDP per Capita Growth Rate for Latin American Countries

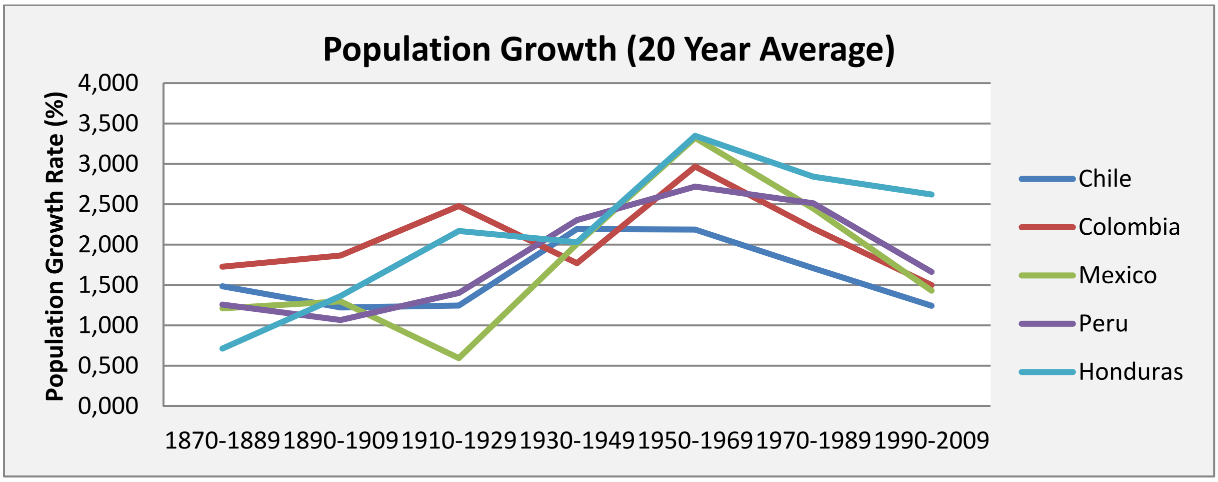

Figure 19: Population Growth Rate for Latin American Countries

Again, these countries show the signs of being in the transitional stage of economic development. There are big fluctuations in the GDP per capita growth rates of most countries, except for Colombia. These fluctuations can mostly be explained by economic mismanagement by the respective governments in that period (Peru) or revolutions (Mexico 1910-1917).

4.4 Conclusions

The following countries show signs of being in the Modern Growth Regime: France, The Netherlands, The United States, Japan, The United Kingdom, Hong Kong, South Korea, Taiwan and Singapore. China and India show signs of a transition into the Modern Growth Regime over the last 40 and 20 years respectively.

The African countries, the Muslim countries (except for Saudi Arabia and the UAE), the Latin American countries, the up and coming economies and Brazil show signs of being in the transitional stage of development. There are two exceptions: Saudi Arabia and the United Arab Emirates shows signs of being in the transitional stage, while their GDP per capita are among the level of developed nations. This can be explained because of our use of GDP per capita growth rates instead of income per capita growth rates, and their dependence on oil exports. One of the influencing factors of GDP is export, and since these countries have an economy based on oil exports, these are heavily influencing the outcome of our classification.

Why can almost all of the countries be classified in either the transitional stage or the

Modern Growth Regime? There are two reasons for that. First, most of the countries researched in this paper used to be colonies of the Western countries. This means that in most of those colonies, some important factors for economic growth were already available. For instance, most African countries were colonized for their natural resources. This means that there had to some infrastructure to transport those resources within that colony. Also, the colonizing country implemented a certain kind of local government, to make the colony run smoothly. When the colonies eventually gained their independence, they did not have to reinvent everything themselves. They could just use everything the former colonizing country had implemented in their country. This is a big difference with the Western economies. These countries had to go through all of the steps, so from Malthusian era, through the transitional stage towards the Modern Growth Regime. However, everything change they had, could directly be implemented in their colonies, thereby letting those countries at least skip the Malthusian era after independence.

However, this cannot be the reason for some East Asian countries, like China, Japan and South Korea. These countries adopted another strategy. All of the countries developed a highly industrialized economy in a relatively short time span. The industrial sector expanded due to the comparative advantage these countries had with their ability to adopt existing technology and manufacture with their relative cheap labor force. To illustrate this; according to the Historical database by Maddison, GDP per capita increased from GK$ 1.921 in 1951 to GK$ 17.943 in 1989 (Maddison, 2009). In China, GDP per capita increased from GK$ 778 in 1970 to GK$ 6.725 in 2008 (Maddison, 2009). To give a comparison; GDP per capita for the USA amounts to GK$ 9.561 in 1950, GK$ 15.030 in 1970, GK$ 23.059 in 1989 and GK$ 31.178 in 2008 (Maddison, 2009). From that moment on, these countries developed ever more high-technological industries, thereby catching up to the Western countries. South Korea and Japan have walked this route, and China is on its way to do the same thing. Hong Kong and Singapore focused on the development of the services sector. Hong Kong is the financial services center of East Asia, while Singapore has a mix between high tech industry and services.

This means that the Unified Growth Theory isn’t the best way to classify the economic development of a country. It is too coarse to really make distinctions between countries. The fact that there are technological leaders and followers does give a good explanation for the high GDP per capita growth rate of up and coming economies, relative to the Western countries. Another possibility for further refinement will be the introduction of the technological progress rate. In the next section, I will introduce the patent applications by residents of a selection of countries. This will be my suggested proxy for the technological progress rate.

5. Technological Progress Rate

5.1 Methodology

Next, we will turn our organization towards the technological progress rate. While it is important variable in the Unified Growth Theory, it is quite hard to measure. How do you measure technological progress in a specific country? There are different ways to measure a part of technological change. Among others, one could look at the change in R&D input, a change in the size of a R&D sector, patent statistics, and scientific articles published by the nations' institutions. However, from which variable can one get a good picture of the level of technological change? The choice settled on patent statistics, specifically the patent applications by residents. The choice for this variable is because of its resemblance to the technological progress rate. Only one person or organization can apply for a patent, and it can only be done once. In these aspects, this variable resembles the technological progress rate, since this measures the speed with which technology progresses. Progress cannot be measured using existing technology; every year there has to be new technology to measure improvement. We use the application by residents to ensure that we do not measure the spillover effects from other countries.

5.2 Data

Because of data availability, a smaller selection of countries will be used than before. The new selection encompasses 24 countries, and the time period between 1963 and 2008. There are still data points missing, but we do have enough to get a picture of the level of technological change in specific countries. For normalization, the number of patent applications is divided by the population at the time, divided by 1000. The resulting variable is the number of patent applications per 1000 inhabitants. The results will be shown in 3 different graphs, for clarification purposes.

5.3 Results

Let us start with group 1, which contains mainly developed countries:

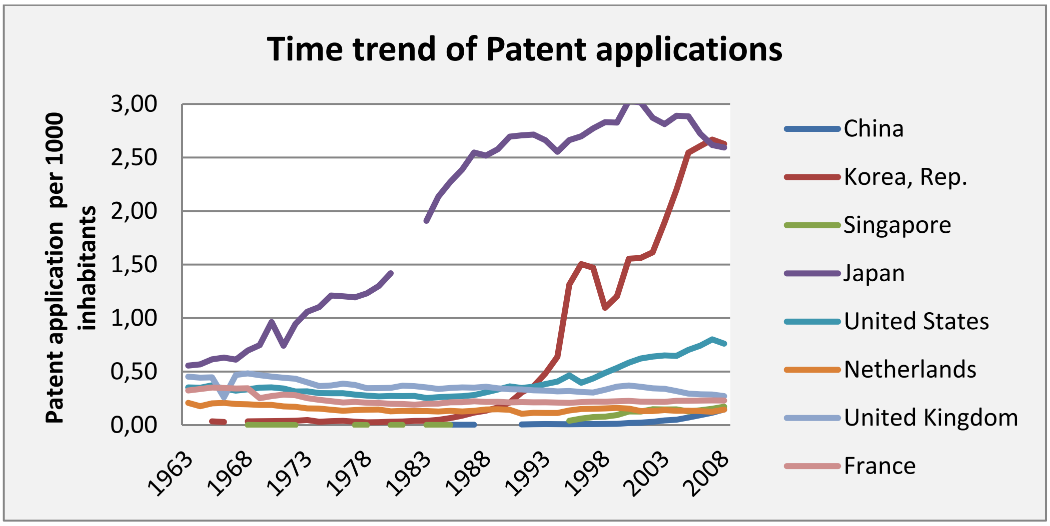

Figure 20: Trend line of Patent Applications, Group 1

We can see different trends here. If we look at the western countries, we can see that the number of patent applications per 1000 inhabitants is on either stable or on a slight decline. This means that the number of patent applications is either slightly rising or holding stable. The Unified Growth Theory states that the technological progress rate is ever increasing, so the observed trend isn't in line with the expectations of the model. The trend lines of Japan and South Korea do show the hypothesized rise. The US also shows signs of increased patent applications. The most important question to answer is why most countries do not show this increase. It is because patents are mostly used to protect new products developed in the manufacturing sector. And most western countries do not have a developed manufacturing sector anymore. Instead, they shifted the emphasis to the services sector. This means that while they do not have the patent applications to prove it, the rate of technological change can still be high. They can buy the products developed in the countries with a strong manufacturing industry, thereby paying for technological change with their earnings made in the services sector.

Next up is group 2, which mainly contains countries in the transitional stage:

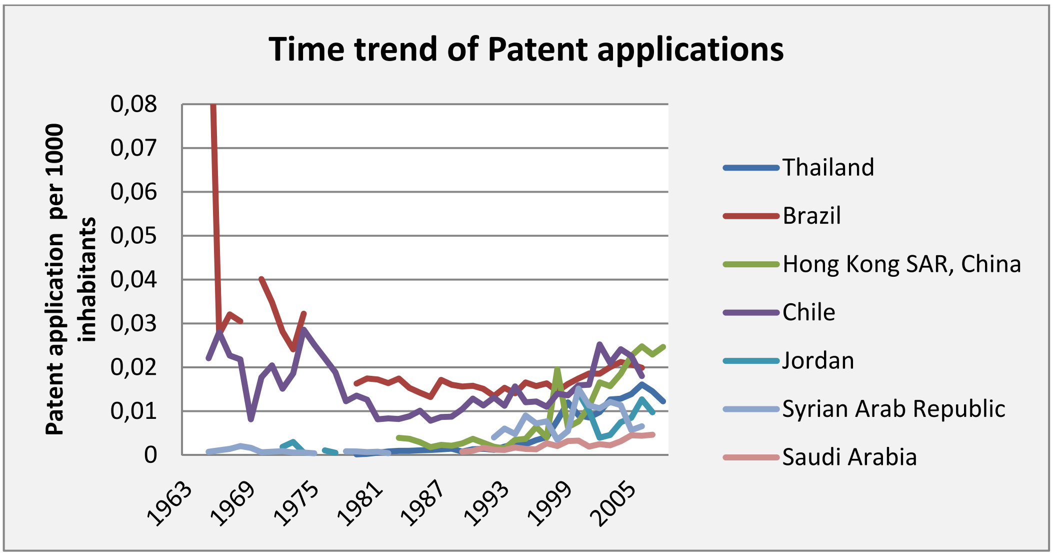

Figure 21: Trend line of Patent Applications, Group 2

Right off the bat, we can see that the levels of patent applications per 1000 inhabitants is between 10 and 150 times smaller than in the previous graph. We can also see a rising trend with most of them. The low level of Hong Kong is largely explained by the same reason as the other western countries. Namely that since Hong Kong has a largely services based economy; it can pay for technological progress with their earnings made in the services industry. The rising trend from the other countries indicates a slow development of the manufacturing sector. The fact that Saudi Arabia has low values, with their relative high GDP per capita, shows another problem. It means that this variable doesn't take into account that some countries can develop a high living standard due to their natural resources. Although I left out the UAE, they will have the same problem. So we established that using patent statistics as a proxy does not account for at least two types of economy.

Finally group 3, also mainly with countries in the transitional stage:

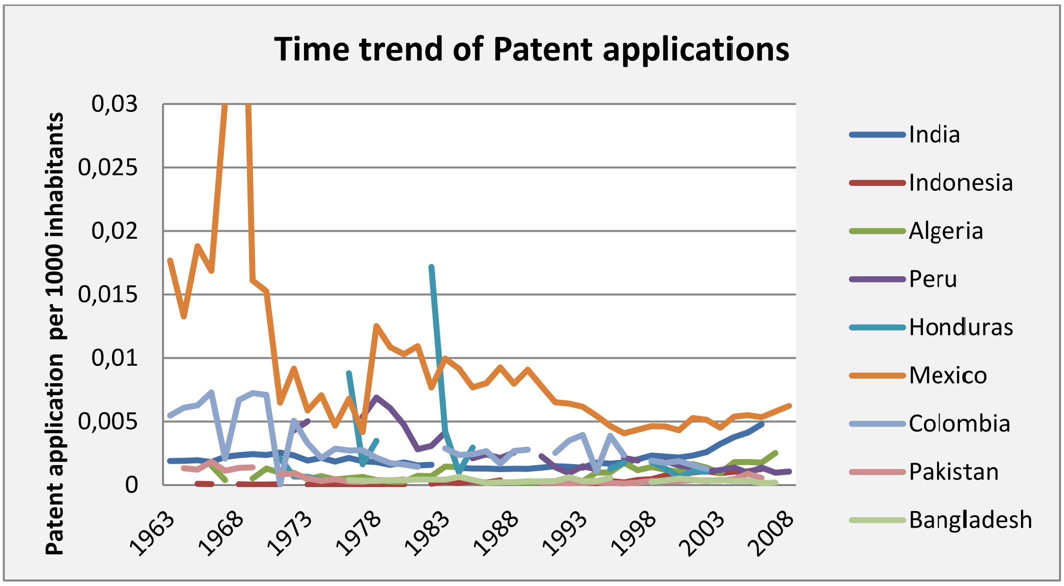

Figure 22: Trend line of Patent Applications, Group 3

These countries have even lower values than the previous graph. From this, we can take that the development in these countries isn't as far along as other countries. The trend line of India seems to be on the rise, and this fact, in combination with the fact that the population has risen more than 1.5% the last decades, shows that India is on the way to development.

5.4 Conclusions

Although patent statistics could be a good proxy for technological progress in highly industrialized countries, it lacks in specificity when it comes to countries with an emphasis on another sector than industry. Therefore I believe is cannot be used alone as a proxy for technological change. We need dummies to correct for sectorial emphasis. One way to do this, is to calculate the amount of GDP generated by each sector, and by using the parametric model by (Lagerlöf, 2006), fill in the data known until today. With this, one might be able to calculate the technological progress rate. If you do this with enough countries, one could make a regression with the technological progress rate as dependent variable; make patent statistics and the dummies for sectorial emphasis independent variables. This is a way to make a fairly reliable way to measure each country's technological progress rate.

6. Econometric Research

6.1 Methodology

We have classified each country according to the average growth rate of the population and GDP per capita. We have found that most of the countries researched, are either in the transitional stage or in the Modern Growth Regime. There are some countries that have transitioned within the measured period, for example China and India. Other countries are difficult to classify because of data availability, like Russia and Saudi Arabia.

The next step is to validate the outcomes of the classification analysis with the hypotheses of a positive relationship between population growth and GDP per capita growth in the transitional stage and the negative relationship in the Modern Growth Regime. These hypotheses are covered in the model description.

For this, we will use a selection of countries in each stage of development to do a panel data study. This is an analysis method which pools the individual time series of the countries. More observations can be used to measure the effect of the different variables. This is more advantageous than a simple time series model, which can use only data for one country to establish a regression. This means that the time span determine the number of observations in the model. Pooling these variables in a panel data model gives the possibility to multiply that number of observations with the number of countries, increasing the number of observations significantly. This makes it possible to carry out a more systematic analysis.

One of the disadvantages of a panel data is when observations are missing. This means that the data is unbalanced (Verbeek, 2008). This analysis encounters the same problem. This means that especially the regression with the control variables will have a lower number of observations. This is because of the data for human capital accumulation, which has one observation per five years.

The regression will be of the following form:

$$(1)\ GDPPCgr_{it} = \alpha + \beta_1 CH\_POP_{i,t-x} + \beta_2 CH\_TP_{i,t-y} + \varepsilon_{i,t}$$

Where $GDPPCgr_{it}$, is the GDP per capita growth rate for country i at time t, $CH_POP_{i,t-1}$is the change in population growth rate (in %) for country i at time $t-x$, and CH_TP_{it} is the change in technological progress rate (in %) for country i at time $t-y$. These variables are chosen, because they are the three central variables in the Unified Growth Theory. The change in population growth and technological progress are lagged, to give the GDP per capita growth time to 'react' to the change in the population growth.

Next, we will expand the previous equation with different factors to determine if other variables might influence the result we get. I will use the following variables to see if they might influence the result.

First up is the inflation rate. This is added to the equation, because many different articles state a relationship between inflation and economic growth, like Fischer (1993) and Barro (1996b). Both found a small, negative influence of inflation on economic growth. On the other hand, Mallik and Chowdury (2001) found a positive relationship between inflation and economic growth.

The accumulation of human capital is the second control variable. This is a special variable, because although it is closely related to technological progress in the Unified Growth Theory, is has no direct effect on the GDP per capita growth rate. This is why this variable is omitted from the base regression. Human capital can have a mixed effect on GDP per capita growth. First, it can be positive, because human capital can improve productivity. The second effect can be negative, because during the process of human capital accumulation, an individual cannot work, thereby not contributing to productivity. This is especially the case when human capital is accumulated through education.

The next variable is openness to trade. According to Barro (1996a), trade has a positive relationship with economic growth. Frankel and Romer (1999) found a positive relationship between trade and income. Other authors, like Rodriguez and Rodrik (2000), state that these relationships are false, because of wrong methodology or poor indicators. They did not find a significant relationship between open trade policies and economic growth. It will be interesting to see if there is a relationship between trade and growth in this instance. And if there is a relationship between these variables, what kind of influence it will be.

The final variable will be the initial level of GDP per capita. According to Barro (1996a), there is a negative influence of initial level of GDP per capita on GDP per capita growth.

Furthermore, this is confirmed for OECD countries in the book 'Economic Growth' by Barro and Sala-i-Martin (2004). But the outcome for a wider sample, in the same book, shows a slight positive relationship. So it will be interesting to see what kind of influence will show in the different groups.

With these variables added, the equation is as follows:

$$(2)\ GDPPCgr_{i,t} = \alpha + \beta_1 CH\_POP_{i,t-x} + \beta_2 CH\_TP_{i,t-y} + \beta_3 HC_{i,t-z} +$$

$$+\beta_4 INFL_{i,t} + \beta_5 TRAD_{i,t} + \ INIT_i + \varepsilon_{i,t}$$

Where $INFL_{it}$ is the inflation rate (annual consumer price index, in %) for country i at time t, $TRAD_{it}$ is the level of trade (imports and exports as % of GDP) in country i at time t, $HC_{i,t-z}$ is the level of human capital (in average years of educational attainment) for country i at time $t-z$, and $INIT_i$ is the initial level of GDP per capita (in 1990 Geary-Khamis $) for country i in 1960.

These regressions will be performed in two different variations. The difference in the variations will be the number of years the change in population growth, the change in technological progress and the accumulation of human capital will be lagged. This is done to see if there is a difference in the dynamics of the growth paths between the different stages. In the first variation, variant 1, the lags will be 2 years for the change in population growth and technological progress, and a 5 year lag for human capital. The second variation, variant 2, will contain a 1 year lag for both change in population growth and technological progress, and 3 years for the accumulation of human capital.

The equations are performed with time fixed effects. Time fixed effects are used to account for unobserved heterogeneity that is common over time, and varies across nations.

China and India will be evaluated separately. This is done to test if there is a break in the influence of the change in population growth on GDP per capita growth. The Chow Breakpoint Test can determine if there is a real switch in that relationship. That is why the tests like that for the two groups are skipped. Only a Chow Breakpoint test will be performed on the base equation for both countries.

6.2 Data

The data for all variables but the human capital data is collected from the World Bank World Development Indicators. The timespan for this regression runs from 1960 until 2009.

All data will be divided in two groups; one group for the countries in the transitional stage, a group for the countries in the Modern Growth Regime. The group in the transitional stage can specifically be tested for the positive relationship between population growth and GDP per capita growth. The same goes for the negative relationship in the Modern Growth Regime.

Because of data availability, some countries will be scrapped from the sample. In total, the transitional group will contain 16 countries, and the Modern Growth group will contain 7 countries. The total number of observations is 800 for the transitional stage and 350 observations for the Modern Growth Regime. This will diminish further when the regressions are done, because of missing data.

The data for human capital will be provided by the Barro-Lee dataset on educational attainment (Barro & Lee, 2010). This dataset shows the average years of schooling, among others. The reason for this choice, and not for example the net enrollment rate in secondary school, is the fact that this data is available from 1960 until 2010, whereas the other data is limited to a period from 1995 until 2008, at the most. A disadvantage is that this dataset only provides data in five-year intervals. A possibility is to interpolate the omitted data. According to the article, this should be done using a formula containing changes in the enrollment rates. But since this information is not readily available, another option is to increase the years of schooling linearly, assuming an increase because of an ever increasing technological progress rate. This influx of new technology every year needs an increase in schooled professionals to use them. If there is a dip in the years of schooling, it is mostly a small dip.

A separate dataset, with interpolation of the data points, showed no explicit differences in outcome from the base dataset. So, there will be no interpolation of schooling data.

6.3 Descriptive Statistics

6.3.1 Dataset Modern Growth Regime

	GDP per capita Growth Rate (%)	Change in Population Growth Rate (%)	Change in Technological Progress Rate (%)
Mean	3.3781	1.0307	4.4248
Minimum	-7.5246	-552.6345	-67.4597
Maximum	23.2025	1574.660	388.6483
Standard Deviation	3.5105	108.5381	28.2990

Table 1: Descriptive Statistics Modern Growth Regime (Source: World Bank WDI)

Table 1 shows the descriptive statistics for the Modern Growth Regime. GDP per capita growth rate for the period is on average 3.38% for the period 1961-2009. Its minimum value is -7.52% and its maximum value is 23.20%. The change in population growth has a mean value of 1.03% over the period, with a minimum value of -552.63% and a maximum value of 1574.66% (This is an increase in population growth in the United Kingdom, from 0.005% to 0.089%). The change in the technological progress rate has a mean value of 4.42%, with a maximum value of 388.65% and a minimum value of -67.46%. Overall, all variables are highly volatile. The change in population growth and technological progress are especially volatile. This is because of the small percentages in this dataset. An increase as shown above, at the change in population growth, shows that a relative small increase in population growth rate may contain a big first order difference.

6.3.2 Dataset Transitional Stage

Table 2 shows the descriptive statistics for the transitional stage:

	GDP per capita Growth Rate (%)	Change in Population Growth Rate (%)	Change in Technological Progress Rate (%)
Mean	1.9871	-0.9795	35.9156
Minimum	-21.1409	-53.7826	-99.3589
Maximum	31.8323	205.2763	11021.71
Standard Deviation	4.6906	9.1125	538.9453

Table 2: Descriptive Statistics Transitional Stage

GDP per capita growth has a mean value of 1.99% with a minimum value of -21.14% and a maximum of 31.83%. It shows a higher volatility and a lower mean than the GDP per capita growth rate for the Modern Growth Regime. The change in population growth has a mean value of -0.98% with a minimum value of -53.78% and a maximum value of 205.28%. The change in technological progress has a mean of 35.92%, with a minimum value of -99.36% and a maximum value of 11021.71% (this is from Colombia, where the patent applications per 1000 residents went from 1 in 1972 to 114 in 1973). Again, the change in population growth and technological progress show a high volatility, although the change in population growth has a lower volatility in the transitional stage than in the Modern Growth Regime. This is mainly due to the maximum value in the Modern Growth Regime. For the change in technological progress, the opposite situation occurs, mainly because of the situation with Colombia described above.

Overall, the dataset is characterized by high volatility. This is caused by the form chosen to perform the regression. If one measures changes, positive of negative, in small growth rates, the measured change will be very high. Consider the examples of the maximum values of the change in population growth in the UK and technological progress in Colombia. However, to test the hypothesis, we need these forms of the variables. The hypothesis states that in the Modern Growth Regime, the GDP per capita growth rate rises as population growth falls. Unless there is a negative population growth, this hypothesis cannot reliably be tested. Therefore this dataset will be used with the extreme values.

Next section will show the results of the regressions performed, and these results will be discussed.

6.4 Results

6.4.1 Variant 1

The following table contains the relevant outcomes for the regressions performed on the Modern Growth Regime:

	MGR eq. 1		MGR eq. 2		Trans. eq. 1		Trans. Eq. 2	
Variable	Mean (s.e.)	Prob.	Mean (s.e.)	Prob.	Mean (s.e.)	Prob.	Mean (s.e.)	Prob.
GDP per capita growth (Dependent variable)	2.809 (2.978)	---	2.408 (2.499)	---	2.357 (4.259)	---	2.564 (3.894)	---
Change in Population Growth (-2)	-0.002 (0.146)	0.134	-0.0094 (0.656)	0.159	0.009 (0.052)	0.873	-0.253 (0.235)	0.288
Change in Tech. Progress Rate (-2)	0.011 (0.562)	0.048	0.005 (0.528)	0.402	-3.73e-5 (4.e-4)	0.922	0.011 (0.008)	0.203
Human Capital (-5)	---	---	0.063 (0.171)	0.717	---	---	-0.185 (0.532)	0.730
Initial Level of GDP per capita	---	---	-3.e-4 (8.6e-5)	0.000	---	---	-6.7e-4 (6.7e-4)	0.318
Inflation	---	---	-0.105 (0.062)	0.095	---	---	-0.001 (5.3e-4)	0.011
Trade	---	---	3.e-4 (0.004)	0.929	---	---	0.012 (0.020)	0.568
C	2.762 (0.152)	0.000	4.870 (1.709)	0.007	2.372 (0.214)	0.000	3.772 (1.826)	0.044
No. of observations	282		50		403		69	
R^2	0.403		0.638		0.228		0.282	
Prob. F-statistic	0.000		0.000		0.000		0.096	
Durbin-Watson stat.	0.897		0.912		1.497		0.999	

Table 3: Outcome regressions variant 1

Let us discuss the Modern Growth Regime first. The base equation shows a small influence of the change in population growth and technological progress on GDP per capita growth. In the case of the change in population growth, this is the hypothesized negative influence. Although it is not significant at the 10% level, it does come close, and as such, does have explanatory power. In the case of technological progress, this is positive influence, and significant at the 5% level. The probability of the F-statistics confirms that the subset of all the variables has significant explanatory power at the 1% level. The Durbin Watson statistic does suggest serial correlation.

Equation 2 checks for robustness of the outcome with control variables. This shows that the influences of equation 1 hold. There is a drop in significance for the change in technological progress, but the influence is still weak and positive. The change in population growth becomes a bit stronger, and the significance for this variable does not drop that much. The R^2 shows that 63.8% of the variations are explained by this result.

As for the control variables; human capital and trade have a weak, positive, non-significant influence on the GDP per capita growth rate. The initial level of GDP per capita has a very weak negative influence on the GDP per capita growth rate. This influence is significant on a 1% level. Inflation has a negative influence on GDP per capita growth, and is significant on a 10% level.

The base equation for the transitional stage shows a non-significant negative influence of the change in technological progress on GDP per capita growth. This is not in compliance with the hypothesis for the transitional stage. According to the probability of the F-statistic, the whole subset of variables does have explanatory power. This is probably mostly because of the significance of the intercept. The change in population growth has the predicted positive influence, but is highly non-significant.

Equation 2 shows that the results in equation 1 aren't robust. The change in technological progress has switched signs, and the influence of the change in population growth has changed from a weak positive influence to a strong negative influence. Both variables did increase in significance, but are still nowhere near the 10% level. The F-statistic is only significant on a 10% level, not on a 5% or 1% level, as with the other equations in this variant. The R^2 of both equations are quite low, only 27.4% of the variation is explained.

Overall, it seems that this particular setup favors the Modern Growth Regime. The test results show that the hypothesis is confirmed and that the results are robust. The setup does not favor the transitional stage. The results do not comply with the hypothesis and are not robust when tested with control variables.

6.4.2 Variant 2

Next up is variant 2, where the change in population growth and technological progress are lagged for 1 year, and human capital is lagged 3 years.

	MGR eq. 1		MGR eq. 2		Trans. Eq. 1		Trans. Eq. 2	
Variable	Mean (s.e.)	Prob.	Mean (s.e.)	Prob.	Mean (s.e.)	Prob.	Mean (s.e.)	Prob.
GDP per capita growth (Dependent variable)	2.847 (2.957)	---	3.019 (3.558)	---	2.411 (4.184)	---	1.306 (5.057)	---
Change in Population Growth (-1)	-8.1e-4 (0.001)	0.567	0.014 (0.010)	0.156	0.016 (0.051)	0.761	0.195 (0.166)	0.246
Change in Tech. Progress Rate (-1)	0.004 (0.006)	0.491	0.022 (0.024)	0.381	3.e-4 (4.e-4)	0.494	5.e-4 (5.e-4)	0.324
Human Capital (-3)	---	---	0.104 (0.257)	0.688	---	---	0,298 (0.653)	0.650
Initial Level of GDP per capita	---	---	-2e-4 (1e-4)	0.066	---	---	-0.001 (8e-4)	0.201
Inflation	---	---	-0.001 (0.168)	0.995	---	---	-0.002 (0.002)	0.522
Trade	---	---	-0.001 (0.005)	0.823	---	---	0.004 (0.024)	0.858
C	2.830 (0.151)	0.000	3.815 (2.648)	0.157	2.426 (0.212)	0.000	2.279 (2.357)	0.337
No. of observations	289		57		406		77	
R^2	0.384		0.543		0.211		0.286	
Prob. F-statistic	0.000		0.001		0.000		0.063	
Durbin-Watson stat.	0.973		0.931		1.611		1.098	

Table 4: Outcome regressions Variant 2

The base equation of the Modern Growth Regime show similar results as in the first variant, with the difference that the results are less significant. The significance of the F-statistic implies that there is explanatory power in the subset of the variables. The Durbin-Watson statistic suggests serial correlation.

The second equation shows that the results are not robust. The change in population growth has switched signs, while the influence of the change in technological progress is much stronger. The significance of the variables has improved. As for the control variables; only the initial level of GDP has a significant, but weak negative influence on GDP per capita growth. The other variables are not significant. The R^2 shows that 54.3% of the variations are explained. The F-statistic suggests that the subset of variables has explanatory power.

The base equation for the transitional stage shows the hypothesized influence of population and a weak positive influence of change in technological progress on GDP per capita growth. These results are not significant. The F-statistic suggests that these variables do have explanatory powers. The Durbin-Watson statistic falls below the value of the 5% critical value, so there is evidence of serial correlation.

Equation 2 confirms the robustness of the results in equation 1. There is some change in the strength of the influence and the significance has improved. Human capital and trade have a positive, but non-significant influence. The initial levels of GDP and inflation have a weak, negative and non-significant influence on GDP per capita growth.

The F-statistic suggests that the variables do have explanatory power. The Durbin-Watson statistic suggests serial correlation.

The R^2 of equation is still lower than when one looks at the Modern Growth Regime. This can be said for all the equations of the transitional stage. This is most likely because of the volatility of GDP per capita growth and population growth. Moreover, unlike the Modern Growth Regime, the countries in the transitional stage may have different paths at different times. One country can have a higher growth than others, or while one countries' growth rate is positive, another countries' growth rate can be negative in the same period. This can cause the non-significant relationship and bad R^2. But since the result is robust, we can assume that there is a relationship between the variables.

These results are difficult to compare to previous research, since none of the authors have researched the relationship between GDP per capita growth and population growth in a regression form. Most authors use historical data in the form of graphs to find evidence of the specific version of the Unified Growth Theory they are using. These authors include Galor, Strülik and Weisdorf, and Boucekkine et al. (Strülik & Weisdorf, 2008b; Boucekkine, de la Croix, & Licandro, 2002; Galor, 2005).

When comparing the results of these regressions with the results of Barro (Barro R. J., 1996a, p. 80), there are similarities between the results for the Modern Growth Regime, and the results found by Barro. Inflation, population growth (fertility rate in Barro), initial level of GDP per capita and human capital have a similar relationship. This is interesting, since Barro used a two-stage least squares regression in a neo-classical framework, while this research uses an ordinary least squares regression in a Unified Growth model framework (Barro R. J., 1996a, p. 81). This seems to suggest that the Unified Growth Theory isn't necessary, since a neo-classical framework has similar empirical results. However, one must realize that the point of the Unified Growth Theory is that a countries economic development can be explained using only two variables, population growth and the technological progress rate. In this sense, the Unified Growth Theory can be even simpler than a neo-classical framework.

6.4.3 China and India

Let us turn our attention to China and India. These countries have been found to have transitioned into the Modern Growth Regime in the last 50 years. To prove this, a Chow Breakpoint test is performed on the base equation, without the change in technological progress.

	China		India	
Variable	Mean (s.e.)	Prob.	Mean (s.e.)	Prob.
GDP per capita growth rate	7.359 (5.382)	---	3.533 (3.795)	---
Change in Population Growth	0.034 (0.017)	0.048	-0.139 (0.161)	0.390
C	7.303 (0.753)	0.000	3.448 (0.558)	0.000
Probability Chow Breakpoint Test (Year)	0.0119 (1980)		0.1065 (1994)	

Table 5: outcome regression and Chow Breakpoint test

First up is China, with the regression of the base equation and the outcome of the Chow Breakpoint test. The year 1980 is chosen as the breakpoint. From the Chow Breakpoint test, it is clear that the alternative hypothesis of a structural break in 1980 is significant. This means that there has been a structural change in the population growth around 1980. It can be argued that this is because of the one-child policy, but in combination with the GDP per capita growth, it is more likely that the transition towards a Modern Growth Regime is finalized in this period.

For India, the whole timespan is explored for the structural break. The Chow breakpoint test pictured is the closest to significance. Since the null hypothesis of no structural breaks isn't broken at the 5% level, there are no structural breaks, and there is no evidence that a transition has occurred. However, the change in population growth does show to have a negative influence on GDP per capita growth. This is indicative of a country in the Modern Growth Regime. Furthermore, closer inspection on the population growth rate shows a spike in the period 1951 to 1979, and the biggest spike was in 1961, the first period of our timespan. After this period, the change in population growth rate is predominantly negative. This can explain the lack of a structural break.

6.5 Conclusions

This section of the thesis was designed to test the outcome of sections 4 and 5. The main questions were:

- Is there a positive influence of population growth on the GDP per capita growth rate in the transitional stage, and a negative influence in the Modern Growth Regime?
- What kind of influence does technological progress have?
- Are these results robust?
- Is there a structural break in the relationship between population growth and GDP per capita growth for China and India?

The results for the two groups show that for the base equations, the hypotheses of positive influence in the transitional stage and a negative influence in the Modern Growth Regime are partly confirmed. Although the significance of the variables do not exceed the 5% level, the F-test for both groups show a significant explanatory power. Variant 1 suggests that the results for the Modern Growth Regime are robust and the transitional stage is not. Variant 2 suggests the opposite; the result for the transitional stage seems to be robust here, while the result for the Modern Growth Regime is not.

Variant 1 seems to be the right relationship for the Modern Growth Regime, while variant 2 is a better fit for the countries in the transitional stage. This might be due to the fact that the transitional stage is more volatile than the Modern Growth Regime. Economic growth will respond more directly to changes in population growth and technological progress than in the Modern Growth Regime. Variant 2, with only 1 year lag for population growth and technological progress will fit better in this stage.

A reason for the non-significant results could be the fat that the variables are highly volatile. This is mainly because the changes in growth rates of population growth and technological progress are used to determine a relationship with GDP per capita growth rate. However, when small growth rates increase or decrease, the actual change can be very big, causing a high volatility.

A comparison with the results of other authors is difficult, since the cited articles have not used regressions to validate their outcomes. Instead, they developed a specific variant of the model, and searched for evidence to support their specific model.

The Chow Breakpoint test for China shows evidence of a structural break in 1980, which confirms the notion that the country transitioned into the Modern Growth Regime around that time. India does not show the same signs. This can be explained by the fact that the break in Figure 11 is mainly caused by a spike in the era 1951-1975, and where the biggest changes occurred in the period 1951-1960. From then on, the change in population growth rate has predominantly been negative. This prevents the test to see a structural break.

7. Overall conclusions and recommendations

The central question of this thesis was if we could use the Unified Growth Theory to effectively classify countries in different stages of economic development. To research this question, we randomly selected 33 countries, and compared GDP per capita growth rates and population growth rates to the parametric simulation, as done by (Lagerlöf, 2006). We found that the whole selection can be classified as either in the transitional stage or the Modern Growth stage. There was no country that could really be classified as being in the Malthusian stage. Within the Modern Growth stage, most countries can also be qualified as technological followers and technological leaders.

In the course of the research I found that, although one can classify these countries, classification using this theory only gives a coarse indication of the level of development. For example, India and China are classified as being in the Modern Growth Regime as technological followers. But there is also a big difference between China and India. However, this is not shown in the graph.

More clarification could be given using the technological progress rate. One problem with this approach is that technological progress is difficult to describe and measure. We suggested using patent statistics to overcome this problem. This variable shows some comparison with the nature of the technological progress rate. For example, one can only apply for a patent once, and only by one person. So every year you get new technology patented, and therefore this variable can be a good proxy for technological progress. The results show that one can see the difference between countries, even between China and India. There is a drawback to using this variable. Since patents are predominantly used in the manufacturing sector, there is bias towards countries with a strong manufacturing sector. But one can argue that due to trade and availability, countries with a different sectorial emphasis can also use the technological progress, paying for it with the earnings from that particular sector. To give a micro-economic example; an employee of a Dutch insurance firm can buy and use the same 3D-plasma television as the South Korean who works at the plant that produces this television. This is a drawback of the Unified Growth Theory as a whole, because this theory assumes there are only 2 sectors; agriculture and manufacturing.

In the final part of the analysis, the previous results were tested using regressions, and checked for robustness using control variables. Two variants were used to find the optimal regression. Variant 1, with 2 year lags for population growth and technological progress, seems to explain the relationship between population growth, technological progress and GDP per capita growth in the Modern Growth Regime. Variant 2, with 1 year lags for population growth and technological progress, seems to explain the relationship between the three variables in the transitional stage. In both cases, the results are robust when checked for control variables. The fact that two different variants explain the two different stages stems from the fact that the transitional stage is much more volatile than the Modern Growth Regime, and as such will react to changes quicker. There are similarities in the outcome of this research, and that of Barro (Barro R. J., 1996a). However, when the problem of measuring technological progress can be solved, the Unified Growth Theory can provide a simpler way to measure economic development.

I recommend further studies into the technological progress rate. This is an important variable, not only to the Unified Growth Theory, but in a lot of macro-economic theories. One specific suggestion is researching the feasibility of calculating the proxy, as suggested in the conclusion of the results of the technological progress rate. With a better proxy for the technological progress rate, one can really make progress in study of macro-economic development.

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