The New Growth Theory: Does it work?

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Abstract

Recent Growth Theory focuses on the importance of political economy, using mainly exogenous growth frameworks. However, there is another strand of research. The Jones Critique on scale effects causes the development of semi-endogenous R&D based growth models, which are consistent with time series evidence. Furthermore, accumulation of human capital is taken serious again. However, education is no longer an ordinary input in the production function. Instead, investment in education is considered and Mincerian returns to schooling are estimated. Moreover, researchers start to model complementary effects of knowledge and technology directly. Papageorgiou and Perez-Sebastian (2002) provide one interesting example.

I am curious about the models' ability to cope with several facts of economic growth. The facts include divergence and the failure of many explanatory variables in cross country growth regressions to be robust to changes in the underlying information set. In addition, growth rate changes show no persistent trend.

After confirming these facts, I analyse the underlying model and compare its characteristics and implications to them. The steady state growth rates depend solely on exogenously given population growth and parameters. Average schooling years turn out to be a constant in steady state. Labor movements do matter. the model can replicate the transition paths of miracles as well as the growth experience of developed economies, closed to their steady states, pushing forward the technology frontier. Indeed, this model predicts convergence, although there could be ways to introduce divergence by accounting for barriers in form of monopoly rights. Unfortunately I not managed to do so.

However, I use cross-country, panel data analysis to check the influence of infomation technology and schooling on growth. The results are ambigious. Secondary schooling does matter in each case. Personal computer endowment and other variables show varying results, dependent on the underlying estimaion technique. Finally, policy conclusions are drawn. Since complementary effects are worth for growth, polititions should subsidies both, research and puplic, especially secondary, education. However, simply subsidizing jobs in R&D and providing school material is not the key for future growth. Incentives and control mechanisms have to be set correctly.

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1 Introduction

Economists have come a long way in explaining phenomena of economic growth. Starting with Ramsey's intertemporally separable utility function and Harrod, Domar's combination of Keynesian analysis and growth, one has to go directly to the work of Solow and Swan, 1956. They use a neoclassical production function with constant returns to scale and diminishing factor returns, positive elasticity of substitution and constant saving rates. The prediction of these models is (conditional) convergence. I refer to the topic of convergence and conditional convergence in section 3.1.1. Because of diminishing returns, countries with relatively low starting levels of per capita GDP tend to grow faster than others. Coming closer to the steady state level, economies grow more slowly until there is no growth at all in steady state. The steady state depends crucially on the saving rates, population growth and the underlying production function. The reason why todays economists use the neoclassical growth model, besides suggestions concerning the introduction of governmental policy and human capital stocks, is the fact that conditional convergence is said to be empirically funded and can therefore explain certain growth experiences. A problem with all these models is that, indeed, we do not observe diminishing growth rates in developed economies, especially in the US. Growth rates have no clear tendency to decline over time, abstracting from some European economies. Moreover, saving rates do not differ systematically with the level of development. This is in sharp contrast to the Solow model, where there is no mechanism why different technologies are used but income differences occur due to different saving rates because of varying tax codes or preferences across countries. One of the promising revivals of the Solow model is the work of Mankiv, Romer and Weil (1992), who address to income differences. They introduced human capital in the standard Solow approach. The authors conclude that allowing for different savings and population growth rates and different willingness to accumulate human capital, countries converge to different steady states. Their prediction concerning the explanatory power of the model, they show that such a model can account for more than two third of international income differences, is viewed critically among other researchers. If a poor country is poor because lack of skills, skilled worker there must have relatively high earnings. However, they have not. Furthermore, unskilled labor is less likely to move to rich countries than skilled ones. Interestingly, they acquire human capital through education, which slows down the diminishing returns and therefore reduces the predicted speed of convergence. Investment in education can therefore be more productive, the returns increase. Newer neoclassical models anticipate that technology adoption may be costly and the price depends crucially on the structures of the industry or on governmental policy like protectionism. The amount of resources required for technology adoption depends also on the world technology stock, which is, however, assumed to grow exogenously. These models are treated extensively by, e.g., Parente and Prescott. The total factor productivity (TFP) represents countries' fraction of the stock of world knowledge that is used and is determined by policy variables. In these models, small changes in governmental policy or institutions can have large effects on the per capita income *level* of an economy. Technology adoption may not take place in developing countries because of interest groups' unwillingness to allow for this. The East Asian economies, e.g., broke down these barriers and miracles could occur. I will refer to some of these countries' policies in subsection 3.1.3. Parente and Prescott (1994) indeed show that such improved exogenous models are consistent with the data of South Korea and Japan in catching up to the US. In general, the traditional neoclassical growth theory has quite pessimistic implications on future growth experiences. There is no influence of policy actions on long run growth *rates*. Long time before economists tried to model barriers, there was stimulating work in progress in 1965, when Cass and Koopman went one step back to Ramsey and treat savings as being endogenously determined due to households' optimization. However, they hold on to the conditional convergence hypothesis and long run growth still depend on exogenous technological progress and this A is fallen from heaven [1]. After a decade of oil crisis and business cycle research, researcher changed the structure of growth models to come away from the diminishing returns assumption. Lucas (1988) introduces human capital with constant marginal returns and an influence on the A. In 1991, the standard Ak approach was developed by Rebelo (1991). In these models an economy will grow endlessly because of the assumption of constant factor returns and increasing returns to scale, doubling all inputs can increase output more than 100%. Romer addresses the increasing returns assumption directly to the only partly excludability of knowledge. there exist social benefits from new inventions. The society gains from spillovers. Considering this, Aghion, Howitt[2]/ Grossman, Helpman/ Romer[3] endogenize the A and concentrate on innovations and technological change as reasons for growth. In his path breaking works, Romer (1986, 1987, 1990) adopted the aspect of nonrivalous knowledge and realized that, because of this characteristic, imperfect competition could be a reasonable assumption to describe not only technological progress

[1] The underlying problem of all these models can be formalized as follows: There exist constant returns to scale only on capital and labor, $F(\lambda K, \lambda L, A) = \lambda F(K, L, A)$. From Euler we can conclude that in perfect competition models: $Y_t = KF_K + LF_L$ and prices equal marginal products, $Y_t = R_t K_t + w_t L_t$. Total output pays the inputs. Nothing is devoted to technology inventions

[2] They concentrate on quality ladder models, including creative destruction of old innovations. This approach addresses to Schumpeters' ideas. Indeed, evidence from postwar experiences shows that economies could not just reach the old situation but further improvements.

[3] He developed the famous variety-of-products framework, new goods are introduced but old ones do not vanish

but also growth. Technology is no longer a pure public good because one can exclude others. One might think of theorems, which are indeed non excludable, but one might also think of software or even cable TV, which are excludable in different stages. These goods are nonrival, however, there is a fee to pay. Since research creates new knowledge and this causes technological progress than it is naturally to assume that there have to be incentives to devote labor to R&D. One can imagine that you could gain from having invented something due to patent law restrictions and that this gain is because of monopoly power. The excludability depends not only on the nature of a good but also on legal systems. Inventors can make money out of their invention. This is a direct incentive for research. Thus, if ideas do not decrease over time, a country must not stop to grow, but all depends on policy variables. In the endogenous framework, the long run growth *rate* is no longer unaffected by policies. In these models, the economies are very sensitive to policy changes.[4] However Jones (1995) uses time series analysis to examine AK and R&D based endogenous growth models. He shows that there is evidence against both endogenous structures, especially against the R&D models. As mentioned above, the most striking difference between endogenous and exogenous theories is that the endogenous one relies on an effect of permanent changes in the policy variables on the long run growth rate. However, looking at US data there is no persistent change!! in the GDP per growth rates anyway. Jones conclude that the explanatory variables should also have this behavior. Instead of a proof for this fact, he finds strong evidence for persistent changes in the determinants of long run growth and therefore inconsistency with time series theory. In newer models of semi-endogenous growth, initialized by Jones (1995b) and Segerstrom (1998), an increase in the labor share devoted to R&D has only level effects on growth but does not permanently influence long run growth rates. The relationship between labor in R&D and the growth rate of technology is no longer linear because of criticism of the scale effect, inherent in endogenous R&D based models. I will introduce the reader to the structure of such models more detailed in section 3.2.3. Endogenous growth theory does also have to cope with immense criticism in several ways and from various authors. However, if it is not necessary, I will not refer to these general critiques.

[4]Because of the nonrival nature of inventions, these goods are 'produced' only once. This implies high fixed costs. Therefore, average costs exceed marginal costs. In R&D models, subsidies to research might be very important because of underinvestment in research otherwise. However, because of high prices over marginal costs, one could also consider a subsidy to the purchases. Furthermore one could think of externalities. A new invention might have an influence on the costs of further inventions. Intervening in the market can mean to demand a tax or devote a subsidy. It crucially depends on the direction of the effect.

As the above mentioned 'barriers' literatures implies, several authors again focus on exogenous theories of growth. Generally speaking, todays development and growth economists can be divided into two groups, one group favors the neoclassical approach and the other mainly focuses on endogenous theories. Both sides can explain partially what's going on in the world of growth but non of them has an overwhelming answer to the question: "Why do some countries produce so much more output than others?" (Hall and Jones (1999)). I'm going to reveal if semi-endogenous tendencies offer a better explanation of growth and cross-country income differences than older growth models. Therefore I proof the ability of the model of Papageorgiou and Perez-Sebastian (2002) to capture empirical fundamentals of economic growth. First of all, despite immense work is done to proof conditional convergence, newer studies reveal that there is divergence in income across country and that we should not be too optimistic about future development. We face the phenomenal growth experience of the so-called Asian Tigers and Botswana's strong improvement in the last decades. Contrary to this, countries like Burkina Faso and Chad were not able to catch up. Models of economic growth should be able to explain these contrary experience or should just directly address to only one of them.

Inherent to a wide range of research today, economists face several variables that are said to be direct explanatory. However Levine and Renelt (1992) examine the robustness of the predicted correlation between growth rates and explanatory variables over time and found nearly any reason to totally believe in former studies. Cross-country regressions are and were commonly used to predict the effect of changes in policy or institutional variables on long rum growth rates. However, Levine and Renelt only found robustness for secondary-school enrolment and investment shares on growth rates of GDP per capita. Thus, considering the results from Levine and Renelt (1992), besides others, the work of Papageorgiou and Perez-Sebastian catches my attention. They use the semi-endogenous R&D framework to analyze mainly the transition to the steady state. However, they introduce endogenous human capital formation via schooling decisions. Furthermore, they allow for imitation. Therefore I decide to take Papageorgiou and Perez-Sebastian (2002) as the baseline model of my analysis. I analyze the economy, focus on the chosen fundamentals and compare the ability of the underlying model to cope with these facts. Cross-Country and SUR regressions confirm the importance of schooling and, partly, social infrastructure. Furthermore, they reveal the importance of technology use for growth. Surprisingly the internet plays a minor role. However, the results are fragile due to an incomplete data set. Unfortunately I could not solve the problem of causality. I had to assume the exogeneity of right hand side variables, although this is really douptful. To conclude, the in the last three years extended semi-endogenous approach with the complementary nature of human capital and technology is a fruitful direction of research, although one should spend more time in clearifying the causality channels and measuring quality of education.

I will proceed as follows. In section 2 I give an overview of recent research on schooling of Barro and Lee. Section 3 offers empirical fundamentals, a good growth model should not deny, or better, should be able to explain. Furthermore, I will review new criticism of endogenous growth models. The section motivates the model choice and analysis. The next section presents a non-scaled R&D growth model with imitation and endogenous human capital from Papageorgiou and Perez-Sebastian (2002), which is analyzed in section 5. I state the results and answers concerning to the above raised questions in section 6. Following these results, section 7 provides cross-country growth regression results, that support at least the importance of the uncderlying variables. Then, I will draw policy conclusions and raise problems. Section 9 concludes.

2 Literature

Since I refered to the most important literature in the introduction, I will now focus on recent work of Barro and Lee. New panel data sets (Barro and Lee (1998, 2000)) invite researchers to analyse schooling more detailed than before. Barro and Lee also provide a range of empirical results to their readers. Schooling has an important role in measuring human capital. However, not only the quantity of schooling, usually measured by time of school attainment/ years of schooling, but also the quality of education does matter. That's why Barro and Lee examine the effects of differences in resources and international test outputs. They use test scores because there exists a positive correlation between them and growth rates of per capita GDP in cross country regressions. These tests of cognitive achievement and the drop-out and repetition rates, that are extraordinary low in East Asia and very high in Sub-Saharan Africa, indicates the schooling output. Input factors directly address to the quality of education. Barro and Lee test influences of parental background, like education and income, teacher pupil ratios etc. on growth. They are curious about the relation of inputs and test scores and define a production function for education $Q = Q(F, R) + \epsilon$, where Q is the quality of schooling. F, the family factors, are said to support pupils learning attitude and ability, also by just offering more nutrition to children. The authors focus on parental, or partly fathers' education and current employment situation which both increases demand for education. R includes the resources devoted to schools. The effect of teacher related factors like salaries[5] and pupil-teacher ratios[6] and the access to books and other materials and real public expenditures per pupil[7] in general are expected to play a role in students' final output. Several authors propose that there might be a difference between developed and developing countries where an increase in inputs has influences on output because the increases in the beginning of accumulating inputs mean an important achievement and can bring high returns to the pupils. The first computer or the first calculator might have larger effects on class output than the 20th. Furthermore, inputs like the length of a school term, which also includes weather conditions, are considered. The error term captures additional unmeasured factors. The underlying tenor of Barro and Lee's work is, that, problems with data sets and missing data at all make analysis concerning educational quality quite difficult. This addresses partly on missing data for the education level of the teachers in the analysis or if as many as possible countries take part in international tests and if these tests are normed in procedure and evaluation. Barro and Lee (1998) estimate the production function given above, using their collected and partly estimated panel data. They specify the education production function as follows

$$Q_{ijt} = \alpha_{ijt} + \beta_1 F_t + \beta_2 R_t + \epsilon_{ijt}.$$

Q_{ijt} signifies test scores in subject i for pupils of age group j in year t. The α contains possible test differences. F and R have not changed. The authors used SUR-method, to allow for different error variances and linkages between the errors. The regression results

[5]Private school teachers' salaries are not included. While salaries rise across countries and especially in East Asia, excluding formerly central planned economies, the ratio of teachers' salary to per capita GDP declines worldwide. However, the ratio is higher in developing countries especially in Sub-Saharan ones.

[6]The authors provide a table of 23 OECD, nine formerly central planned and 73 developing countries. Primary schools have decreasing ratios in the most developed countries but moderate decline in developing countries. Secondary level, ratios are similar between regions. There is a fall in the developed world and a rise in the developing countries. An increase in the ratio is said to imply worse education quality.

[7]The authors are forced to exclude private expenditures because of missing data. This influences especially secondary education, where private expenditures are in general more common. Data are available for example from the UNESCO statistical yearbooks. The authors use the GDP deflator given by Summers-Heston 5.6 Pen World Table for ppp-adjustment. Public spending on primary education has a positive trend over time for all countries, except Sub-Saharan Africa and formerly central planned economies. However, considering all developing countries, we face a decline in expenditures in secondary education in this group of countries. Expenditures has risen in OECD countries, in East Asia and in Middle East/ North Africa, stayed constant in Latin America and fell in Sub-Saharan Africa, South Asia and in formerly central planned economies. If we rely on Levine and Renelt (1992), secondary education should be more important for growth than primary. Reducing the expenditures can be an important failure of countries reflected in bad growth rates.

were are quite interesting. The family background has a significant and high influence on students test scores. The education of the parents also matters. As expected, the ratio of pupil to teacher has a negative influence on students' output. However, the wage does not account for much of the quality of educational output, although it goes in with the right sign. The time length spend in school and the log of total educational spending per GDP are not significant at all. Obviously, what matters is not school input in general, but special variables like less students per teacher do make the difference. Two results are remarkable. First, Barro and Lee had to cope with a significant dummy for Asian economies. They refer to this as "Asian value". special traditional, cultural and religious aspects result in extraordinary respect towards teachers and in a high value of education and discipline in general. Second, they found significant positive coefficients on mathematics and science scores but significant negative coefficients on reading test scores. The first fact can be explained by considering the fact that you need assistance and more instructions to learn math and science is based on experiments and direct research. Reading can also be practiced at home. Moreover, rich families have access to reading material. However, families that are highly educated provide good help for mathematics and science, while just rich people cannot easily offer this. Family background and special school input variables do matter. The data set on educational attainment until the year 2000 accounts for drop-outs and repeaters. it also addresses to different starting years of schooling across the world. The number of people, completed a school level is offered for the age group of 15 years and over or for the grousps of 25 ages and above. This indicates current workforces human capital background, built up in schools. Barro and Lee take the evolution of the population over time into acount. Their data set is especially used in section 7 and throughout the text. However, the quality problem remains.

3 The Facts

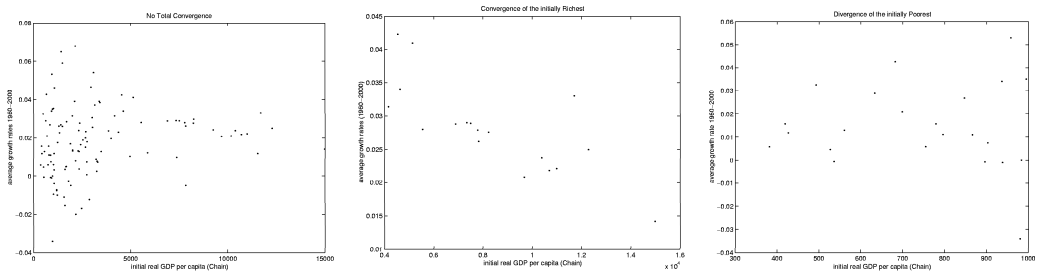
3.1 Empirical Fundamentals

Kaldors' well known stylized facts[8] inspired me to pick out and explain facts, that I consider as being important when thinking about growth models. Note that each of the following subsections is incomplete. They provide only extractive details and do not take all viewpoints into account.

[8]Although not all of his points seem to be doubtless today, Kaldor states several facts concerning to economic growth experiences: 1. Output per worker shows continuing growth. 2. Physical capital per worker grows over time. 3. The rate of return to capital is nearly constant. 4. The physical capital to output ratio is steady. 5. The shares of labor and capital in national income are constant and 6. There are immense differences in the growth rate of output per worker across countries.

3.1.1 Conditional Convergence

Although we observe worldwide divergence[9] over a long time, there are two concepts worth mentioning. The direct counterpart to divergence is, of course, convergence. Total convergence is clearly not what we observe in data. Due to diminishing factor returns and constant returns to scale, the Solow model would imply absolute convergence if one abstracts from different steady states. This is counterintuitive. There are different rates of investment between countries and thereby different saving rates, highly correlated with investment rates. However, there might a convergent club - a club of countries with very homogenous characteristics. Consider, for example, Baumol (1986). He examines several industrialized countries' behavior over time, from 1870 to 1979. Using the following regression, he finds evidence for strong convergence across countries, b=0.995, $R^2 = 0.87$: $ln(Y/N)_{i,1979} - ln(Y/N)_{i,1870} = a + b * ln(Y/N)_{i,1870} + e_i$.. However, De Long (1998) points out that one has to consider also poor countries, whose data sets are often incomplete in contrast to countries having been rich in 1870 or rapid growing economies, and that there are measurement errors of initial per capita income, which highly biased the outcome towards convergence. If we look at Figure 1, we can find strong evidence against general conclusions, based on Baumols' analysis.



(a) Including 112 countries (b) Including the 18 initially Richest (c) Including the 23 initially Poorest

Figure 1: Initial GDP 1960 and Average Growth Rates 1960-2000

Furthermore, I regressed the initial GDP per capita in 1960 on the average growth rates 1960-2000 using, first, a sample of 112 countries and, second, a sample of the 16 initially richest economies. The results confirm the figure above. Standard errors and t-statistics are given in brackets.

- First regression result: $gr = -0.0114(0.0145)[-0.7856] + 0.0038(0.0019)[2.0476] * ln(init)$, $R^2 = 0.037$.

- Second regression result: $gr = 0.1473(0.0558)[2.6393] - 0.0134(0.0061)[-2.1898] * ln(init)$, $R^2 = 0.255$.

[9] See 3.1.2 for convenience.

Only the second regression stands in line with total convergence. In the first regression, the initial income coefficient is significant, but small and positive. Moreover, the explanatory power of the regression is too small to take it serious.

Abstracting from overall convergence, the concept of conditional convergence may be an appropriate approach to describe worlds' development of income and growth. The concept can be found in the neoclassical model; an economy converges to its own steady state and steady states may differ between countries. If a rich economy has high saving rates in comparison to a poorer country, the rich one could be considered to be farer from its steady state than an the other economy. Therefore, it will be the case that this economy has faster growth, i.e. a higher β. The concept goes back to Barro [10] and Sala-i-Martin (1995b), who found evidence in the data, that there is something like a conditional distribution, i.e. countries that have similar characteristics tend to converge to each other, others do not. Barro and Sala-i-Martin (1995b) find strong evidence for β-convergence among European regions and US' state. The convergence rate, however, is considered to be 2% and not about 5.6%, as the original Solow model predicts. Concerning the United States the authors found out that southern states had low per capita income in 1880 and therefore on average higher growth rates. Western regions were relatively rich in 1880 and have relatively low growth rates. Furthermore, the personal income dispersion have been fallen over the last hundred years. Considering the σ convergence in the neoclassical model, one could conclude, that, if states had a deviation in 1880 that was higher than the steady state σ, the fall would imply convergence to the steady state deviation. However, since 1980 σ increases within regions, although the average log of real per capita incomes are narrowing. Since 1974, the dispersion of GDP also increased until the beginning of the 80's, aminly due to oil shocks. Considering GDPs of 73 regions within Europe after the Second World War, they found a correlation of -0.7 between the log of relative 1950 per capita GDP and relative growth rates from 1950 to 1985. The β-convergence is the same within and between countries; around 0.018. The coefficient is only stable over subperiods if they add structural and agricultural components to the regression. I shortly summarize the underlying method of these results[11]. As above-mentioned, the authors consider two distinguishing convergence concepts to account for different pattern of convergence. The

[10] The short form of the Barro regression can be given as $g_{t,t-1} = \beta lny_{t-1} + X'_{t-1}\alpha + \epsilon_t$. If β is bigger or equal to zero if and only if steady state income differences are included. These determinants are included in the X matrix.

[11] This should convince the reader that the results of Barro and Sala-i-Martin (1995b) do not naturally exclude the possibility of a worldwide trend to divergence.

main underlying equation is

$$(1/T)log(y_{it}/y_{i,t-T}) = x_i^* + log(\widehat{y}_i^*/\widehat{y}_{i,t-T}) * (1 - e^{-\beta T})/T + u_{it},$$

with y_{it} as per capita output or income; x_i^* indicates the steady state per capita growth rate (exogenous labor augmenting technological progress), $\widehat{y}_{it}$ denotes output per effective worker (number of workers, adjusted for the effect of technological progress) and $\widehat{y}_i^*$ is the steady state level of output per effective worker. The β vector, the convergence coefficient, determines the rate of convergence of $\widehat{y}_{it}$ towards $\widehat{y}_i^*$ - it measures the speed or the rate with which a country is able converge to the average per capita income of the examined countries. β-convergence is conditional because it depends on given steady states of the growth rate and the output per worker. However, although there is β-convergence, this does not imply that the standard deviation also falls over time. Shocks can still influence the error term and therefore increase dispersion of income. We have to look directly at σ-convergence. The standard deviation of per capita income across countries converges to a constant; σ. This type of convergence addresses to the changes in the distribution of per capita income across the underlying sample of countries or regions over time. Other important findings from this analysis are: Convergence increases if technology can freely move from rich to poor economies. However, physical capital tends to flow to rich economies, if the technology used there is more productive and institutions are better; divergence increases. Contrary to this, labor mobility implies faster because of faster appearing diminishing returns. To conclude, when we allow for different steady states, that is, when we account for different education, policies etc., results become more robust. Directly speaking, conditional convergence holds because of controlling for spillovers from, e.g. the initial level of schooling. But that's what partly drives divergence.

3.1.2 Divergence

The Aztecs and the Incas had been the most richest and most urbanized cultures in the world, in 1500. On their former territory today partly live starving people in huts without electric light and clear water. In Canada, one of the most industrialized countries in the world today, grizzlies might had been the most intelligent form of living 500 years ago. As Acemoglu et. al (2001) state [12], this is not a mean reversion but

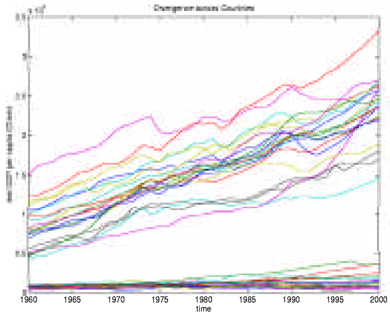
[12] He established the 'institution hypothesis'. Although this hypothesis is very meaningful, I will not refer to this strand of research in my work. Let me therefore provide a brief overview. Acemoglu et. al go back to colonial times. They used the rate of settler mortality as instrument to reveal large effects of institutions on per capita income. Having better institutions is a direct incentive for investing in capital, countries use factors more effectively which is reflected in higher income levels. After controlling for this effect, countries closed to the equator are not poorer in general. This denies

a 'Reversal of Fortune'. We do not have to go that far back in history to underline the importance of taking divergence seriously. Between 1870 bis 1990 the ratios of per capita incomes between poorest and richest economies increased sharply, and so did the standard deviation of log income across countries. The data from 1960 until now tell the same story; the gap increases.

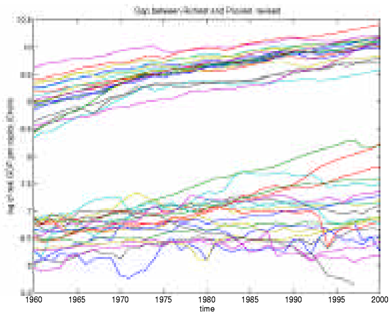
Using more sophisticated methods, Pritchett (1997) reveals that growth rates of developed countries do converge but growth rates between developing and developed countries do diverge over time. Furthermore growth rates in developing economies are far away from each other, there are a lot of outperformers but also a lot of countries that developed rather badly. The developed countries, in contrast, stand closed together. Divergence dominates worldwide behavior. Especially closed economies tend to diverge. Note, that former India and China are best examples for this. So closed economy growth models that predict convergence are at odds with the data. In general, theories that emphasize convergence are obviously only relevant to explain miracles. Easterly and Levine (2001) find evidence against convergence, too. GDP per capita differences are growing. They found no evidence for diminishing returns to capital and the US do not face the predicted slower growth. The neoclassical model fails to explain this. Easterly and Levine (2001) show that rich nations in 1870 grew in general faster than former poor ones. Differences are highly persistent. Figure 2 confirms this. There is no tendency that gaps close. Instead, the standard deviation of income increased from 0.94 in 1960 to 1.09 in 1997 (Jones 1997).[13] Not at least because of an ongoing dispute, Benhabib

the strong geography hypothesis. European settlers established different institutions in their colonies, depending on the prosperity and population size before their arrival and on their mortality rates. On the one hand, extractive institutions were established in regions with high mortality rates. Furthermore, good transport possibilities, high population density and agriculture made it easier for the settlers to get resources out of the colonies in their home countries. Examples for this behavior are colonies in Latin America and names like 'Ivory Cost'. On the other hand, in colonies with low mortality rates of the settlers and less original population made it easier to live in regions. Institutions from the home country were copied. Former British colonies are now highly developed economies, not at least due to their famous common law. The pilgrims went to America because of high mortality in Guyana. The colonization has directly caused the reversal by completely changing institutions and lives in these regions. Only countries with institutions, that set the right incentives to the people, could have profited from the industrialization. The established institutions have been very persistent, the good ones due to the expected high returns of investment and due to 'checks and balances' and the bad ones due to incentives on small elites who gained a lot from extractive policies. To conclude, indirectly doubting the results from Kremer (1992) and Jones (1995), the authors associate a ten percentage points higher population density in 1500 with a four percent lower income per capita today and a ten percent points higher urbanization in 1500 is even linked to twice as high GDP per capita today.

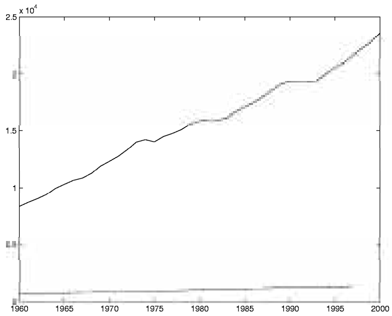
[13] Sala-i-Martin shows that one has to take into account that big economies, like China, catch up recently and therefore provide evidence for a narrowing gap because of the huge country size in comparison to other markets.



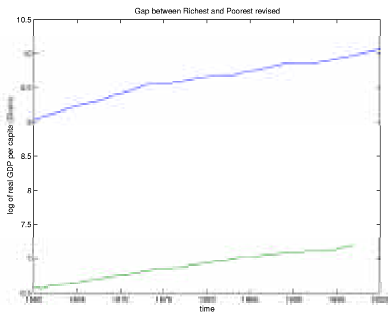
(a) The Gap between the initially Richest and Poorest



(b) Taking logs



(c) Taking the means



(d) Taking logs again

Figure 2: The Gap in GDP per Capita over Time across Countries, 1960-2000

(2003) recently studied the relationship of inequality and growth in detail, considering various attempts before. He found a hump-shaped relation. Small deviations enhance growth. However, if inequality rises more and more, growth will fall. This might be linked to the necessary redistribution, which reduces returns from investment. How do the divergence results cope with conditional convergence evidence? Coming back to the results of convergence studies, Quah (?)criticizes the standard approach of convergence analysis. The idea was to control for transitional dynamics by using initial income and choose explanatory variables that explain permanent growth or trend. It is therefore assumed that there is a steady state growth path for each economy, approximated by a time trend. The problem is that the explanatory variables can have an influence on the time trend. However, he can't exclude this, looking at the data. He looks for an alterntive. He found out that there is no correlation between time trends 1962-1973 and 1974-1985 for 118 countries. Instead he found heteroscedasticity and significant changes; long run growth pattern are highly unstable. So, the assumption of stable growth paths and analyzing cross-country variations is worth questioning. He therefore follows another strategy. Quah looks at a AR(1) process which values are distributions of incomes across countries and not within: $F_{t+1} = M * F_t$, given F_t. M includes the average annual transition across time. It is approximated by dividing countries relative to the average incomes into groups and then weighting them stage wise. The used 5*5 Markov chain transition matrix includes entries for the probability that a country in state j, corresponding to the income level, transits to state k. If the order of the process will go to infinity, this is the long run cross-country income distribution characterization. The spectral density characteristics of M then gives the convergence speed. The distribution can move towards an unimodal or a bimodal one. The second seems to be true, cross-country incomes move to the extremes. Countries in traps do not come out.[14] Even among OECD countries are tendencies of divergence since the beginning of the nineties, although macroeconomic indicators converged. Interestingly, Hollanders, Soete and ter Weel (1999) found out, using a variance decomposition, that standard variables like labor and capital or patents and R&D cannot explain the divergence in the nineties. The authors suggest that divergence may occur among OECD countries relatively to the US because of better knowledge-use and another information and research structure than in Europe. Furthermore, the internet and new communication methods are better used in US firms or industries than in other OECD economies - especially for commercial issues.

To conclude, the world diverges rather than converges. There are barriers to human development and technological innovation. Within certain groups convergence occurs but between groups divergence is todays issue. The so-called advantage of backwardness is not often observed.

3.1.3 Miracles and Poverty Traps

Looking for good policy advices to enhance growth opportunities means to work with examples. Countries can provide a lot of information concerning modeling growth in general. This does not mean that one should focus on experiences that appear often and forget about seldom occurring empirics. We do not know where to find the key for explaining growth and income differences and developing policy packages. However it is necessary to look what's going on. I will consider outliers that are not representative for the whole developing world but representatives for extraordinary good and bad experiences. The average[15] lies in between these groups and grows more or less slow after

[14] There are several authors, e.g. Jones (1997), Kremer, Onatski, Stock (2001), that contradict to Quahs underlying method and to his results, which crucially depend on including oil producing economies.

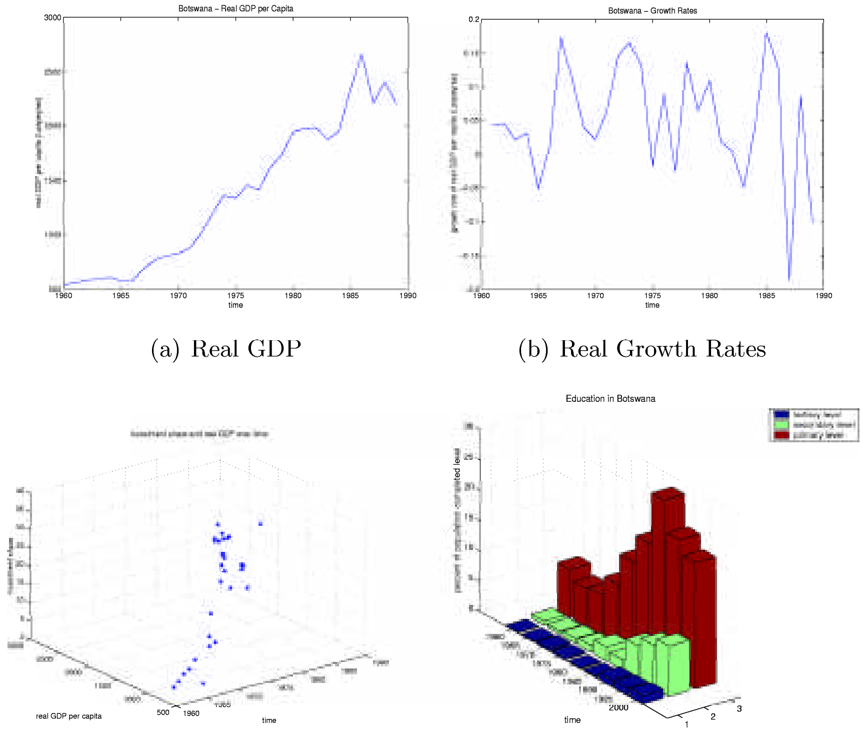
[15] I do not consider certain transition economies, although some of them, like the Ukraine and other former Soviet Union members, face total stagnation today. Most inhabitants of these regions live in countries that are is still in a process of recovery and progress and might belong to already industrialized economies and I will not refer to European outperformers like Portugal, Malta or Ireland, because there, European integration played a mayor role in the development process.

having grown fast, one might think of Mexico or Argentina or not, like the Philippines or Kenya.

Miracles

Although there are tendencies to predict divergence across countries, Jones (1997) shows that in the last decades, we can report slightly more miracles than traps. These miracles give reason to hope for more catch-ups in the future. Maybe one can find factor combinations, all these economies have in common; because "If we understand the process of economic growth - or of anything else - we ought to be capable of demonstrating this knowledge by *creating* it in these pen and paper (and computer equipped) laboratories of ours. If we know what an economic miracle is we ought to be able to *make* one." (Lucas (1993), p. 271). We should be aware of outperformers in regions were we would expect no growth at all. Lying in the middle of nowhere, Botswana is one eye-catching example. Botswana has nearly no problems caused by ethnic division because there is non. The region was relatively stable over time, there was nothing about corrupt politicians. The country is governed very liberally. Freedom of press and market openness were essential factors for attracting foreign investment and industry. Figure 3 summarizes Botswana's performance over the last 40 years. Contrary to the other miracles considered below, the country has quite high fluctuations in the growth rates. This reveals that it was and is highly addicted to the world market and the economic well-being is still not very stable. However, investment rose over time and the country provides today more schooling than ever before. What we observe is a coincident behavior of GDP and educational attainment. Especially the rise in people over the age of 15 educated at a primary level is tremendously. In the last twenty years, people started to attain secondary level education, too. Since primary education can only be the basis for development - Section 3.1.5 will reveal that secondary education is the issue of concern - this new increase gives further hope for the countries performance. The economy is very stable. Therefore the countries government will not face too high redistributional pressure while increasing the level of knowlegde of its population. Moreover, if the performance of the country remains that good, people might face low incentives to migrate to richer countries. Clearly, a good growth model should be able to replicate the US performance and the Japanese GDP path since World War II. However, if we look at the data, the East Asian Tigers - the NIC's[16] - come into our mind. The East Asian miracle was and is a deeply analyzed issue, not at least because one hopes to replicate the performance in other countries. In an ongoing debate, several authors emphasize the role of investment. Young (1995) predicts that the accumulation

[16] We speak about Hong Kong, Taiwan, South Korea and Singapore and maybe Thailand and Malaysia.



(a) Real GDP (b) Real Growth Rates

(c) Real Investment (d) Educational Attainment

Figure 3: Botswana

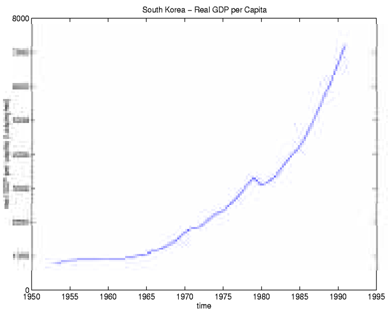
of capital can explain a major part of the East Asian miracles. The high growth rates are proportional to the development of the investment shares. According to Young, the 'Gang of Four' has had this fabulous growth experience because of factor accumulation and not due to technology progress. However, his approach is criticized a lot. He does not involve elasticities of substitution nor does he differ between used technologies. Furthermore, including public investment is ambiguous; the complementary effects of investment in equipment and infrastructure are not very robust. Easterly and Levine (2001) find that a lot has to be 'explained' by the unexplained TFP variable or residual. To conclude, capital accumulation takes place where the incentives to accumulate are, i.e. where technology innovation increases the gains from capital accumulation. Technological change offsets the diminishing returns to capital. According to Romer (1993), one has to differentiate between objective gaps and idea gaps. Opening to western ideas and engaging in trade can close the idea gap very rapidly. Some countries refuse to do so and isolate themselves. Others, like Japan, have more open policies and succeed. The objective gap, the missing of good infrastructure, like roads and hospitals, and factories is closed afterwards and takes more time. High and robust correlated with the investment share, trade variables indeed seem to be important. A change from inward orientation and barriers for imports towards an open policy regime changes the trade balance. Exports grew and so did GDP. However, why did the people decide to export? Import restrictions brought profits to home country firms. These firms could afterwards engage in exporting products. Incentives towards export orientation were not directly set by governmental policy. More important is an export-oriented decision making process and not a product oriented one. For these countries, export growth is closely related to income growth. This can be due to a comparative advantage of these countries when opening to international trade. We observe falling capital output ratios and therefore rising growth rates. Furthermore, most miracles have had only a few difficulties to have a balanced budget. These factors might explain high growth rates at the beginning of the growth process, but most miracles are miracles because they have sustained growth. Explanations for this may be a liberalization of financial markets in general, an intensive and sufficient provision of public goods like telecommunication and transportation and last but not least unusually high educational attainment. Furthermore, sustained growth can be explained by lower costs of trade policies in the beginning of development, where the economic structure of a country is mostly an agricultural one. Having used the right policy variables to hold to growth in this sector and to be able to provide proper infrastructure, restrictions will have higher costs while a countries' industry develops. One day, when the industrial structure becomes more complex, it is too costly to hold to barriers and the countries liberalizes. Another possibility is that opening to international trade forces the country to develop good mechanisms to react on shocks etc, i.e. to provide stability. That's how discipline is imposed on governmental actions, mistakes are more worse than before [17].

South Korea and Taiwan are two very different, export-oriented examples of East Asian Miracles. The main difference in the development of both countries is the influence of governmental policy. While the South Korean government has an extraordinary high influence on the industrial structure, the Taiwanese government has a supportive role behind the scene. After the Second World War Korea was still a poor country without any infrastructure and low growth rates. However, in the middle of the 60's, the country started to grow and didn't stop doing so until the end of the 70's when the country started to engage in heavy industry and run a lot of depts. Inspite of running into heavy crisis, the economy started to grow again in the mid 80's. This happened because investment didn't break down at the beginning of the crises - incentives to invest were still there, which helped the country to improve again. The country grew before policy actions were undertaken. Furthermore, the country still borrowed a lot of money and could accumulate not also physical, but human capital. They focused on

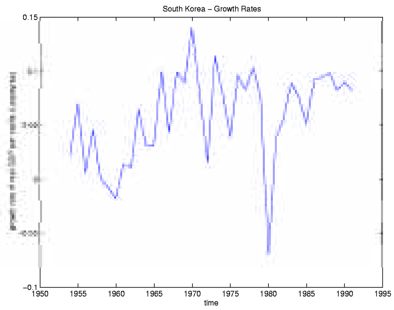
[17] Singapores government raised wages in the 80' s and was directly punished by growth slowdown.

education and increased hours worked. Each part of the rescue was essential for the Korean economy to recover. The dept crisis of Korea did not become a growth crisis. However, governmental action in South Korea resulted in an industry consisting of only a few big companies. Market mechanisms didn't function at all. The government did not deregulate the economy but interfered even more, including the financial sector. There was a high degree of efficiency due to the created scale effects but the distribution was rather uneven. The governmental engagement in loans due to ownership of lending banks makes the state responsible for possible failures of the industry. This is a typical moral hazard problem. Firms were invited to be less risk averse. In the end of the 70's, the country started to liberate the financial sector. This helped a lot. However, Korean industry requires big orders because of the still existing large firm size and the government is still highly active concerning to the industrial sector. Contrary to the South Korean experience, Taiwan chooses another policy. This is reasoned in a complete different starting situation. The Taiwanese industry is and was determined by a large number of firms of medium and small size. The influence of government or a direct involvement is naturally small, not at least because of eligatarian attitude towards economic development. Just a concentration of resources in a few private hands should have been prevented. In Taiwan, the high export rates and returns are caused by or distributed to a large number of firms. Labor-intensive products were exported but the government didn't care about the underlying production technology. The market mechanism functioned well enough. The government act through the channel of incentive setting on exporting industries. However, Taiwan could not profit from economies of scale. Fortunately, many traders distribute small orders to many firms or divide big orders into small parts. the acceptance of small orders in Taiwan can be considered as comparative advantage to Korea. However, because of a laissez faire attitude, the nontraded sector suffered a lot. Infrastructure and social security were and are still quite low. In contrast to South Korea, government didn't engage in the countries living standards improvement.

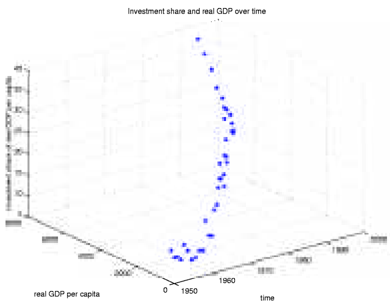
Both countries have also several things in common. Lets look at the Figures 4 and 5. GDP per capita increased exponentially over the past decades from around 1000 in 1950 to around 8000 $ per capita in 1990. Both countries' average growth rates over the last 40 years are above 6 %. The behavior of real investment underlines this performance. It increases continously over time, although in the 1980s there is a slight slowdown of the investment share in Taiwan. This difference to Korea might be caused by the underlying technology use - HighTech, which requires a greater amount of investment, is mainly used in South Korea. However, considering the peoples level



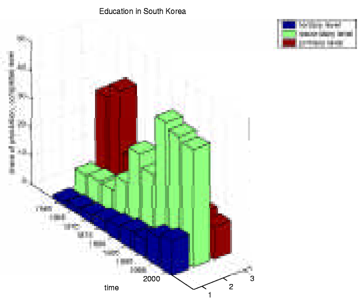
(a) Real GDP



(b) Real Growth Rates

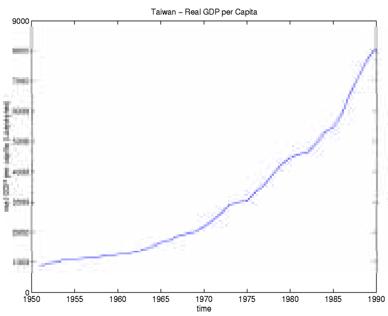


(c) Real Investment

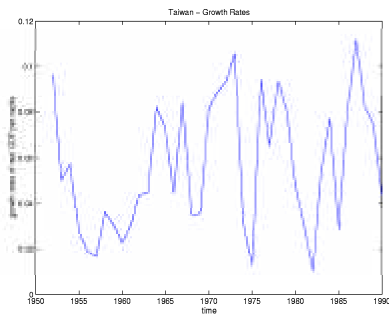


(d) Educational Attainment

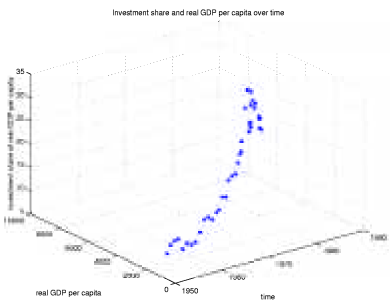
Figure 4: South Korea



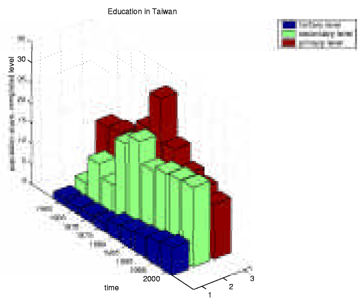
(a) Real GDP



(b) Real Growth Rates



(c) Real Investment



(d) Educational Attainment

Figure 5: Taiwan

of education, the picture becomes more uniform again. Contrary to Botswana, both countries face a very high initial endowment of primary educated people. The labor force can use technology and fulfill more advanced tasks. Firms just have to train their already educated workers. This is a comparative advantage. Once started development, secondary schooling expanded a lot. But Taiwans performance seems to be stagnant in the last decades. This might be due to the fact that the agrarian sector is still important and that education is costly. Technology was not only used anymore but also developed. The so called 'Asian Value' comes into play. Peoples education is very strict, students engage a lot and take their teachers seriously. Learning discipline seems to be important throughout the history of these countries. If the quality of education is also good, this can be very fruitfull for development. However, the causality is not yet clearified. On the one hand, education may have risen because of educated workforce demand. This lagging behavior is supported by the Korean experience in the beginning of the eighties. Growth rates have been fallen while secondary education fell with a lag of about two years. Less people completed secondary education; maybe because the return where predicted to be lower than before. On the other hand, education may have increased the attractiveness of East Asian countries for the world market. This is true for the baseline education that was already given before the countries were on their ways to become miracles. In the last years, we observe a higher portion of the workforce that have completed a tertiary level, i.e. that went to universities. This could symbolize the countries change towards inventing and no longer imitating countries that took place in the mid 1980s.

The main implication of these examples is that countries had to face very different initial situations, emphasized or not by governmental actions, which again are based on traditional aspects or initial structure. Failures of certain policy actions cannot be interpreted as generally bad policy, but as a part of complex dynamics of development. Every single miracle has its own history. What we also observe is that governmental policy is not the main factor of economic growth, but can improve the performance of a country. However, one should realize that the government in general is likely to hold to a policy position. Besides this, keep in mind that growth rate fluctuations are quite low and GDP per capita increased continously, abstracting from the Asian Crisis in the end of the 1990s.

Contrary to Korea and Taiwan, who focused on education and partly on technology adoption, many countries depend strongly on minerals [18] and on the development of the

[18]In general, economies with a lot of natural resources tend to grow slower than economies other economies because they do not concentrate on manufacturing. Furthermore, the traded goods, resources, do not need that much labor and capital, which therefore concentrates in the non-traded sector

agricultural sector. However, LD-countries are often characterizes by a deeply underdeveloped agricultural sector. Farmers do not have access or cannot afford appropriate technology that offers higher returns and complements labor input. Mostly, we also speak solely about home production. Furthermore, countries often export cash crops, whose market prices are very volatile and have immense influences on a countries' well being.

Poverty Traps

It is a great deal to find pattern of growth in general, but it is even more difficult to account for the so-called Poverty Traps, countries that do not grow at all or have even negative growth rates,[19] like Chad and Burkina Faso.I will shortly review the performance of three LD-Countries. Keep in mind that these are not even the poorest ones. This is mainly because of the lack of data, which, in general, biases economic analysis of especially Africa. Consider the performance of Central Africa, Niger and Zaire in Figures 6, 7 and 8. Contrary to the miracles' GDP, their yearly GDP varies between 100 and 800 $ per capita and declined sharply since the mid 1970s. Therefore, the growth rates are mostly negative. Furthermore, they vary a lot with high amplitudes. The bad performance of these economies is also partly reflected in the investment share. In general, the investment rates are really low. In central Africa, the decline over time is very obvious. More ambigious is the role of investment in Niger and Zaire. In Niger, the figure reveals three cummulation regions. One recognizes the two peaks in GDP per capita and the relatively low and not trending investment shares. Because of the performance at the end of the observation period, we cannot conclude that a fall in GDP is align with a decreasing investment share. Zaire's picture is slightly different. Since the rise in income coincides with increasing investment, in the eighties investment stays relatively high although the countries performance gets worse every year. Obviously it is not used efficiently. Looking at the performance of LDCs, we find differences between relatively richer and poorer countries in the educational level, but within a country one cannot find a link between changes in the percentage of educated workforce and growth experiences over time. This is also true for the given examples. Especially Zaire's performance supports this view. Secondary education expanded in the eighties while the country got poorer. Therefore, it does not seem to be the case that the returns to education were

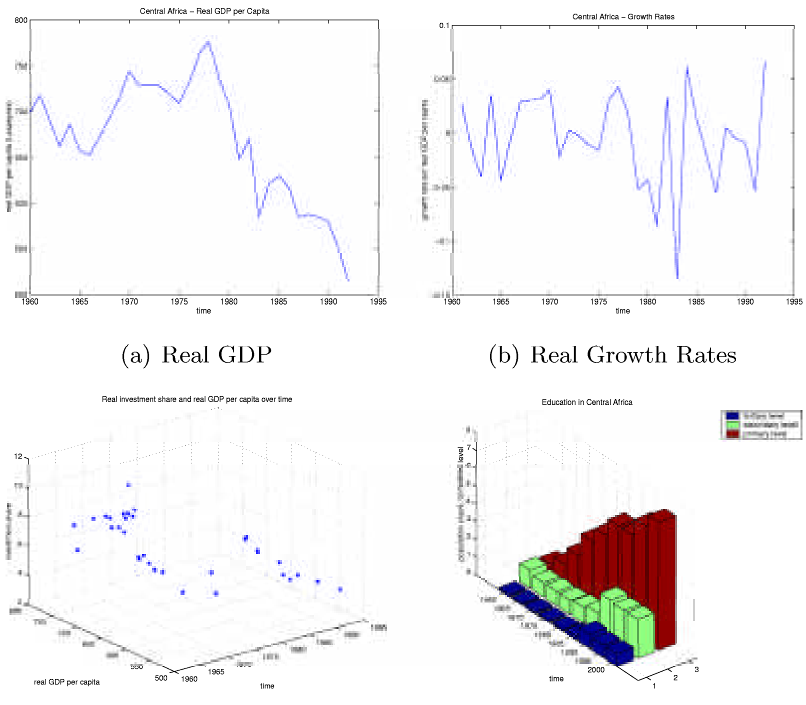
production, where the returns are low.

[19]To motivate the need of discussion of the sensitivity of endogenous models towards LD-countries, I want to give a link to the CD-version, which includes a summary of 'The Story of Abu', often used by Easterly in his presentations. A lot of variables are considered to be influential when speaking about growth. It is about health, saving and investment restrictions, institutions and incentives. From: A Quiet Violence, by Betsy Hartman and James Boyce, 1983, a quasi journalistic account by two economists of life in Bangladesh 1975.

extraordinary high but that there was foreign intervention, forcing schooling. Note that the percentage of population is still extremely low in every example and in each group of education. Maybe the learnt things are not relevent for the workforce's tasks. The rise in secodary education takes also place in the other two countries, although not with such a high amplitude. However, basic education rose continously over time, not at least because the general view has been that education is the foundation for prosperity. Maybe a higher level of baseline education made the economies more resistent to shocks. If this is the case then only for the last decade. Using Penn World Table 6.1 we find data for the years 1990 to 2000 that do not confirm this. GDP declined even more.

Considering increases in education, Africa expanded its education on average relatively more than Asia, but has lower growth rates of output per worker. Also Transition Economies have high attainment rates and are on average stagnant[20].

To conclude, keep in mind that, in general, GDP per capita does not vary that much in all poor economies. Some have fairly constant GDP over time and show therefore a stagnant behavior, although, growth rates in general do have higher amplitudes than developed countries.

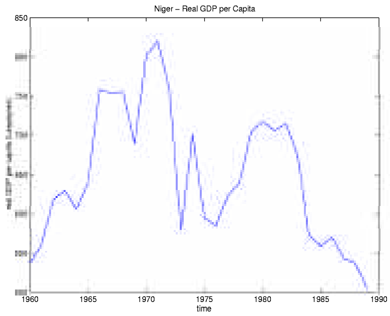


(a) Real GDP (b) Real Growth Rates

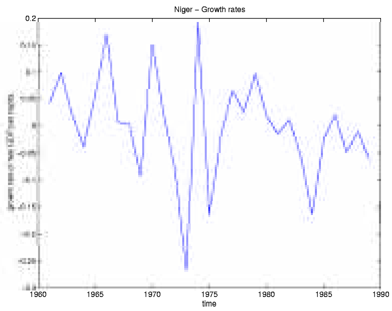
(c) Real Investment (d) Educational Attainment

Figure 6: Central Africa

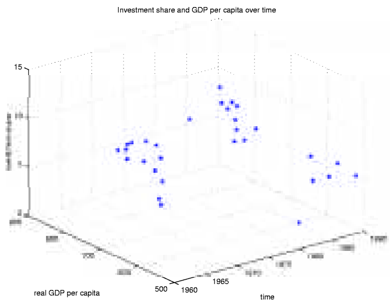
[20]By the way, the CD version contains additional figures for Malawi, Haiti, Singapore and Thailand in addition.



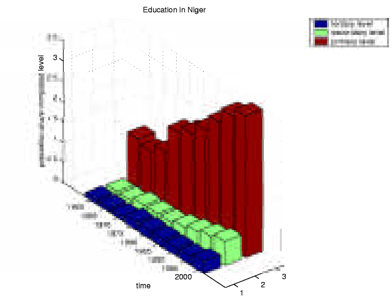
(a) Real GDP



(b) Real Growth Rates



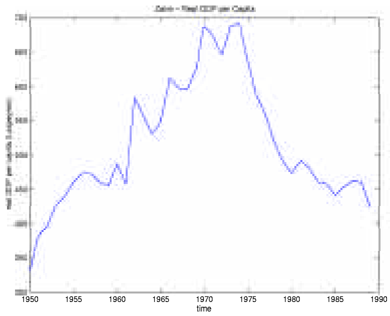
(c) Real Investment



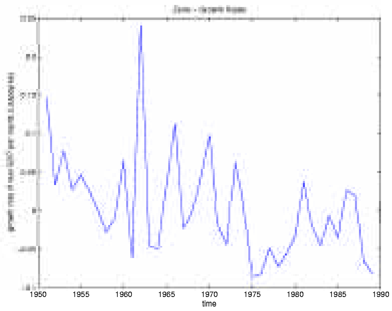
(d) Educational Attainment

Figure 7: Niger

Analytically, a trap can easily be generated. Countries are trapped in bad equilibria 'because of' the S-shaped growth rates of capital stock (sf(k)/k) that arises under the existence of varying returns. There are two stable steady states, one with a high k and one with a low one. Furthermore in between these stable steady state is an unstable one that cannot hold over time. The stability of the low steady state k implies that there is nearly no way out of this equilibrium. Possible resources of poverty traps are high fixed costs of growth like industry start-up costs or, more general, infrastructural costs. Overcoming these costs means that in the very first beginning an economy can face highly increasing returns. This could happen due to immense innovations or high enough additional investment that overcomes the fallback position. Furthermore there can be spillovers among sectors, which arise when the domestic market is not too tiny. This addresses to the 'big-push' idea. However, if markets do not have a certain size and if initial fixed costs are too high to take, a country is in a poverty trap and cannot get out of it easily. The explanatory power of multiple equilibria is very difficult to prove empirically. It is even harder to draw policy conclusions or advices. Multiplicity just means that there are several possible output levels for a fixed stock of capital and labor. This could explain TFP differences. Recently, economists found methods to calibrate and estimate these models and there seems to be high explanatory power of countries'



(a) Real GDP



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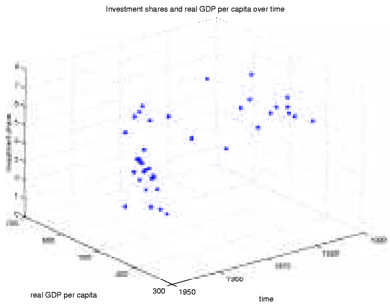
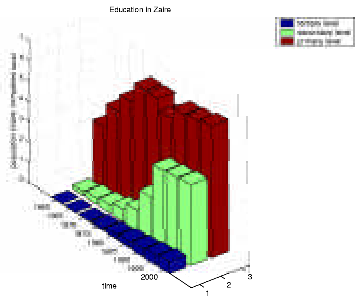


(c) Real Investment



(d) Educational Attainment

Figure 8: Zaire

experience [21], however, the question of why some countries are far behind others is still unsolved. Recent studies come closer to the answer. There are certain attempts to express the failure of disasters, like Chad or Burkina Faso, to grow. Parente, Prescott (1994) find evidence that over the long run, countries grow at the same rate. The only thing that causes deviations from this rate is the existence of technology barriers; long run differences in the levels should be in the focus of such an analysis. Moreover, technology transfer prevents that countries diverge. They offer several models concerning to barriers to growth. Monopoly rights might be one explanation for 'Barriers to Riches'. One could imagine that there are incentives for governments to protect their industries from international competition through the creation of appropriate laws. Recent work is concentrated on identifying and modeling corrupt institutions or malfunctions in political systems that can produce barriers, e.g. in form of foreign investment cut-offs or rises in domestic security expenditures. Generally speaking, people cannot save and invest and are not able to innovate if incentives are poor. Furthermore, uncertainty seems to be important. It discourages domestic savings and investment. There is also evidence for a linkage between growth rates and military coups, related to political instability and uncertainty. Low levels of income and low growth increase the possibility

[21] For one calibration method of a two-sector model see Graham and Temple (2001). Furthermore, there is some evidence for equilibrium switches in some countries.

of military coups and the probability for a new coup depends on the amount of coups having had before. It is not the coup itself that influences long run growth but the leadership afterwards. As the examples above suggest and as we already know, Africa is the continent to which the trap theory addresses. It is not the case that Africa suffers from not getting foreign aid or capital, physical and human. What we observe is instability, underdeveloped financial systems, high government deficits, high ethnical division, bad infrastructure and educational systems. Several studies suggest that the influence of interest groups in connection with rent seeking behavior are guilty for the underprovision of public goods and therefore for not providing the basis for a better performance. There is investment, private and public, but it is not used efficiently among a sample of African countries, excluding Botswana. In labor-intensive industry in Africa, people can work with most of internationally used technology. Thus a combination of factors like low level of education, non-openness, bad policies etc., act together in not using the, partly high, investment levels properly. This is confirmed by the fact that investment increased while changes in the growth rates were not obviously or directly influenced by that. Closely linked to these observations is a study of Chari, Kehoe, P. and McGrattan (1996). They find evidence that stochastic distortions in investment decisions can account for income differences across countries. The distortions - the authors introduce regime switches; in one regime, distortions are persistent, in others volatile - symbolize incentives against investment like bad governmental policy, corruption or resistance to technology adoptions. While these authors focus on distortions to investment, they indirectly address this to disincentives due to governmental policy or bad environments. That's why they do not contradict to the work of Hall and Jones (1999), who show that differences in growth among countries are not mainly due to different factor accumulation but due to productivity differences and thereby due to differences in social infrastructure. The productivity level itself is influenced by institutional arrangements, policies or tax structure etc and so is accumulation. Government is responsible for growth of GDP per capita. It can act in two distinct directions, growth enhancing or contraproductive, e.g. in form of corruption. A government can set incentives for skill accumulation or inventions. Furthermore institutions can prevent corruption, lobbying and rent seeking. Thus, they consider social infrastructure as explanatory variable for productivity and this again directly addresses to the amount of output per worker. They do level accounting [22] of a simple Cobb Douglas production function for several

[22] Instead of previous studies, they use capital to output ratio instead of capital/labor because along the balanced growth path, capital to output is proportional to the investment rate. The authors uses data from 1988 of 127 countries; labor input in form of number of workers, physical capital, output and average school attainment and the rate of return from education: 13.4% , 10.1, 6.8, from Psacharopoulos (1994). The capital share is 1/3. Externalities are ignored because of missing evidence. They consider

countries i=1,..N.

$$Y_i/L_i = y_i = (K_i/Y_i)^{\frac{\alpha}{1-\alpha}} h_i A_i,\ h_i = H_i/L_i, H_i = e^{\phi(E_i)} L_i.$$

They find out that productivity differences are similar to those of output per worker and therefore explain indeed a lot of this variation across countries. An extract from Hall and Jones' (1999) Table I, page 91 shows the contribution of the factors to output/worker. Hall and Jones also argue that former studies that show different results

Table 1: Results from Level Accounting (Hall and Jones, 1999)

Country	Y/L	$(K/Y)^{\alpha/1-\alpha}$	H/L	A
United States	1	1	1	1
West Germany	0.818	1.118	0.802	0.912
United Kingdom	0.727	0.891	0.808	1.011
Hong Kong	0.608	0.741	0.735	1.115
Japan	0.587	1.119	0.797	0.658
India	0.086	0.709	0.454	0.267
Zaire	0.033	0.499	0.408	0.160
average (127 countries)	0.296	0.853	0.565	0.516
Standard deviation	0.268	0.234	0.168	0.325
Correlation with Y/L (logs)	1.000	0.624	0.798	0.889
Correlation with A (logs)	0.889	0.248	0.522	1.000

may be wrong. Mankiv, Romer and Weil (1992) for example consider econometrically estimated elasticities but assume that productivity and accumulation of capital are uncorrelated across economies. However, countries with high incentives for capital accumulation will also use inputs more efficiently than others. The above given accounting results do not contradict with that. It can be seen that capital accumulation is only a small part of the story, but is says nothing about the quality of accumulated capital. Furthermore, if a country has low infrastructure, accumulated capital is not necessarily used in production but is spend on 'fences' or private protection in general. Of course the used capital cannot contribute a great deal to productivity. There are a lot of papers that describe workers' choice among production and diversion. Mostly more equilibria are possible and therefore the existence of poverty traps can be explained. However, if a region functions well, no fences are needed at all. The authors therefore test the strong hypothesis that at least social infrastructure is the main thing to explain differences [23].

the data as ratios to the US data.

[23] They used the following regression equation

$$logY/L = \alpha + \beta S + \epsilon,\ \widehat{S} = \gamma + \delta logY/L + X\theta + \eta.$$

The outcome is that differences in social infrastructure are important for differences in countries' output per worker. Furthermore, they influence the accumulation of human and physical capital.

Let me refer to another problem, a growth model should acount for. Combining the result of divergence across economies and the existence of miracles and traps and asking for explanations of these phenomena, one can think of magnets somewhere. We observe very high differences between areas. There are slums in big cities, there are booming cities in regions, i.e. in Africa, booming regions in countries, and countries diverge. The richest 20 nations have 15 percent of world's population but produce 50 percent of world's GDP. Lucas (1988) said: "What can people be paying Manhattan or downtown Chicago rents for, if not for being near other people?". What we observe is migration of educated people out of poor into rich, already densely populated regions; population density and income are also highly correlated. This reinforces the concentration process. In the US, we find a high concentration of poverty and ethnic divisions in special regions. Borjas (1995) concludes that there are strong neighborhood and ethnic externalities, which explain these clusters. Consider BoWash, identical people have higher wages in cities with high average human capital than in other cities. Possible answers for this factor movement and the concentration of economic activity are again social infrastructure differences, reputational effects or other policies that create certain incentives. Others address to transportation costs (Fujita, Krugman, Venables (1999)). They say that these costs are high in comparison to congestion costs, although this does not necessarily be the case. Small TFP differences can have an immense impact on economic performance. Kremer (1993) addresses to this fact. He showed that skilled workers, who make no or only some mistakes, will work in firms with other skilled and high paid workers because wages and output increase in the skill level. Furthermore, there are positive correlations between wages of different occupations within firms. In his model, imperfect matching occurs due to not completely observable skills, which causes underinvestment in human capital. He suggests that subsidies to education may act as complements and therefore create multiplier effects. His theory is consistent with the fact that poor countries are characterized by small firms, while large companies operate in richer ones and with large income differences between countries.

Besides this, we have to compare the existing growth models to the general existence of high concentration. Of course, under the assumption of perfect markets, it stands in

where $\widehat{S}$, social infrastructure, is endogenous and not exogenous because it might be not independent of the level of output per worker.

contrast to the diminishing returns assumption of the neoclassical model. Klenow and Rodriguez (1997) ask if the "..neoclassical revival has gone too far" and the answer might be yes. It cannot explain income differences between ethnic groups nor can it explain the movement of factors towards rich regions. Admittedly, the barriers literature tries to solve the problem of innovation moving not to the poor and mostly unskilled workers are not able to move because of costs of moving. However, the baseline assumptions of these models, that capital should flow from rich to poor countries and mainly unskilled people should immigrate into rich countries, seem to contradict with the concentration phenomenon.

The distribution of income level is skewed to the right, towards higher levels occurring more often. Savings and population growth is not. However, these variables determine income in the Solow model. New Growth Theory, i.e. theory of endogenous growth, might be able to cope better with these facts. Technology with its nonrival nature makes spillovers more likely. These spillovers lead endogenously to matching of 'rich' people, which has a negative effect on poor ones.

Considering these results and the story of miracles and traps, the problem of modeling growth becomes clearer. Until now, it does not seem to be a good idea to use models that predict convergence for explaining both, miracles and traps. Endogenous growth models, especially R&D based models, may be able to explain the rapid growth of certain countries. The question if governmental policy in these models should have level or rate effects stays unanswered. What remains is the fact that pure capital accumulation cannot be the only reason for growth. Maybe factors and technology or factors and good policy act complementary in increasing growth. Thus, considering all these facts might help to evaluate and develop better growth models.

Besides modeling issues, concentrating on explanatory variables or packages of them is the key factor to give policy advices. The next subsection therefore focuses on the power of results from several cross-country growth regressions and the derived policy conclusions.

3.1.4 Robustness of Explanatory Variables

Since the industrial revolution there is an overall immense increase in GDP per capita. However, we face high variation in output across countries and the income distribution is very persistent. Therefore, researchers try to find explanatory variables for growth. Thus, numerous researchers use the method of cross-country regression to identify variables that are determinants for long-run growth rates. Several policy variables or institutional determinants are identified to be correlated with growth. However, in a striking paper, Levine and Renelt (1992) suggest that varying the information set, i.e. including or excluding other maybe explanatory variables, may lead to different results concerning the significance of the considered variable. They examine several predicted interactions and conclude that almost all correlations are fragile under changing information sets. Almost none of the tested variables survived this sensitivity analysis. To get into detail, Levine and Renelt use an extreme bound analysis (EBA) and consider the following regression equation

$$Y = \beta_i I + \beta_m M + \beta_z Z + u,$$

where Y denotes per capita growth or the investment share, depending on which dependent variable is involved. The I-matrix includes variables that do not alter, M includes the variable whose correlation with the dependent variable should be analyzed for robustness and Z consists of varying variables, identified by several authors to be relevant factors for growth. Levine and Renelt (1992) run many regressions with a varying Z matrix to get values for the upper and lower bound for the β_m vector, which is not rejected by hypothesis tests. If the coefficient vector stays significant, then the partial correlation of M and Y is considered to be robust.[24] However, the results are considered to be fragile in case of a not significant β vector under at least one information set. Furthermore, results are fragile if the sign of β changes. Concerning the growth rates of GDP per capita as dependent variables, the only explanatory variables that are robustly and therefore significantly correlated are initial secondary schooling enrolment rate (SEC), which is not significantly correlated with the investment share, initial level of real GDP per capita 1960 (RGDP60)[25] and investment shares of GDP (INV). Other variables often said to have a significant influence on growth rates and therefore to account for income differences between countries, like coups and revolutions, which are significantly, negatively correlated with the investment share, population growth and trade policy variables, are fragile. However, they found robust positive correlation between the ratio of international trade to GDP and investment share in GDP and between investment share and growth [26] The table below is copied from Levine

[24]The base regression includes only the M and I variables, the bounds include standard deviations and are taken from the 'worst' variable combination in Z.

[25]Levine and Renelt provide further evidence for the conditional convergence hypothesis. Initial income in 1960 is negatively correlated with growth until 1989. However, initial income in 1974 is not robustly correlated with real GDP per capita growth rates. Therefore, above stated divergence does not contadict.

[26]Furthermore, their sensitivity analysis reveal that the results do not change considering export rates instead of trade shares or imports and that the predicted direct correlation between policy variables or institution and fiscal indicators and growth rates cannot taken be seriously. The authors suggest

and Renelt (1992) and functions as visualization of the above stated results. Besides these findings, Sala-i-Martin (1997) criticize the analysis to be too restrictive. He validades the robustness of more explanatory variables being correlated with growth rates.

While Levine and Renelt (1992) focus on correlation robustness rather than on causality issues, the role of human capital in general was analyzed and empirically proved by a variety of researchers. One of the most popular and path-breaking works in this direction is the famous regression from Mincer (1974). He regressed a persons number of years in school/ oder educational level E_i, the number of years worked and the squared number of years worked, both represented by x_i, on the log wage of a person

$$lnw_i = \gamma x_i + \beta E_i$$

Mincer's results were striking. He and others found estimates for an about 6 percent increase in log wage due to an additional year of schooling. The Mincerian approach can be included in the production function by including the return to schooling, estimated with the above-mentioned regression. This is also proposed by Bils and Klenow (2000).

To conclude, Levine and Renelt (1992) show that secondary-school enrolment matters, i.e. is positively correlated with growth rates of GDP per capita. I found a correlation coefficient for initial schooling in 1960 and average GDP per capita afterward of 0.6828 including a sample of 88 countries. the correlation coefficient of initial schooling and growth rates is naturally less, but still a value of 0.27649. Figure 9 illustrates the relationship again.

Because of these results and the recent revival of Mincer's findings, models including human capital seem to be a good choice to consider. Human capital typically appears through different channels in growth models. Some focus on on-the-job-training or learning-by-doing. Others just state the existence of human capital in production that differs from the labor force and is used for example in R&D or as special production factor. However human capital is difficult to measure. If we abstract from on-the-job-learning, one appropriate measure to catch human capital differences across countries is the introduction of schooling into growth models. Since secondary schooling is robustly correlated with growth rates of GDP per capita, this subsection gave further reason to do so.

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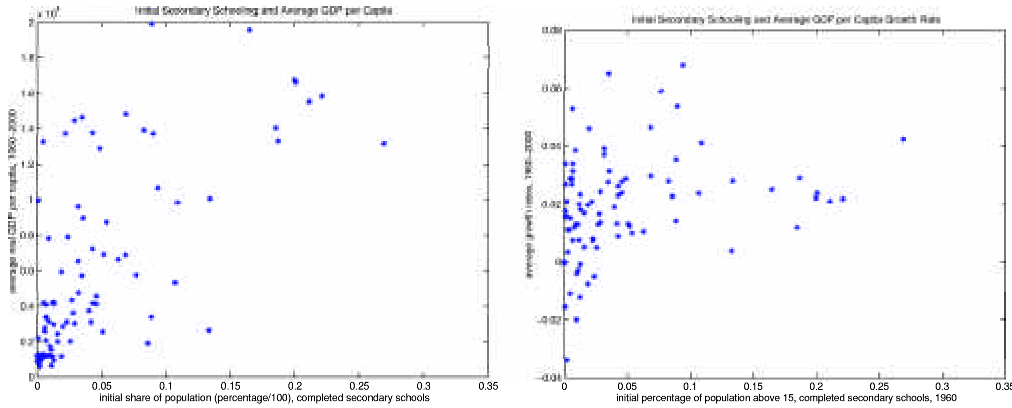
that one should consider more complex interactions or nonlinearities explaining the influence of policy packages on growth rates. They do not deny the possibility that political and institutional changes or policies influence long run growth.



(a) Initial schooling and average GDP per capita in a sample of 88 countries

(b) Initial schooling and average growth rates in a sample of 89 countries

Figure 9: Initial Secondary Education and Average Output, 1960-2000

3.1.5 The Lack of Persistent Growth Rate Changes

Before I will come to modeling issues, I examine the behavior of growth rates[27] over time. It is widely known that, in general, growth rates have higher amplitudes in developing, than in developed countries. The variation is much higher in these countries because they are more sensitive to shocks. More interesting is the behavior of growth rates over time. Contrary to the Solow-model predictions, growth rates do not diminish over time. However, they also do not increase. The changes are not persistent. Indeed Figure 10 gives evidence for no clear tendencies of growth rates. Countries, that exhibited high growth rates between 1960 and 1979 do not have on average lower or higher growth rates in the second subsample. Moreover, countries do not come closer together and, if there is a tendency at all, then it is the tendency to maintain the average growth rate. Analyzing growth rates of developed countries reveals that the series of the growth rate of GDP per capita from 1960 to 2000 is stationary in the levels, I(0), for all countries. Unit roots are rejected at a significance level of 1%, abstracting from Japan. Its null hypothesis rejected needed a significance level of 10%. I used an Augmented Dickey Fuller test, although it is biased to reject the null hypothesis too often. However, other tests confirm the results. The optimal lack order to include was chosen automatically, using the Schwartz-Criterion. There is no evidence for a trend in the growth rate changes[28]. Changes in the growth rates are not at all persistent over time. I also tested several developing economies and could maintain the results.

Because country characteristics are persistent and growth rate changes are not,

[27] by the way, if not taken from the PWT 6.1, all growth rates are derived as follows: $g_t = \ln(Y_t/Y_{t-1})$

[28] Indeed, this is the fundamental basis of the Jones critique on endogenous growth models. He (1995) directly involve time trend tests. I will refer to his evidence in section 3.2.1

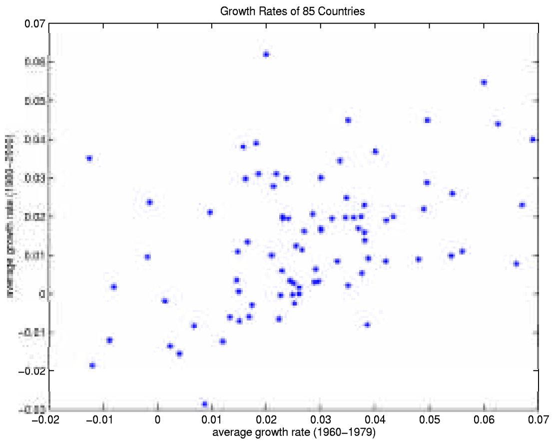


Figure 10: The Relationship of Average Growth Rates over Time

Table 2: Results of Unit Root Analysis (ADF-test) of Growth Rates for 11 developed economies.

	t-Statistic				
Country	test-stat.	Crit. Val.	Prob.	R^2	Result
AUS0	-6.0169	-3.6056	0.000	0.4879	reject H_0
AUT 0	-6.5169	-3.6056	0.000	0.5278	reject H_0
CAN 0	-4.9568	-3.6056	0.0002	0.3927	reject H_0
CHE 0	-4.4580	-3.6056	0.001	0.3434	reject H_0
ESP 0	-4.0106	-3.6056	0.0034	0.2974	reject H_0
FRA 0	-4.2745	-3.6056	0.0016	0.3247	reject H_0
GBR 1	-5.6727	-3.6105	0.000	0.4773	reject H_0
JPN 0	-2.9046	-2.6069	0.0537	0.1817	reject H_0
NOR 0	-4.3577	-3.6056	0.0013	0.3332	reject H_0
SWE 1	-4.5188	-3.6105	0.0008	0.3635	reject H_0
USA 1	-5.3792	-3.6105	0.0001	0.4805	reject H_0

Dataset: PWT 6.1, Data: Growth rates of Real GDP (Chain). Note that in each case, the test statistic is bigger than the critical value in absolute values.

shocks are likely candidates to explain the high variances in growth rates over time. This should be kept in mind for the rest of the analysis. All policy suggestions are not robust to the fact that maybe growth rate behavior is determined more by, i.e. terms of trade shocks than by policies. In general, growth rates are not very highly correlated over time and growth rate differences are considered to be just transitory. [29]

3.2 Endogenous Growth Theory vs. Time Series Analysis

3.2.1 The Jones Critique

Jones (1995) analyses time series behavior to test for the prediction that level changes can be responsible for a growth rate change. Thus, the lack of persistent growth rates changes is the underlying basis of Jones' (1995) time series tests on endogenous growth models. The behavior of growth rates is already analyzed in section 3.1.5. In general, per capita GDP shows a linear trend. Growth rates have no persistent trend, i.e. there is no hint for assuming that something have had persistent effects on the growth rates.

To go into detail, I will separately consider the Ak and the R%D approach, starting with the analysis of Ak models. Jones argues that these models are not that good because of their prediction of infinite horizon effects of increasing investment. Jones found large persistent movements in the investment rates. Nonstationarity can be found in most of the considered sample series. Although, total net investment is not trending, investment on durable goods like machineries is. ADF tests on investment shares data only cannot reject the null hypothesis of unit roots for four countries. Since unit roots are observed here, we should also find them in the growth rate series, the variable that should be explained by a unit root process. This is not the case. The total investment to output share of most OECD countries is also trending. To be consistent with growth rate time series, there have to be offsetting effects among the variables of Ak models, influencing the behavior of growth rates. Otherwise, growth rates should have increased persistently over time. However, this is at odds with the data. Let's look at the standard Ak approach. The broad interpretation of k as being physical and human capital in every form allows us to consider a very simplistic structure of the economy. Given the following constant technology production function by

$$y = Ak_t,$$

the budget constraint and the capital accumulation equation

$$c_t + i_t = Ak_t,$$

[29] On the CD-version is additional material on autocorrelation and partical autcorrelation of GDP and growth rates. It is only partly relevant for the analysis and therefore seen as side issue.

$$k_{t+1} = (1 - \delta)k_t + i_t.$$

This yields to the growth rate of output and capital which is denoted by

$$g_y = g_k = (1 - \delta) + \frac{Ai_t}{y_t}.$$

So, in steady state, when investment increases - the investment output ratio rises immediately - Ak models predict a direct rise in the growth rate of a countries GDP. Obviously the persistent increases in the investment rates since the Second World War contradict this restriction. Therefore Jones can conclude that Ak models do not provide a good description of the driving forces behind growth in developed countries. Furthermore, Jones analysis the time of how long changes in investment rates indeed have real effects on growth rates. He found out that these effects are just transitory and not existing after about six to eight years and not infinite, as Ak- models usually imply. Table 4 in the appendix is copied from Jones (1995b) and reports his results from estimating the equation

$$g_{it} = \alpha_i + \beta_i t_i + A(L)g_{i,t-1} + C(L)\Delta i_{it} + \epsilon_{it},$$

which includes different intercepts and linear trends for each country to account for movements that are exogenous due to the underlying structure.[30].

The R&D framework is tested with a similar intuition. The standard R&D approach assumes that a rise in R&D level should directly raise the growth rate of output, especially if the economy is in its steady state. The microfoundation of R&D based growth models makes them very attractive and, as an outcome of these models, technological progress in form of innovations raise productivity and, finally, the growth rate. The labor share devoted to research influences the steady state growth rate of the economy. The prediction that a subsidy to research increases the labor share in R&D and that this results in an increase in the long run balanced growth rate is inherent to R&D based model structure. Furthermore, an increase in the total number of labor force is also reflected in a predicted increase in the steady state balanced growth of the same amount, holding the R&D share constant. Indeed, an increase in the labor force is linked to an increase in the number of researchers. This creates the 'scale effect'. This

[30]Jones takes the joint time series of investment rates and growth rates and builds up the following equation

$$g_t = A(L)g_{t-1} + B(L)i_t + \epsilon_t$$

and transforms it into

$$g_t = A(L)g_{t-1} + B(1)i_t + C(L)\Delta i_t + \epsilon_t.$$

$\forall\ B(1) > 0$, permanent positive shocks on investment have permanent positive effects on growth. He can't find any proof for this. therefore he sets $B(1)$ equal to zero and estimates the above given equation to check for transitory effects. These effects die out roughly after the 8th period.

effect is not easy to test because of technology transfers. The standard equation for the evolution of productivity can be written as

$$\dot{A}/A = \delta L_A.$$

This implies that TFP is proportional to labor in the R&D sector. If the share L_A/L is constant, than the growth rate of knowledge is proportional to the level of labor supply. This is not observed in data. Moreover, the scale effect of increasing units in research increases growth rates is also not true. Jones plots the number of researchers and TFP over time for several OECD countries. TFP shows negative or no trends, the labor share devoted to R&D instead has one. Growth rates are stationary and R&D workers increase exponentially over time; time series evidence speaks a clear language against a permanent influence of increases in R&D on the growth rates. Jones also considered all countries in one sample to allow for technology diffusions effects. The results didn't change. Models in the style of Aghion, Howitt/ Grossman Helpman/ and Romer based on R&D have to be rejected. Growth rates of per capita output and TFP do not increase with the level of R&D resources. To conclude, evidence against R&D models is even stronger than the evidence against the more general Ak-style of endogenous growth.

3.2.2 The Revival of Ak Models

Economists are aware of the time series analysis of Jones and its predictions concerning endogenous growth models. Jones' work can function as a framework for testing the "goodness" of new models. However, this does not mean that researchers should come away from endogenous growth predictions. McGrattan (1998) overcomes a part of the critique of Jones by considering longer periods.

She examines historical data from 1870 to 1989 of 11 countries, using a nine year MA GDP growth rate series, four periods lagging and four leading, to take the world wars into account and gross fixed domestic investment as percentage of GDP valued in current prices for investment output ratio. Before World War I the investment and the growth rate time series fluctuate a lot but in general for most of the countries she could not find systematic deviations from the trends. McGrattan finds strong evidence that, among OECD and among Asian non-OECD countries, changes in investment rates and growth rates are indeed coincident, i.e. periods with high investment rates are also characterized by increasing growth rates. Postwar investment data show strong upward trending behavior, especially among the Asian miracles. In general, there are times in which growth rates do not grow while investment rates do. However, these deviations are not considerably large in comparison to, for example, ten-year movements. Jones' findings reveal patterns of shorter periods. McGrattan also examines the behavior across countries. On average, investment rates and growth rates are positively correlated. The slow growing countries have an average investment share of seven percent, while fast growers face a share of about 25 percent of output. For the overall correlation McGrattan find a value of 0.87, which is indeed high and confirmed to be robust by Levine and Renelt (1992). Having shown very long run consistency with data sets, McGrattan (1998) afterwards develops a model that involves or even explains Jones' findings of short run counterintuitive data movements. Go into detail, the Ak model allows for constant growth rates of output, although investment partly increases. This implies that we can divide investment into at least two parts. As reality suggests, households rent different forms of capital to the firm sector, which uses the capital either for structural improvements like buildings and infrastructure in general or for new technology and equipment. Production therefore follows the Cobb-Douglas function $y = Ak_e^{\alpha}k_s^{1-\alpha}$. This implies different returns to capital input and investment and therefore one could consider different tax rates. The representative household than maximizes his CRRA utility $U(c_t) = c^{1-\sigma}/(1-\sigma)$ with respect to the budget constraint and the capital accumulation equations

$$c_t + x_{st} + x_{et} = (1-\tau_s)r_{st}k_{st} + (1-\tau_e)r_{et}k_{et} + T_t,$$

$$k_{s,t+1} = (1-\delta)k_{st} + x_{st},$$

$$k_{e,t+1} = (1-\delta)k_{et} + x_{et}.$$

T denotes the transfers from the government. After solving the optimization problem, the growth rate is given by

$$g = \left(\beta\left\{1-\delta + A[\alpha(1-\tau_e)]^{\alpha}[(1-\alpha)(1-\tau_s)]^{(1-\alpha)}\right\}\right)^{1/\sigma}.$$

The short form,

$$g = 1-\delta + A\left(\frac{(1-\alpha)(1-\tau_s)}{[\alpha(1-\tau_e)]}\right)^{1-\alpha} x_e/y.$$

reveals the direct effect of tax rates on the capital output ratio. There is also an indirect effect through to equipment investment to output ratio. Lower tax rate on equipment investment for example implies a change in investment in equipment. If the taxes on structural capital move in the opposite direction just until the term $(1-\tau_e)^{\alpha}(1-\tau_s)^{1-\alpha}$ stays constant, we would see constant growth rates, although the equipment-investment to output ratio would increases. Meanwhile total investment is nearly constant.

However, Jones' data analysis says that growth rates are constant over time and total investment rises. McGrattan suggests that this can be explained by considering low labor supply. Households intertemporally decide how much time they spend on working and how much on leisure. Policy changes have influences on this decision. If labor supply falls growth rates will suffer. However, this does not consequently mean that investment rates do not increase. To get formal, consider the following economy. The representative household maximizes his utility function with respect to consumption, hours worked and investment in physical and human capital facing a constant preference parameter ψ and constant relative risk aversion σ

$$max_{c_t,x_{kt},x_{ht},l_t} \sum \beta^t \frac{[c(1-l)^{\psi}]^{(1-\sigma)}}{(1-\sigma)}$$

s.t.

$$(1-\tau_{ct})c_t + x_{kt} + x_{ht} = (1-\tau_{kt})r_t k_t + (1-\tau_{ht})w_t h_t l_t + T_t,$$

$$y_t = Ak_t^{\alpha}(h_t l_t)^{1-\alpha};$$

the wage and the rental price for capital are denoted by w_t and r_t respectively and τ_i are tax rates on physical and human capital and on consumption and $T > 0$ is a transfer to the households paid by the government. Government uses tax income to pay transfers and to buy goods. From the first order conditions we can see that labor supply is given by

$$l = [g^{\sigma} - \beta(1-\delta)]^{\frac{1}{1-\alpha}}[\alpha(1-\tau_k)]^{\frac{-\alpha}{1-\alpha}}/[(\beta A)^{\frac{1}{1-\alpha}}(1-\alpha)(1-\tau_h)].$$

The first partial derivative of l with respect to the growth rate g is positive. This implies that, c.p., if policies effect growth rate positively, the labor supply will also increase. The investment output ratios can than be formalized as

$$x_k/y = [(g-1+\delta)/[g^{\sigma} - \beta(1-\delta)]]\,\beta\alpha(1-\tau_k)$$

$$x_h/y = [(g-1+\delta)/[g^{\sigma} - \beta(1-\delta)]]\,\beta(1-\alpha)(1-\tau_h),$$

with

$$\partial(x_k/y)/\partial g < 0,\ \partial(x_h/y)/\partial g < 0,\ \forall\sigma > 0.$$

Imagine consumption taxes are falling and both income tax rates stay constant. Although people are risk averse, they will start to consume more and, to be able to do so, they will also work more. People tend to spend more and invest less. Therefore investment rates will fall although growth rate rises. The relationship obviously also holds vice versa. This implies that Ak models can be constructed in a way that is consistent with Jones' findings. The structure of Ak models does not permit the observation of increasing investment share and constant growth rates. One just has to introduce certain policy regimes that affect the household's working decision, which has an impact on the growth rate.

To conclude this subsection, McGrattan provides evidence that, over the long run, the comovements of investment shares and growth rates hold. Policies that focus on investment decisions have an impact on growth rates. Concerning shorter periods, little changes in the structure of Ak models can replicate Jones' findings without violating the Ak intention by introducing the fact that labor supply is inelastic. It is not just the investment output ratio that is influenced by government's policy decisions but also the capital-output ratio or labor-leisure choice. The amplitude of growth rate changes does not have to be equal to investment rate changes.

3.2.3 Revival of R&D Models

More serious than the Ak critique and more general is the issue in endogenous R&D-based models. While the level of R&D resources does increase over time, growth rates of per capita output and TFP do not. This contradicts to the implication of these models; R&D *level* increases are said to have an influence on the growth *rates* of output. Furthermore, offsetting effects are indeed more doubtful than in the Ak-model case considered above. Several authors find methods to overcome the scale effect. Some models can maintain the old implications of R&D based endogenous models, others do not. Belonging to the first group, the work of Howitt (1999) and Young (1998) should be mentioned here. They divide innovations into vertical and horizontal ones and argue that under the assumption that the marginal product of horizontal R& D diminished more faster than of vertical. The quantity of labor in the research sector can rise, without influencing the steady state growth rate.

Chad Jones himself proposes another approach. Jones (1995b) slightly changes the R&D equation. He found a way to hold to the underlying microstructure and the endogenous nature of technology.[31]. Instead of the standard equation one can consider A to the power of ϕ. Two possibilities occur. From the baseline Ak-model we know that returns to inputs are equal to one. However, if we consider the stationarity of growth rates, one should predict that this is too high. Maybe successful new inventions might occur less often if the level of knowledge becomes higher. When $\phi < 0$, we have these negative externalities. However, if $\phi > 0$ we would have positive externalities; the probability of new inventions would increase with higher levels of technology. This seems to be true for inventions like the personal computer that offer the possibility for a number of new inventions. In the following model we consider just cases with $\phi < 1$,

[31] In the Mathematical Appendix, I give the whole microstructure of a semi-endogenous growth model mainly based on Jones (1995b)

because equality is rejected in Jones' (1995) time series analysis. The introduction of $l_A^{\lambda-1}$ with $0 < \lambda \leq 1$, as shown below, can account for externalities, that occur due to duplication. This would be just a waste of inputs.

$$\dot{A} = \widetilde{\delta} L_A, \text{ with } \widetilde{\delta} = \delta A^{\phi} \Leftrightarrow \dot{A} = \delta(L_A A^{\phi} l_A^{\lambda-1}).$$

In equilibrium

$$\frac{\dot{A}}{A} = \frac{\delta L_A}{A^{1-\phi}}$$

holds. The growth rate of technology goes to a constant along the balanced growth path. Thus, we can take the logarithm

$$\ln g_A = \ln \delta + \lambda \ln L_A - (1-\phi) \ln A$$

and find the total differential

$$\frac{1}{g_A}\frac{dg_A}{dt} = \frac{1}{\delta}\frac{d\delta}{dt} + \lambda \frac{1}{L_A}\frac{dL_A}{dt} - (1-\phi)\frac{1}{A}\frac{dA}{dt}$$

$$\Leftrightarrow 0 = \lambda \frac{dL_A/dt}{L_A} - (1-\phi) g_A.$$

This yields to

$$g_A = \lambda n/(1-\phi).$$

For $\phi < 1$ there is no longer a scale-effect along the balanced growth path. Considering constant output/capital per capita ratios and the fact that consumption and output per capita grow at the same rate yields to the overall growth rate of the economy

$$g_y = g_A = g_k = g_c = \lambda n/(1-\phi)$$

instead of the growth rate of the classical endogenous R&D model

$$g \equiv \delta L_A.$$

$\forall \phi < 1$ steady state growth path exists and depends just on the exogenously given growth rate of population, n, and no longer on the level of the labor force. Furthermore it depends on the parameter values for ϕ - if ϕ equals one, we are back in the Romer case, then this economy has no balanced growth path - and λ. Steady state growth is determined by innovation growth, which in turn is again dependent on the population growth rate. The main implication of endogenous growth gets lost within this procedure. The share of labor that works in the research sector and the total labor force level do not matter for long run growth any longer. Of course, there might be transitional level effects but not more. A constant tax or something would also disappear when taking the total differential of the R&D equation. Concerning the welfare implications of this model, the centralized social planner solution does finally not differ in the growth rate, but in the labor shares, devoted to the sectors. The social planner anticipates externalities[32]. In case of positive externalities, $\phi > 0$, the share of labor devoted to R&D will be higher in the social optimum than in the decentralized solution. If the externalities are negative, than L_A/L will be higher in the decentralized solution than in the social optimum. Negative externalities due to duplication will increase the labor share on the decentralized problem. Calibrating the model, Jones found out that underinvestment in research occurs regularly under reasonable parameter values. Moreover the reaction on the markup is more important than on variations in the externalities parameters. An interpretation for the scale effects is still possible. If here is no exchange of new ideas between economies, countries with higher initial labor share will grow faster, because once developed ideas are nonrivalous. These differences are transitory, but may last long. The fact that population growth is required for increases in the growth rate of output needs to be examined closely. One could argue that the thing to tell is just that there are no innovations without scientists. However, again, a lot of researchers show that both growth rates are not correlated with each other or that there is even a negative correlation. Therefore, this model is only in line with developed economies' growth performance. Countries that invent more than copy, fit better because the driving force of growth is technology growth through new ideas. The small policy influence on long run growth rates is more consistent with the neoclassical approach than with R&D based endogenous models. However, there is endogenous growth through research, made by profit maximizing agents. Several authors caught up this semi-endogenous approach first offered by Jones (1995b) not at least because of the convincing microeconomic background, growth due to profit maximization of researchers, intermediates and final good producers, and because of the consistency with observed time series.

Taken this evidence of R&D models and recent developments serious, although it might lead to older, well-known implications for growth improvements through governmental policy, I want to examine the features of a semi-endogenous R&D growth model and allows for imitation of developed technology.

[32] The share of labor devoted to R&D is given by $s = \frac{1}{1+\Psi}$, where $\Psi = \frac{1}{\lambda}\left[\frac{\rho(1-\phi)}{\lambda\, n} + \frac{1}{\sigma} - \psi\right]$ in the centralized solution and $\Psi = \frac{1}{1-\alpha}\left[\frac{\rho(1-\phi)}{\lambda\, n} + \frac{1}{\sigma}\right]$ in the decentralized solution $(1/1-\alpha)$ is the markup for the monopoly in the intermediate sector. Governmental policy can account to this markup and therefore intervene more or less successful, dependent on the other parameter values. As one can see, if the steady state growth rate increases, the share L_A/L increases as a consequence!

4 A Non-Scale R&D Growth Model - Imitation and Human Capital

As the above discussion shows, older models that resist on the scale effect predictions are no data-consistent way to describe economic growth. Furthermore, if one wants to explain growth and not development or income differences, one should focus on models that create growth endogenously. In my eyes, the semi-endogenous approach seems to be a promising way to do so. Moreover, taking an R&D model ensures that the model is microeconomically backed up. Since secondary schooling seems to be robustly correlated with growth, I am interested in the effect of schooling in semi-endogenous growth models, although the channel of causality is still debated. However, it is quite naturally to assume complementaries between the amount of schooling and the effective usage of knowledge. The accumulation of high skills requires advanced technologies, like laboratories and software, but technology also needs skilled people that handle new technology effectively and, of course, develop it. One possibility is to exploit the properties of complements. Investing in education and building up human capital does not automatically mean to get advanced technologies, too. As discussed in section 3.1.3, human capital will migrate to rich countries. Thus, it is important to include human capital into the law of motion for technology.

Papageorgiou and Sebastian-Perez (2002) develop a model that accounts for all the above-mentioned features. Papageorgiou and Perez-Sebastian's (2002) model stands in line with older R&D models of endogenous growth. Research and development, which are directly integrated in the model structure, are responsible for innovation and imitation that drive the growth process. Furthermore endogenous accumulation of human capital and endogenous technology growth function as complements. So, growth is generated within the model economy. However, long run growth, or better long run growth rates, depend crucially only on changes in exogenous parameters. In contrast to Chad Jones, they also consider countries that do not push forward the technological frontier but catch-up through the channel of imitation. Therefore it is somehow in the spirit of Prescott and Parente's work on barriers, i.e. one could introduce barriers to adoption and therefore explain the failure of certain countries to grow.

The next two subsections explain the underlying economy in detail and state the maximization problem before solving the model in section 5.

4.1 The Economy

The microeconomic foundation is consistent with the analysis in subsection 10.3.1. The economy still bases on profit maximizing agents and consists of three sectors. The R&D sector produces new designs and ideas and charges a price from the intermediate sector that is identical to the present discounted value of the intermediate's monopoly rents. The intermediate sector consists of a infinite number of firms that buy the new R&D ideas and use capital input to vary them. So they can behave monopolistically while selling the new durables/intermediate goods to the final sector. The final sector produces consumption goods using labor and durable inputs. Diminishing returns do not arise because of a permanent inflow of new input goods from the intermediate sector. On an aggregated level, we consider a Cobb-Douglas production function with human capital to production H_{Yt} and physical capital K_t and the aggregate technology level A_t as inputs.

$$Y_t = A_t^{\xi} H_{Yt}^{1-\alpha} K_t^{\alpha}, \tag{1}$$

where α denotes the capital share, $1-\alpha$ is the share of skilled labor and ξ symbolizes the technology elasticity of output. The law of motion for technology is given by

$$A_{t+1} - A_t = A_t^{\phi} H_{At}^{\lambda} \left(\frac{A_t^*}{A_t}\right)^{\psi}, \tag{2}$$

where A^{ϕ} with $\phi < 1$ accounts for the amount of influence of the stock of already existing technology in t on the growth rate of technology and δ denotes the depreciation rate of technology. In this model economies interact by having ideas and copying them. The catch up term $(\frac{A_t^*}{A_t})^{\psi}$ shows that, the farer a country is away from the technological frontier, the higher the possibilities of improvement with imitation. The worldwide technology level growth exogenously, small economies are not able to influence it. Furthermore, $0 < \lambda \leq 1$ symbolize decreasing returns to research. As in the Jones model, one could imagine, that there are externalities due to duplication or that, the more ideas are invented, the harder it gets to find a new one. However, in this model duplication in form of imitation should occur regularly to come closer to the technological frontier. Considering the aggregated production function and the evolution of technology, one finds the above-mentioned complementarities between technology and human capital. $H_{jt}^{1-\alpha}$ can be divided into $h_t * L_{jt}$, $j = A, Y$, to account for the effectiveness of the overall level of human capital per capita. High levels induce a better use of technology and therefore more efficient production. Moreover, more inventions are made. Having more human capital, an economy is able to enhance both, productivity and technology growth. The only source of human capital formation is the schooling sector. Contrary to other models, schooling means investment in human capital and does not try to describe the stock itself. A countries' population, L_t, is divided into people in school, L_{Ht}, and the labor force, which consists of labor in the production sector and labor devoted to R&D, L_{Yt} and L_{At} respectively. The authors abstract from homework and unemployment, which are main factors in underdeveloped, or better, developing countries. To introduce the labor portions into the production function, the authors refer to Bils and Klenow (2000)

$$H_{jt} = e^{f(S_t)} L_{jt},\ \forall j = A, H \ \Leftrightarrow h_t = e^{f(S_t)}, \tag{3}$$

where $f(S_t) = \eta S^{\beta}$, $\eta, \beta > 0$ and $f'(S_t)$ denotes the return from schooling, estimated in a Mincerian regression and S_t the average attainment in school of the labor input in period t. Note that, the higher the initial labor share devoted to R&D, the higher the possibility to catch up. The evolution of S_t is given by the following law of motion[33]

$$S_{t+1} - S_t = \left(\frac{1}{1+n}\right)\left(\frac{L_{Ht}}{L_t} - nS_t\right), \tag{4}$$

where n denotes the exogenously given population growth rate.

4.2 The Central Planner's Optimization Problem

Considering a central planner problem requires a description of the households' decision-making process. We consider an infinite horizon problem. Preferences are expressed through consumption decisions. The representative households' utility function is standard. The intertemporal elasticity of substitution equals $1/\theta$ and the future is discounted with ρ. The household is endowed with one unit of time each period, which consists of time spend in school and working. The central planner maximizes expected lifetime utility with respect to the constraints described above, to the labor identity equation and to the standard capital accumulation equation included in the budget constraint of the economy.

$$max_{\{C_t S_t A_t K_t L_{Ht} L_{At} L_{Yt}\}} \sum_{t=0}^{\infty} \rho^t \left(\frac{\left(\frac{C_t}{L_t}\right)^{1-\theta} - 1}{1-\theta}\right), \tag{5}$$

s.t.

$$Y_t = A_t^{\xi}(e^{f(S_t)} L_{Yt})^{1-\alpha} K_t^{\alpha}, \tag{6}$$

$$I_t = K_{t+1} - (1-\delta_K)K_t = Y_t - C_t, \tag{7}$$

$$A_{t+1} - A_t = \mu A_t^{\phi}(e^{f(S_t)} L_{At})^{\lambda} \left(\frac{A_t^*}{A_t}\right)^{\psi} - \delta_A A_t, \tag{8}$$

$$S_{t+1} - S_t = \left(\frac{1}{1+n}\right)\left(\frac{L_{Ht}}{L_t} - nS_t\right), \tag{9}$$

[33]See 10.3.2 for a detailed derivation

$$L_t = L_{Yt} + L_{At} + L_{Ht}, \tag{10}$$

$$\frac{L_{t+1}}{L_t} = 1 + n, \forall t = 1, ...\infty, \tag{11}$$

$$\frac{A^*_{t+1}}{A^*_t} = 1 + g_{A^*}, \tag{12}$$

given initial factor endowment L_0, K_0, A_0)and initial average schooling attainment S_0. The human capital formation equation is already plugged in.

5 Model Analysis

I will now come to the analysis of the model. In the following paragraphs I refer only to the most important calculation steps.[34]

5.1 The Euler Equations

To obtain a solution for the above stated problem, one can find a value function for the state variables average school attainment, technology and capital. The value function is given by

$$V_t(S_t, A_t, K_t) = \max_{\{L_{Ht}, L_{At}, I_t\}} \frac{\left(\frac{A_t^{\xi}\left[e^{f(S_t)}(L_t - L_{Ht} - L_{At})\right]^{1-\alpha} K_t^{\alpha} - I_t}{L_t}\right)^{(1-\theta)} - 1}{1-\theta}$$

$$+\rho V_{t+1}\left[S_t + \frac{1}{1+n}\left(\frac{L_{At}}{L_t} - nS_t\right); A_t(1-\delta_A) + \mu A_t^{\phi}\left(e^{f(S_t)}L_{At}\right)^{\lambda}\left(\frac{A_t^*}{A_t}\right)^{\psi}; K_t(1-\delta_K) + I_t\right]$$

First, I differentiate this function with respect to the control variables, L_{Ht}, L_{At} and I_t. Then one can define policy rules in the form of

$$L_{Ht} = L_H(S_t),\ L_{At} = L_A(A_t) \text{ and } I_t = I(K_t)$$

and plug them into the value function. Differentiating this function with respect to the state variables and then using the Envelope Theorem give three Euler equations. I replace certain functions from the central planners' problem to simplify the solution. Finally, this approach results in the following Euler equations.

$$\left(\frac{C_t}{L_t}\right)^{-\theta}\frac{(1-\alpha)Y_t}{L_{Yt}} = \frac{\rho}{1+n}\left(\frac{C_{t+1}}{L_{t+1}}\right)^{-\theta}\frac{(1-\alpha)Y_{t+1}}{L_{Y,t+1}}[1 + f'(S_{t+1})\left(\frac{L_{Y,t+1} + L_{A,t+1}}{L_{t+1}}\right)] \tag{13}$$

In the optimum, the marginal return from labor put into the production sector equals the discounted marginal utility from school attainment. The central planner anticipated the growth rate of population. The second equation refers to the allocation in the R&D

[34] I refer to this again in the Mathematical Appendix.

sector. Analogue to the equation above, the planner is indifferent between devoting an additional unit of labor to the output sector or investing in R&D; marginal returns equal each other.

$$\left(\frac{C_t}{L_t}\right)^{-\theta}\frac{(1-\alpha)Y_t}{L_{Yt}}=\frac{\rho}{1+n}\left(\frac{C_{t+1}}{L_{t+1}}\right)^{-\theta}\frac{\lambda[A_{t+1}-(1-\delta_A)A_t]}{L_{At}}*$$
$$\left\langle\xi\frac{Y_{t+1}}{A_{t+1}}+\left[1-\delta_A+(\phi-\psi)\left(\frac{A_{t+2}-(1-\delta_A)A_t}{A_{t+1}}\right)\right]*\left[\frac{\frac{(1-\alpha)Y_{t+1}}{L_{Y,t+1}}}{\frac{\lambda(A_{t+2}-(1-\delta_A)A_{t+1})}{L_{A,t+1}}}\right]\right\rangle \quad (14)$$

Solving for capital and investment, the last Euler equation is given by

$$\left(\frac{C_t}{L_t}\right)^{-\theta}=\frac{\rho}{1+n}\left(\frac{C_{t+1}}{L_{t+1}}\right)^{-\rho}\left[\frac{\alpha Y_{t+1}}{K_{t+1}}+(1-\delta_K)\right] \quad (15)$$

If this equation is fulfilled, the optimizing agent or, as in our case, the central planner is indifferent between consumption today or investment and consumption tomorrow. It depends on the preference parameters, the population growth rate and the depreciation rate of capital.

We will need the conditions for the optimal allocation given here, when we derived the steady state growth rates to solve for the labor shares in the steady state, devoted to each sector.

5.2 The Steady State

The population growth rate is given exogenously by n. Because of the above given identity (10), along the balanced growth path, the labor shares are constant. The steady state amount of schooling can therefore be derived from (9) by dropping the time index and solving for S_{ss}.

$$S_{ss}=(1/n)u_{H,ss}=(1/n)\frac{L_H}{L}_{ss}. \quad (16)$$

On the balanced growth, investment in human capital is undertaken in the amount, needed to provide the steady state level of school attainment. Thus, schooling does not affect the steady state growth path. From the above given equations, we can now derive the growth rates. Taking the logarithm of the technology evolution equation (2) yields to

$$\ln A_{t+1}-\ln A_t=\ln\mu+\phi\ln A_t+\psi\ln A_t^*-\psi\ln A_t+\lambda\ln H_{At}-\ln\delta-\ln A_t$$

After finding the total diffential[35]

$$\frac{d\,A_{t+1}/d\,t}{A_{t+1}}-\frac{d\,A_t/d\,t}{A_t}=\phi\frac{d\,A_t/d\,t}{A_t}+\psi\frac{d\,A_t^*/d\,t}{A_t^*}-\psi\frac{d\,A_t/d\,t}{A_t}+\lambda\frac{d\,H_{At}/d\,t}{H_{At}}H_{At}-\frac{d\,A_t/d\,t}{A_t}$$

[35]Note that, in steady state, $\frac{d\,A_{t+1}/d\,t}{A_{t+1}}-\frac{d\,A_t/d\,t}{A_t}=0$.

$$\Leftrightarrow 0 = (1-\phi+\psi)\frac{d\,A_t/d\,t}{A_t} + \psi g_A^* + \lambda n$$

one can easily solve for the growth rate of technology

$$\Leftrightarrow \frac{d\,A_t/d\,t}{A_t} = g_A = \frac{\psi g_A^* + \lambda n}{1-\phi+\psi}.$$

The steady state growth rate of technology increases with the population growth rate and with the growth rate of the technology frontier, given $\psi < \phi$. The interpretation is straightforward. Population growth means more people, devoting labor to R&D. This just means more potential inventors. Note that this is not a fallback to models, where increases in the share of R&D researchers produce changes in the growth rates. The exogenous growth rate of the technology frontier implies higher catch-up possibilities. However, the programs in the appendix as well as the underlying paper refer to gross growth rates. Concerning to this equation, I briefly give the calculation. The gross growth rate is defined as $G_A = 1 + g_A$. Furthermore, $e^{g_A} \cong 1 + g_A \Leftrightarrow \ln e^{g_A} \cong \ln(1+g_A) = \ln G_A$, which implies that

$$G_A = e^{\frac{\psi g_A^* + \lambda n}{1-\phi+\psi}} = e^{\frac{\psi \ln G_A^* + \lambda \ln G_{H_A}}{1-\phi+\psi}}. \tag{17}$$

$$\text{This equals } G_A = \left(G_{A^*}^{\psi} G_{H_A}^{\lambda}\right)^{\frac{1}{1+\psi-\phi}}. \tag{18}$$

Since the labor grows at the rate n and the average school attainment level doesn't grow at all in steady state, it can easily be written as

$$G_{A,ss} = \left((1+n)^{\lambda} G_{A^*,ss}^{\psi}\right)^{\frac{1}{1+\psi-\phi}}. \tag{19}$$

To obtain a feasible solution, the authors assume that the steady state technology growth of a country equals the steady state technology frontier growth; given $\psi/(1+\psi-\phi) < 1$ and $A \leq A^*$. Therefore the overall gross growth rate is given by

$$G_{A,ss} = G_{A^*,ss} = (1+n)^{\frac{\lambda}{1-\phi}} \tag{20}$$

Rewriting this equation in terms of growth rates reveals the steady state growth rate of Jones' semi-endogenous model, $(\lambda/1-\phi)n$, abstracting from imitations. However, the growth rate of technology is not equal to the overall growth rate of the economy.[36] The steady state growth rate of output is given by

$$g_{Y,ss} = \frac{\xi}{1-\alpha} g_{A,ss} + n \tag{21}$$

and depends on the technology growth path, the capital share and on the population growth rate. So does the gross growth rate

$$G_{Y,ss} = G_{A,ss}^{\frac{\xi}{1-\alpha}}(1+n). \tag{22}$$

[36] I am going to state and explain the results. The calculation is given in the Mathematical Appendix, subsection 10.3.2.

In the steady state, growth rates of output, capital and consumption are equal. Plugging in the gross growth rate for technology yields

$$G_{Y,ss} = G_{K,ss} = G_{C,ss} = (1+n)^{\frac{\lambda\xi}{(1-\alpha)(1-\phi)}}. \tag{23}$$

In a non-scale economy, the long run growth rate does not depend on endogenous variables. It is totally determined by the model parameters and the exogenously given population growth rate n. Although schooling is endogenous, it is a constant in steady state. The steady state gross growth rate depends positively on the population growth *rate*, the capital share and the technology gap parameter. This implies that, if the technology gap is weighted a lot in the technology evolution equation, high ψ, countries that are more far away from the frontier have better possibilities to catch up through imitation. Furthermore, the higher the λ the more productive is the economy, i.e. diminishing returns decrease. The steady state growth rate depends positively on ξ, the elasticity parameter. The higher the reaction of output on technology input, the higher the growth rate. This is due to the labor share engaged in R&D, explained below.

After having calculated the steady state, one has to determine L_H/L, L_A/L, L_Y/L. Therefore one needs the Euler equations (13, 14, 15). The labor shares are derived by working with gross growth rates. The steady state shares[37] are

$$u_{H,ss} = 1 - \frac{1}{f'(S_{ss})}\left[\frac{G_{y,ss}^{\theta-1}(1+n)}{\rho} - 1\right] \tag{24}$$

$$u_{A,ss} = u_{Y,ss}\frac{1}{\left[\frac{1-\alpha}{\lambda\xi(g_{A,ss}+\delta_A)}\right]\left[G_{y,ss}^{(\theta-1)}\left(G_{A,ss}/\rho\right) - (\phi-\psi)(g_{A,ss}+\delta_A) - (1-\delta_A)\right]} \tag{25}$$

$$u_{Y,ss} = 1 - u_{H,ss} - u_{A,ss}, \text{ given the identity equation of labor.} \tag{26}$$

Note that the steady state 'labor' share, that goes to school rises with the returns to education. Indeed, this implies also that there could be no school attainment at all, if returns to education approach zero. Contrary to the first share, there will ever be investment in R&D and labor devoted to production because of a high marginal productivity if inputs go to zero. The share also rises with the discount factor, ρ. A higher preference parameter implies lower discounts of future utility in the intertemporal function. The future becomes more worthy for higher ρs. Furthermore, for high intertemporal elasticity of substitution, $1/\theta$, from the utility function, one observes high school attainment. If the inverse of θ falls, c.p., the share of people in school will be reduced. Intuitively, when the intertemporal elasticity of substitution decreases, peoples are more likely to consume today than to wait until tomorrow. These preferences do not leave room for schooling.[38] The steady state share of people devoted their time to schooling depends

[37] In each case, $u_{i,ss} = \frac{L_i}{L}|_{ss} \forall\, i = H,\ A,\ Y$. A detailed calculation is given in the appendix.

[38] This implies that in countries, where this elasticity is extremely low, it is low because of insecurity concerning resources.

negatively on the growth rate of output per capita. If output grows fast, people would engage in production because of higher returns.

The steady state labor share in the research sector increases, as $\phi - \psi$, λ or ξ increase. In the first case, $\phi - \psi$ must be bigger than zero. Therefore, the effect of knowledge on the R&D production, ϕ, must be positive and bigger than the technology gap parameter ψ. For small ψ, a countries' labor will move to the R&D sector. This would be consistent with data; countries closed to the technology frontier engage more in R&D than others, because the more closed you are to the frontier, the harder it gets to imitate. Second, the steady state labor devoted to R&D will rise, as the returns to effort in R&D increase. This is quite intuitive. High degrees of diminishing returns, small λs make factors less productive than lower ones. Therefore, a high λ promises higher factor productivity and therefore higher demand for this factor and higher wages. Third, the share rises with technology-output elasticity. The more elastic output reacts to technology, the more likely is it to increase output with rising technology. The interaction of the growth rate of output and technology and the steady state share of labor devoted to R&D is ambiguous because the steady state share of output enters the equation, too. The steady state labor share devoted output depends on all the included parameters and gross and growth rates. These interdependencies are not that interesting. It is more important to understand why the research sector is extended or why there is school attainment.

Because of the independency of steady state growth on policies and on endogenous shares of labor etc., it is worth to consider the transitional dynamics. If they are long, there might be room for policies, influencing the transition to the steady state path.

5.3 The Transition

To examine the transition, one finds constant steady state variables by normalizing the system with $\frac{1}{A_t^{\xi/(1-\alpha)} L_t}$. The resulting variables are denoted by $\hat{k}_t$, $\hat{c}_t$ and $\hat{y}_t$. To solve for the equilibrium, we again need control and state variables. The control variables are given by the three transformed Euler equations and the population constraint, coming from the labor identity. The redefined state variables are the laws of motion of human and physical capital and the technology gap motion equation, everything in terms of transformed variables.[39] After having linearized the new system, one constructs it as follows. There is a vector, including all the underlying states and controls at time $t+1$, which should be expressed in terms of the Hessian matrix, containing all first derivatives,

[39] The system to solve is given in the Mathematical Appendix.

evaluated at the steady state, multiplied by the states and controls at time t

$$\vec{x}_{t+1} = H\vec{x}_t.$$

Given this, one can calculate the asymptotic speed of convergence of normalized output, denoted by

$$1 - eigen = -\frac{(\hat{y}_{t+1} - \hat{y}_t) - (\hat{y}_{t+1,ss} - \hat{y}_{t,ss})}{\hat{y}_t - \hat{y}_{t,ss}},$$

where *eigen* denotes the largest eigenvalue of the Hessian matrix, lying inside the unit circle. However, to compare this model with others without the introduction of schooling, it is useful to consider the asymptotic speed for output per worker, $Y/(L_Y + LA)$, instead of output per capita. Indeed, new speed is equal to the speed of normalized output per capita times the gross growth rate of output per capita, subtracting the growth rate of output.

The authors study mainly the transitional dynamics of their model. since I an interested in the models' behavior concerning the above-analyzed facts, I will not go into detail in this section. I briefly summarize their main results. The Appendix contains Mathematica and Gauss Programs from the authors[40] that solve the model numerically. Abstracting from the schooling sector and from imitation, the asymptotic speed of convergence is 0.0179[41] and that the steady state growth rate of output per worker, that is indeed output per capita (set schooling to zero), is 0.0023. The result for the speed is good - closed to 0.02. However, the steady state growth rate is too small. Since one let the parameter ϕ go to 1, the growth rate would rise. Such high increasing returns would be again at odds with the data and, in this model, the asymptotic speed would be closed to zero. To hold on to the suggested parameter values, the authors provide results for imitation, which are closer to 2.0. Furthermore, they estimate the returns from schooling. Including the schooling sector, output per worker has an asymptotic speed of convergence equal to 1,32 percent, given assumed steady state growth rate of 1,6 percent. This is smaller than in the benchmark case and the model with imitation and without schooling [42].

Since I am interested in the effect of schooling, I now focus on the calculation of human capital, determined by the schooling sector and on the implications of this sector. Looking at the production function and at the law of motion for technology, reveals that the factor $f(S)$ has to be calculated. As several authors, Papageorgiou and Perez-Sebastian refer to the work of Bils and Klenow, using the following approach.

[40] I do thank Sebastian-Perez and Papageorgiou for sending me their programs.

[41] The underlying parameter values are given in the appendix, together with the used programs.

[42] Labor, or better, population is now distributed to three sectors.

They express $f(S)$ as ηS^{beta}. Differentiating with respect to S and then taking the logarithm results in the following equation

$$\ln f'(S) = \ln \eta\beta + (\beta - 1) \ln S$$

Thus, the following regression parameters are estimated and concrete values for η and β are calculated.

$$\ln f'(S)_i = a + b \ln S_i + \epsilon_i, \ \forall i = 1, ..n \text{ countries}$$

They used data from Psacharopoulos (1994) for S and β from the Mincerian regression equation. They find a β-value of 0.43 and η being 0.69. Given the other parameter values and the equation for the share of people in school/total population, S_{ss} is about 12 years. The results from introducing the schooling sector are quite interesting. Remember that in this model economy, human capital and technology are said to act complementary. The authors now found out that the economy is relatively more invariant towards variations in parameter values, i.e. shocks from outside. One reason is the introduction of a third sector in general. However, since the speed of the transition is allowed to vary over time, maybe in the beginning of the transition the influence of education on growth is larger. This could imply that raising education in developing countries could reduce the relatively high sensitivity to shocks of developing economies. The examination of the transitional dynamics reveals that the model fit is quite good. The experiences of Japan and South Korea are replicated quite well.

6 Model Results and The Facts

In this section, the results from the above-introduced model are discussed. The main attention is paid to the role of schooling and R&D. I draw a line between the model and the fundamentals explained in section 3.

Time Series Analysis and the 'Scale-Effect'

Since the model is based on Jones' semi-endogenous approach, it also fulfills his time series implication requirements. The growth rate of output depends solely on parameter values and exogenously given population growth. The question is, whether this is an important contribution and whether another framework would have change the results. The answer is yes. Especially for advanced economies, the steady state growth rate would be trending and larger than expected, since the labor share engaged in R&D rose and population growth rates decreased. Furthermore, polcy conclusions would differ. Concerning standard R&D based growth models, effects of subsidies to R&D workers in general should affect the growth rates. In the underlying model of this paper, transitory effects are the issue of today. Since the transition is long enough, there is still room for policies, influencing levels. This is more pessimistic than in former analysis, but also explains the fragility of policy packages, including educational and technological concerns, towards single actions.

Before answering the ability of the underlying model structure to account for the facts of section three, let me clearify something. A good growth model does not have to be able to explain everything. It is more important to draw conclusions with the underlying background of a model's intention. If one is interested in explaining conditional convergence, the underlying theory would not adreess to divergence issues. An economist who tries to explain how countries push up the technology frontier, wont necessarily refer to the experience of countries catching up.

The Robustness of Education

The main reason for the introduction of investment on education in growth models is the robustness of schooling variables, especially secondary schooling, in cross country growth regressions. Here, this is done through the channel of using Mincerian returns from education. This is an improvement to the former introduction of educational enrolment as measure for human capital. The estimated steady state of average attainment is about 12.03 years, which is in line with estimated US performance. Furthermore, education enters the production function, as well as the technology equation. This addresses to the complementary character of technology and human capital. In addition, households can devote their time to research or education, abtracting from output for a moment. Discounted future wages need to be higher than todays opportunity costs of going to school. The central planner solution reveals that labor moves from one sector to another, dependent on which demands people. The labor share devoted to R&D plays a central role, although it has no influence on the growth *rates*. So does education. In steady state, the economy is just interested to maintain a constant level of schooling. Putting this feature do the data, there is no doubt on the model fit for advanced economies. These countries, especially the USA, are said to be closed to their steady state growth paths[43] and do not show large increases in especially secondary education attainment rates. Instead of this, economies that are far away will show ongoing positive trends in the average level of education on their move to the optimal growth path. We also observe this.

Since we have to speak about secondary education (Levine and Renelt (1992)), let me combine this with technology use and innovation, assuming that secondary education

[43] Recent literature of Jones doubt these generally accepted findings

is a neccesary condition for starting research and abstacting from tertiary schooling[44]. It might be intuitive that although technology might diffuse across economies, firms and countries will not take an advantage out of implementing new technologies if nobody can use them efficiently. However, although there migth be the neccessary human capital, technology does not have to diffuse, or in this case, appear immediately. This feature is clearly not involved in the underlying model structure and can be considered as a shortcoming. Many developing economies use old technologies because of employment of unskilled workers. developed countries do not have this suppply problem of skills and therefore apply consequently new technologies. The model copes with this fact.

Miracles and Poverty Traps

The model directly addresses to the performance of East Asian miracles. It even shows the adjustment paths for Japan and South Korea. The choice of a steady state T_{ss}=1 implies no gap in steady state. A ψ of 0.131 for the Japanese and a ψ of 0.162 for the South Korean adjustment path are reasonable values, using initial conditions of output and capital per worker and schooling years. Since human capital is included, it is reasonable to assume higher values for Korea, because a higher ψ means an increase in the left hand side of equation (**??**. Therefore the Euler equation for the share of population spent time in school considers Koreas high educational attainment increases. The adjustment paths are replicated very well. Growth accounting also reveals the importance of education and R&D labor in the 1960s, inducing changes in the size of the workforce, on which output reacts. For a detailed discussion, see Papageorgiou and Perez-Sebastian (2002).

Concerning poverty traps, the model is a model of growth and not income differences. Therefore it does not provide reasons why countries stagnate. One could assume bad starting values for the state variables, but this does not explain bad long run experiences. Here the role of institutions should come into play. Since the model predicts that the changes in the labor shares are important to explain the experience of South Korea and Japan, one might think about failures of reallocation in poorer countries. To replicate these performances, maybe home production is the key argument for less successful stories.

In the beginning of this work, I assumed complements are the key feature in explaining traps and miracls. In most African economies, we observe a rise in at least primary education and also secondary one was promoted heavily over the last decades.

[44] Primary schooling can completely left out since I want to consider complenentary effects with newer advanced technology and not want to speak about handling machines.

The increase was, relatively to the East Asian miralces, very large, but growth rates did not seem to react on it. The model is able to address to this failure through the channel of complementary aspects between technology and human capital. For the East Asian story, these kind of complements may be a solution through the channel of the so called Asian Value. Their relatively lower but steady increase in educated population, excluding high increases in South Korea, was enough to gain from growth. To interpretations are likely. First, as the model suggest, returns from schooling are getting higher during the transition. Second, because of scale effects due to complements, no more improvement was needed. Since the model replicates adjustment paths very well, both interpretation may be partly right.

Divergence, Convergence and Conditional Convergence

The model clearly predicts conditional convergence. However, the speed of convergence is lower in this model, than in models without human capital. Moreover, the speed can vary across time periods. This leaves room for the divergent behavior over the last decades but does not explain the stagnation of some economies, lasting over more than 100 years. The intuition is straigtforward. A model using R&D based growth should not try to replicate performances before the industrialization. An implication towards divergence is not discussed in the underlying model but inherent in R&D models in general. Talking about the behavior of the technological frontier, one must admit that technological change is a very fast process, especially in the computer and information sector. R&D models might assume that the difficulty of developing new ideas increases with the stock of knowledge. However, we do not observe this in several sectors today[45]. The question, if countries may lost chances to catch up to a widened frontier is still unsolved. It may be right that the marginal returns from technology are high in the beginning of the technological development process in a country, but the development of the frontier makes failures of efficient use of technology in poor countries even worse.

To conclude, the models ability to reflect reality is very high. Several countries growth paths can be replicated without violating time series behaviour.

7 Cross-Country Regressions

Since I want to draw policy conclusions, I decided to use cross-country growth regressions to discriminate between the importance of primary secondary and tertiary schooling. Furthermore, I will reveal the effects of technology and schooling acting together.

[45]Especially in the Biotechnology and Information technology recent inventions seem to push the frontier even more.

I use the Barro, Lee data set for educational attainment over the years 1960 to 2000. Furthermore, indicators of technology are personal computer usage, telephone lines and internet users. Since these data are only available for the years after 1989, I use electric power production to account for industrial structures over the years 1960 to 1980. To take social infrastructure into consideration, I use the variable government crisis to capture negative effects from missing social infrastructure. The dependent variable, the growth rate of real GDP per capita, Chain weighted, is taken from the Penn World Table 6.1.

First I do a standard OLS cross-country growth regression exercise. I regress the initial values for schooling, real GDP per capita and government crisis on the average growth rates. Furthermore I try to account for the interaction of population having education and the occurance of gvernment crisis on growth. I also include an interaction between electricity production and schooling. I expect especially secondary schooling to be correlated with growth rates. Moreover, secondary schooling should lower the negative effect of governmnental crisis. The results, which are all reported at a 5% significance level, are presented in Table 3.

The results are ambigious. First of all, this regression shows a negative coefficient in front of initial GDP. That contradicts my prediction of divergence across countries. However, the 62 included countries are not representative for worldwide performance. There is a bias; poor economies are less often. Concerning to the other variables, primary and secondary schooling are significant - the t-values are bigger than 2 in absolut values. This means that there is at least a positive correlation between the initial population share, completed a certain schooling level and the average growth rates over time. Faster growing economies have had a higher initial education level. This confirms the results of the discussion on miracles in section 3.1.3. Furthermore the positive coefficients of the government-crisis-education interaction terms is also significant. Indeed, schooling seems to lower the negative effects, which is unfortunately not significant at a 5% level, but at a 10% one for the second and third regression, of crisis on growth. Education may function as a foundation for overcoming crisis. however, can also be just a issue of offsetting effects, although it would be in line with the results of Papageorgiou and Perez-Sebastian, who show that schooling makes an economy more resistent towards shocks. The electric power production plays a minor role in explaining economic growth. Although, it is positive and nearly significant, the variable itself does not give enough information on a countries' standard of development. Includong the term 'elec*pri' I intended to show a positive and significant relation towards growth, since I thought of the development in the heavy industry, and thereby electric power usage, in the beginning of the sample. This relationship is ambigious, because finally it ca be the case that

Table 3: Cross-Country Regression Results, Dependent Variable: Average Growth Rates, 1960-2000

Variables	Rgr.1	2	3	4	5
Init. GDP	-3.03E-06	-3.14E-06	-2.94E-06	-2.97E-06	-3.08E-06
	(9.15E-07)	(6.35E-07)	(5.92E-07)	(7.76E-07)	(6.91E-07)
	[-3.3084]	[-4.9491]	[-4.9569]	[-3.8252]	[-4.461]
Pri. School.	0.0009	0.0007	0.0008	0.001	0.0009
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
	[7.0279]	[6.0694]	[7.0168]	[6.1133]	[7.2113]
Sec. School.	0.0012	0.0011	0.0008	0.0009	0.0012
	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)
	[3.6632]	[4.0199]	[3.1376]	[3.2810]	[3.5810]
Ter. School	0.0010	0.0012	0.0015	0.0005	0.0001
	(0.0015)	(0.0011)	(0.0011)	(0.0012)	(0.0011)
	[0.6901]	[1.1307]	[1.3528]	[0.4481]	[0.8791]
Gov. Crisis	-0.0017	-0.0074	-0.006714	-0.0023	-0.0017
	(0.0019)	(0.0041)	(0.0034)	(0.0039)	(0.0038)
	[-0.894]	[-1.7827]	[-1.9856]	[-0.5886]	[-0.4462]
GOV*PRI		0.00027			
		(0.0001)			
		[2.0239]			
GOV*SEC			0.0013		
			(0.000425)		
			[2.8192]		
Elec.Power	2.4-07	8.0E-07	6.58E-07	5.02E-06	
Production	(1.4E-06)	(5.4E-07)	(5.3E-07)	(2.67E-06)	
	[0.1663]	[1.4857]	[1.2409]	[1.8792]	
ELEC*PRI				-1.41E-07	
				(7.38E-08)	
				[-1.926]	
ELEC*SEC					3.66E-08
					(6.60E-08)
					[0.5550]
R^2	0.5205	0.5297	0.5448	0.4987	0.5214

Terms in ()-brackets are standard errors, in []-brackets are t-values. Regression 1 and 6 include 61 countries, the others 62. 31 Countries are excluded because of missing data for the one or another explanatory variable.

the correlation between growth rates and primary educated workforce overcomes the less sifgnificant coefficient for electricity production. Tertiary education seems to play no role in describing growth in theis time span. This is not at least due to the fact that teritiary education is only relevant for countries that already reached the technology frontier. To account for an effect in these countries, one should exclude the others and divide the education variable in several components, attributing the differences in the importance of economic sectors. Tertiary education does not automatically mean to profit more from R&D. Since I want to take the interaction of technology and education into account, I run several growth regressions from 1990 to 2000, including initial endowment with telephone lines, personal computers and internet as direct explanatories for growth. The results are ambigious. Let me present one of the most convincing ones[46]. Note that this result is only obtained for mainly developed countries because of lacking datasets. I used a simple OLS regression procedure and got the following results:

$$GR = 0.0119 + 0.0027 * GOVCRISISinit - 0.0054 * NETinit + 0.0054 * PCinit$$

$$+0.0005 * PRISCHOOLinit - (4.77E - 07 * GDPinit + 0.0012 * SECSCHOOLinit$$

$$-0.0006*TELLINEinit-0.001*TERSCHOOLinit-0.0001*SECSCHOOLinit*PCinit,$$

$R^2 = 0.4208$. Unfortunately, the t-values only reveal significance for secondary education, secondary education *times* initial PC endowment and initial PC endowment; the internet even has a negative coefficient. I indeed expected a positive sign for telephone lines and the internet. The only interpretation for this, despite the fact that one could have used more sophisticated methods, that the development of infrastructure, like telephone lines, is a consequence of growth experiences and is highly lagging. I cannot explain why especially the internet is positively not correlated with growth rates. Maybe the initial year was too early, in the sense that the role for development is higher today.

I want to estimate ongoing effects of correlations with the growth rates. Thus, I decide to use a panel regression. Unfortunately the data are only from 1990 to 2000, which is indeed a very short time series. Furthermore, I approximated the values for educational attainment, since they are only available for in five year intervals. I put linear trends in between the starting and ending values of a five year period. This should not bias the results that much, because getting a school degree takes some time. The series are therefore not volatile. However, more important are the missing data on technology use. I use a pool to account for country specific fixed effects, which make the results more robust but also hide the lack of potential explanatory variables. Let

[46] All additional regressions and results are as workfiles on the CD-version.

Table 4: Regression Results Growth Rates: Panel Data, 1990-2000

Included Explanatories	Regr. 1	2	3	4	5
Pri. Schooling		-0.0001	0.0903	-0.0011	0.0595
		(0.0005)	(0.0035)	(0.0011)	(0.0228)
		[-0.2883]	[25.5304]	[-1.0167]	[2.6078]
Sec. Schooling	0.0492	0.0489	0.9590	0.0515	0.7907
	(0.0025)	(0.0025)	(0.0947)	(0.0075)	(0.4424)
	[19.5052]	[19.3860]	[10.1315]	[6.8634]	[1.7871]
Ter. Schooling	0.0421	0.0446	0.4592	0.0462	-0.3152
	(0.0044)	(0.0042)	(0.0701)	(0.0162)	(0.4228)
	[9.5762]	[10.6936]	[6.5517]	[2.8489]	[-0.7457]
Tel.-Lines	0.0074	0.0076	0.0168	0.0086	0.0345
	(0.0025)	(0.0025)	(0.0053)	(0.0076)	(0.0179)
	[2.9402]	[3.0295]	[3.1442]	[1.1331]	[1.9254]
PC	-0.0098	-0.0102	0.0400	-0.0070	0.0853
	(0.0091)	(0.0091)	(0.0138)	(0.0273)	(0.0472)
	[-1.0746]	[-1.1176]	[2.9057]	[-0.2566]	[1.8085]
PC*Sec				-0.0010	
				(0.0002)	
				[-1.0167]	
Internet	0.0025	0.0026	-0.0528	-0.0014	-0.1126
	(0.0071)	(0.007)	(0.0155)	(0.0206)	(0.0515)
	[0.3531]	[0.3609]	[-3.4053]	[-0.0679]	[-2.1878]
NET*SEC	-0.0006				
	(0.0002)				
	[-5.8475]				
weighted R^2	0.3899	0.3991	0.3313	0.4339	0.3344
Method	GLS	GLS	GLS	GLS	Pooled LS
	Cross.-sec.w.	Cross.-sec.w.	fixed effects	Cross.sec.w.	fixed effects

GLS regressions include cross section weights. The fourth regression uses lagged regressors, excluding PC*SEC. Terms in ()-brackets are standard errors, in []-brackets are t-values.

me discriminate between regressions and start with the simple pooled OLS regression, allowing for fixed country effects. The only significant coefficients are those of primary education, telephone lines[47] and internet. Moreover, in the meaning of intuition, the third coefficient even has the wrong sign. Abstracting from this shortcome, the R^2 is really low, although I introduced fixed country effects. Consider now the GLS regressions, allowing for cross-section weights[48]. In general, growth rates and secondary schooling over time are significantly, positively correlated. This supports several empirical studies and underlines again the importance of taking secondary education as a development goal. Also tertiary schooling enters positively in the regression with a similar coefficient. Additionally, the telephone lines are significant in the first three regressions. This supports the theory that the intrastructural effort is linked to a countries growth experience. Allowing for country specific fixed intercepts, the endowment of personal computers matters. However, measures of firms endowment might have been a better proxi for influences of technology use on GDP. Having a home computer is not neccesarily a contribution to growth. Moreover, I could imagine that it is better to rely on the results of the above mentioned initial values regression, since the efforts might show returns in future periods, accounting for time to learn how to work with the new endowment. There 'PC' enters the regression with a coefficient of about 0.0054. Note that the effect of the internet is still ambigious. In the first regression, the combination of schooling and internet shows even significant negative returns. Maybe, indeed countries that have both in large amounts are the most developed ones and have therefore on average smaller growth rates over time. Besides this, as I reported, the fourth regression includes one period lagged values for the single variables. Comparing the t-values with, the second regression reveals that lagged telephone lines endowment have no influence on 'todays' growth. This again addresses to the endogeneity of this variable. On average only 35 percent of the regression are explained. In my eyes, taking into account that I included cross section weights and control for contemporaneous correlation, this is too low. Although this cannot really reveal causality, I use the secondary educated workforce as endogenous variable and regress growth rate, internet user, personal computer and telephone-lines on it. The results are shown in table 5. First of all, the explanatory power is very high. One reason are the used cross-country weights or the fixed effects country specific intercepts. Using both regression, the only variable that does not have ambigious results is the growth rate. This confirms the results above. In general, in industrialized countries, secondary education changes less

[47] This coefficient is significant at a 10% level.

[48] Note that the third regression includes fixed country intercepts, which are said to be more effective. However, the explanatory power of this regression is lower then the others. So, this might have been too much of a good thing.

than technology, especially PC and internet endowment. In developing countries, the opposite is true. I conclude that, on the one hand, secondary education, and on the other hand, technology, change too less to have significant influences on the considered sample. A problem in each of the regressions is of course the assumption of exogeneity

Table 5: Regression Results Secondary Schooling: Panel Data, 1990-2000

	Regression 1			Regression 2		
	coeff.	std.error	t-value	coefficient	std.error	t-value
Growth Rate	0.1736	(0.0262)	[6.6173]	0.0055	(0.0034)	[1.6249]
Tel.-Lines	-0.0331	(0.0054)	[-6.1543]	0.0060	(0.0013)	[4.5771]
PC	-0.0566	(0.0218)	[-2.5979]	0.0059	(0.0049)	[1.2134]
Internet	0.0897	(0.0173)	[5.1752]	-0.0146	(0.0047)	[-3.0815]
R^2	0.9727	weighted		0.9990	unweighted	
Method	feasible GLS			Pooled LS	fixed effects	

Terms in ()-brackets are standard errors, in []-brackets are t-values.

of the RHS variables. One could try to overcome this problem, by using lagged values or take the first differences in the below mentioned SUR estimation procedure. I tried this in several ways, but the main results did not change. However, the last regression explained here reveals room for improvements in the variable set. Moreover, some technical shortcomings have to be explained. The pooled OLS regression is usually not used, if one assumes that there is contemporaneous correlation in the residuals. Furthermore, homoscedasticity[49] is needed. I doubt both assumptions are true. Therefore, the interpretation is to be seen with caution. However, fixed effects in general are more accurate than pure cross country weights, although, a cross-section weighted variance accounts also for the issue of heteroscedasticity [50]. Thus, take the fixed effects results of the weighted GLS regression more serious. In addition, I tried to overcome the weakness of the done regression by using a sample of three decades, estimated separately with a Seemingly Unrelated Regression Procedure. I again take the initial values[51] in 1960, 1970 and 1980, of the explanatories and the average growth rates over ten year periods for 92 countries. Unfortunately, several countries have to be excluded because of missing data. I also allowed for fixed cross section effects, which are in this case time effects. However, although the interpretation is a slightly different one, the main results did not change in any direction. For detailed results, the workfile is included in the CD version.

[49] I tried to account for heteroscedasticity by using the White covariance estimator

[50] However, over time, variances within a cross section do not differ.

[51] Note, that I again avoid using the appproximated data for schooling

To conclude, the above given results leave three questions unanswered. First, I could not draw conclusions aon the effect of IT in explaining growth. I am more optimistic for future studies. Until now, the time series is not long enough to work with these data properly in panel data regressions. Second, one should doubt the implied causality channel. There might also be an influence of growth and schooling and therefore, policy conclusions change dramatically. Bils and Klenow (2000) refer to the Mincerian approach and analyse the effect of growth on schooling in an endogenous growth framework. Their findings are striking. They set up a model, in which the agents choose the time spend in school, anticipating future growth predictions, and come to the conclusion that higher growth means higher returns from schooling and therefore higher attainment rates. Reverse causality can account for a big part of observed correlation. [52] They also found evidence that, contrary to the predictions of simple accumulation hypothesis, wages of young workers in East Asia did not increased as fast as theory would predict. Second, the existence of complenentary effects between schooling and technological use and development is not proved here. However, several authors show empirically its validity. Therefore I take this as given.

8 Policy Suggestions

After having discussed certain empirical feaures and analyzed the underlying model, I will try to draw polic conclusions.

It is obvious that technology increases growth due to higher returns. Supporting investment and adoption of new technologies is proved to be a meaningful thing. However, there can be made mistakes. It should not be a goal to increase the number of researchers through subsidising their office. A good patent law system might be more important to guarantee research and development activity. Of course, technology changes imply also losses for economies, using mainly old technology. People will get unemployed and skills will loose their importance. many countries have flexible institutions. They can efficiently compensate the loosers and gain from growth. Others, mainly several African countries, tend to stick to their policies, no matter what might happen. Therefore, gowth does notz get a chance to take place from the very first moment. The structure of subsidies to new technologies depend strongly on the nature of these inventions. If inventions increase the possibility and efficiency of future technologies and the market is not willing to adopt them due to high invention or installation costs, subsidies might be desirable. Despite all this, the model mainly concentrates on

[52] Furthermore, factors like policy contribute its part to the correlation between schooling and growth.

the complementary character of technology and investment in education. Policy action can therefore address to the distribution and matching problem. High and specialized skills are demanded where high technology is used. Abstracting from high technology, there is good news from Chad. Education demand rises immense. Public schools do not have enough desks for the students. In 1999/2000 nearly one half of the population in school age really goes to school. However, it is accompanied by new problems. Former times afraid of Christian French influence in school, they nowadays teach the Koran while learning the Arab language. Officials admit that there is indeed a problem with enhancing fundamentalism while raising Arabic education, not at least because Islamite funds support private schooling. Moreover, these schools attract more girls than others.

Old technology does not require a highly specialized and educated workforce to be used efficiently. The former Taiwanease experience is the best example for this. Creating new supply of high skilled workers through the channel of secondary or tertiary education enforcement in such an environment and hindering new technology to flow into the country is not the right attempt to gain from educated people. The returns are very low. So are the incentives to stay. people with high human capital will migrate to rich countries. High skilled people supply should create incentives for firms and governments to use and develop advanced technologies to gain from the investment in education. This is especially important for technological leaders. To get concrete, todays Europe should corrects its policy; scientists go more often to the United States to explore their abilities.

Considering to developing economies, enhancing both, technology use and education, should be in the focus of politicians. Therefore, convincing[53] ruling elites, whoever this may be, of the importance of overcoming ethnic and religious conflicts and avoiding any abuse of power is the best thing to do at the basis. However, ruling elites often avoid education enhancing policies because this creating the possibility for mass education also means to get confronted with an increasing interest in political decision processes. This does immmediately increase redistributional pressure. The somewhen reached redistribution can furthermore be growth lowering if most of the population are really poor and inequality is high. It is a widely known fact that a countries perspectives are better, if it has a widely spread middle class, but the way to go in advanced can be rather bad.

There seems to be less success in just providing textbooks and rooms or machineries. Especially Africa has revealed this shortcoming of aid. Africas problem is not just the

[53]"Convincing" in my eyes does not mean enticing governments with aid promises, but giving sustainable aid to countries, which have worked hard to provide a solid foundation for growth.

missing technology endowment complementing human capital, but also the bad quality of education. To improve the returns from education through schooling quality improvement is not an easy task. It is more or less a question of creating ongoing incentives and controls on each stage, beginning with the above mentioned ruling elites and ending with the teachers. Low teachers' salaries act as incentives to sell provided textbooks to their students. However, test scores reveal that textooks do matter in improving the performance of secondary! students. However, in some African schools exist more guns than books. Moreover, if education provides a better future, parents would control schooling results as far as they can. Tecaher do not stand under pressure. The success of school improvements depends crucially on a countries social situation and perspective. Incentives to in invest in the future are really low in many developing countries. the intertemporal elasticity of substitution is not very high. Preferences for food today are in generally higher in poor economies. Easterly (2002) suggests the misuse of skills in poor countries for lobbying, mainly because of missing alternatives.

However, there are other factors that could give reason to hope in Africa. Although Papageoriou and Perez-Sebastian do not adress to agglomeration issues and I could also find only some evidence for the ability of this model to cope with this fact, let me refer to the concentration of economic activity, mentioned in section 3.1.3. Fast development of African cities today increases the potential of economic development. It is important to address aid directly on city-regions. As the cross country regressions partly reveal, communication systems can influence growth. Maybe through the channel of lowering transaction costs. Although effects are under debate, developing the infrastructural situation in the cities might attract new firms. Since firms respond to incentives, one should support other industries then resource extracting ones. As we have seen above, providing education is not enough. Botswanas experience speaks for itself. Liberizing the economy is as important as engaging in school enrolment.

Indeed, to act properly, one has to determine the reasons for stagnation and failure. Theories with more concrete policy implications needed. Furthermore, there is no overall theory deriving policy advices. One has to take differences in country characteristics serious. Moreover, policies have high interdependencies. Isolating single rule is therefore ambigious.

9 Summary and Concluding Remarks

"There is a sense in which we are all endogenous theorists now" (Bradford DeLong). The semi-endogenous R&D approach unites endogenous and exogenous growth ideas.

Technology innovation and - more important for developing countries - imitation are explained endogenously on the basis of profit maximizing agents. Policy conclusions address to potential effects on the level and not on the growth rate of GDP.

Introducing the complementary character of technology and knowledge in form of schooling contributes a lot to former growth analysis and opens a new reasearch sector. Future research should concentrate on modelling the quality of education, linked to households decision making. Furthermore, new measures of knowledge, including on-the-job learning, might be useful to describe the interaction between technology and the level of education more precisely. On a theoretical level, a confrontation of these models to the ideas of Prescott and Parente could be an important contribution. Besides Parentes and Prescotts' doubts on the importance of human capital[54], explanations for failures to imitate are offered. This failure is not modelled explicitely in the R&D based approached, although complements are introduced.

We should not discriminate between both directions of research because there are always many possible answers to a problem. However, it is still difficult to put R&D based models to the data and nearly impossible to draw welfare conclusions. Increasing gowth does not naturally mean to reach welfare improvement; one of the central issues why people engage in growth theory. To conclude, several questions remain unsolved.

[54]They use the reverse way of interpretation. Experts can be imported. The lack of educated workforce supply is not a barrier at all. In contrast, Acemoglu and Zilibotti (2001) show that skill differences create differences in TFP through the channel of mismatches.

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10 Appendix

10.1 Tables

Table 6: Sensitivity Results, Dependent Variable: Growth Rate of Real GDP per Capita 1960-1989, (Levine and Renelt, 1992)

M-variable		β	Std. er.	t	obs.	R^2	Other var.	Result
	high:	19.07	2.87	6.66	98	0.54	STDI, REVC, GOV	
INV	base:	17.49	2.68	6.53	101	0.46		robust
	low:	15.13	3.21	4.72	110	0.49	X, PI, REVC	
	high:	-0.34	0.13	2.53	98	0.54	STDI, PI, GOV	
RGDP60	base:	-0.35	0.14	2.52	101	0.46		robust
	low:	-0.46	0.13	3.38	85	0.56	GDC, X, REVC	
	high:	-0.34	0.23	1.48	100	0.48	X, STDI, PI	
GPO	base:	-0.39	0.22	1.73	101	0.46		fragile
	low:	-0.49	0.20	2.42	85	0.56	X, GDC, REVC	
	high:	3.71	1.22	3.04	84	0.55	X, GOV, GDC	
SEC	base:	3.17	1.29	2.46	101	0.46		robust
	low:	2.50	1.15	2.17	85	0.62	X, STDD, GDC	

Source: Levine and Renelt (1992), Variables: GDC-growth rate of domestic credit, GOV-average rate of government consumption expenditures, GPO-average annual population growth rate, PI-average inflation rate, REVC-index for number of revolutions and coups, STDD-standard deviation of domestic credit growth, STDI-standard deviation of inflation, X-export share of GDP.

Table 7: Response of Growth Rates and Output to a 1-percentage-point Permanent Increase in the Investment Rate.(Jones, 1995)

	Total investment		Producers durables inv.	
Period (year)	OLS dynamic response	OLS cummulative response	OLS dynamic response	OLS cummulative response
0	0.802	0.802	1.020	1.020
1	-0.013	0.789	0.167	1.186
2	0.030	0.819	-0.222	0.965
3	0.055	0.874	0.263	1.228
4	0.081	0.955	-0.012	1.216
5	0.133	1.088	-0.015	1.201
6	0.008	1.096	-0.026	1.175
7	-0.008	1.088	0.009	1.184
8	-0.014	1.074	0.005	1.189
9	-0.007	1.067	0.001	1.190
10	-0.009	1.058	-0.002	1.188
15	0.001	1.062	-0.000	1.188

Source: Jones, Charles I. (1995), p. 511.

10.2 Data Appendix

Sources

- Data on GDP per capita, Chain and Laspeyres weighted, are taken from both, the Penn World Table 5.6 and 6.1. growth rates are also offered in PWT 6.1 otherwise, they are calculated.
- The data for the investment shares are also take from The PWT 5.6.
- Psacharopoulos (1994) offers data for educational investment returns.
- School attainment rates and data on average schooling years are taken from Barro and Lee (2000).
- The data on PC endowment, internet users, telephone mainlines and subscribers and government crisis are taken from the Global Development Network Growth Database, http://www.worldbank.org/research/growth/GDNdata.htm4).

Table 8: Data Set

Country Code	Country Name	Country Code	Country Name
ARG	Argentina	JOR	Jordan
AUS	Australia	JPN	Japan
AUT	Austria	KEN	Kenya
BEL	Belgium	KOR	South Korea
BEN	Benin	LKA	Sri Lanka
BGD	Bangladesh	LSO	Lesotho
BOL	Bolivia	MEX	Mexico
BRA	Brazil	MLI	Mali
BRB	Barbados	MOZ	Mozambique
BWA	Botswana	MUS	Mauritius
CAF	Central African Rep.	MWI	Malawi
CAN	Canada	MYS	Malaysia
CHE	Switzerland	NER	Niger
CHL	Chile	NIC	Nicaragua
CHN	China	NLD	The Netherlands
CMR	Cameroon	NOR	Norway
COG	Congo	NPL	Nepal
COL	Colombia	NZL	New Zealand
CRI	Costa Rica	PAK	Pakistan
CYP	Cyprus	PAN	Panama
DNK	Denmark	PER	Peru
DOM	Dominican Republic	PHL	The Philippines
DZA	Algeria	PNG	Papua New Guinea
ECU	Ecuador	PRT	Portugal
EGY	Egypt	PRY	Paraguay
ESP	Spain	ROM	Romania
FIN	Finland	RWA	Rwanda
FRA	France	SEN	Senegal
FJI	Fiji	SGP	Singapore
GBR	Great Britain	SLE	Sierra Leone
GER	Germany	SLV	El Salvador
GHA	Ghana	SWE	Sweden
GMB	Gambia	SYR	Syria
GRC	Greece	TGO	Togo
GTM	Guatemala	THA	Thailand
GUY	Guyana	TTO	Trinidad and Tobago
HKG	Hong Kong	TUN	Tunisia
HND	Honduras	TUR	Turkey
HTI	Haiti	TWN	Taiwan
HUN	Hungary	UGA	Uganda
IDN	Indonesia	URY	Uruguay
IND	India	USA	United States
IRL	Ireland	VEN	Venezuela
IRN	Iran	ZAF	South African Republic
ISL	Iceland	ZAR	Zaire
ISR	Israel	ZWE	Zimbabwe
ITA	Italy	ZMB	Zambia
JAM	Jamaica		

10.3 Mathematical Appendix

10.3.1 Calculation Method of semi-endogenous R&D Growth Models

This paragraph give a detailed foundation of R%D based growth models. I will mainly refer to the appendix of Jones (1995b?). Two aspects are important to consider. First, it will function as a proof, that the microstructure of R&D models is not violated, considering a semi endogenous approach. Second, I give the background for the in section 4 analyzed model. This allows me to leave upon the micro-calculations there.

The economy consists of three sectors.

The final good producer sector The final sector produces consumption goods, Y. The existing firms are price taker, we are in a perfect competitive environment. Input factors are labor, L_Y and several producers durables, x. The CRS production function is given by

$$Y = L_Y^{\alpha} \int_0^A x_i^{1-\alpha} di. \tag{27}$$

To simplify, a single producer is considered. He maximizes his profits with respect to the inputs

$$\max_{L_Y, x_i} \Pi = \max_{\{L_Y\},\{x_i\}} Y - wL - px_i = \max_{\{L_Y\},\{x_i\}} L_Y^{\alpha} x_i^{1-\alpha} - wL_y - p_i x_i. \tag{28}$$

The FOCs' reveal the equilibrium factor prices, wage and rental price for durables

$$w = \alpha(Y/L) \qquad p_i = (1-\alpha) x_i^{-\alpha} L_i^{\alpha}. \tag{29}$$

The intermediate sector This sector consists of an infinite number of firms, lying in between 0 and A. The intermediate sector transforms capital one to one into producers durables. Therefore, new designs are used. Each firm uses a unique design, bought from the research sector. In so far, they are monopolists. However, the rental price for capital does not differ between firms. Each monopolist maximizes his profits. ACHTUNGUEBERPWIRKLICH?

$$\max_{\{p\}} \Pi = \max_{\{p\}} [p(x)x - rx] = \max_{\{p\}} \left[p \left(\frac{p_i}{(1-\alpha)L_Y^{\alpha}} \right)^{-\frac{1}{\alpha}} - r \left(\frac{p_i}{(1-\alpha)L_Y^{\alpha}} \right)^{-\frac{1}{\alpha}} \right] \tag{30}$$

The FOCs' reveal the price, paid by the final good sector producers and the output quantity of producers durables

$$\frac{\partial \Pi}{\partial p} \overset{!}{=} 0 \Leftrightarrow p_i = \bar{p} = \frac{r}{(1-\alpha)} \qquad \forall i \tag{31}$$

$$x_i = \bar{x} = \left(\frac{(1-\alpha)L_Y^{\alpha}}{\bar{p}} \right)^{\frac{1}{\alpha}} \qquad \forall i \tag{32}$$

The sold amount of a firms' durable and the price demanded from the final sector do not differ among firms. Rearranging equation (31) for r, and plugging it into the profit function yields the equilibrium profits of each firm in the intermediate sector

$$\pi_i = \bar{\pi} = \alpha \bar{p} \bar{x} = \alpha(1-\alpha) L_Y^{\alpha} x_i^{-\alpha} \bar{x} =_{(27)} \alpha(1-\alpha)\frac{Y}{A} \qquad \forall i. \tag{33}$$

Since the amount of producers durable goods equals capital[55], $K = \int_0^A \bar{x} di = A\bar{x}$, the rental price for capital in the intermediate sector is finally given by

$$r = (1-\alpha)^2 L_Y^{\alpha} x_i^{-\alpha} = (1-\alpha)^2 \frac{Y}{K}. \tag{34}$$

The research sector The research sector produces new designs. The stock of knowledge is given as input factor.

The factor prices are

$$w = P_A \delta A^{\phi} L_A^{\lambda - 1} \tag{35}$$

labor flows into this sector until mc (w) equals mp (marginal private benefits)($P_A \delta$) $w = P_A \frac{\dot{A}}{L_A}$

$$r = \frac{\bar{\pi}}{P_A} + \frac{\dot{P}_A}{P_A} \tag{36}$$

dann ist intermediate indifferent zwischen kaufen und produzieren und nicht produzieren. where P_A (naja:?is the price for a patent, bought by the intermediate sector?)eigentlich: costs of purchasing a patent to the intermediate sector. aber auch: pa equals the present discounted value of the intermediate sectors profits.

can also solve the Hamiltonian problem: ....offen ob ich das mache

$$\max_{c_t} \int_0^{\infty} e^{-\rho t} u(C_t/L_t) dt$$

s.t.

$$\dot{K} = rK + wL_Y + wL_A - P_A \dot{A} + A\pi - C$$
$$\frac{\dot{c}}{c} = \sigma(r - \rho - n)$$

nb: eq and balanced growth in decentralized model, st state constant growth rates. in perfect foresight equilibrium of decentralized model, all agents take the time path of variables, that they do not control, as given. consumer: wages and investment, rand d A and resale price and demand of durables as given.

[55] The aggregated production function can be derived as follows: Since$\bar{x} = K/A$, $Y = L_Y^{\alpha} \int A_0 x_i^{1-\alpha} \Leftrightarrow (AL_Y)^{\alpha} K^{1-\alpha}$!!!!! Achtung, wieso muss das a bei denen nicht unter das alpha? dringen dklaeren!!!!!!!!!!!!!!!

10.3.2 Calculation of the Papageorgiou, Perez-Sebastian (2002) model

The Law of Motion for Average School Attainment

In this model, schooling is the only possibility to build up human capital. Therefore, L_{Ht} denoted the number of people in school at date t. The population of an economy is denoted by L_t. Given that $S_1 = 0$, S_2 will be equal to L_{H1}/L_1. In the next period $S_3 = (L_{H1} + L_{H2})/L_2$ and so on. Each year, the average educational attainment is equal to the share of the total number of people, spend time in accumulating knowledge in the past periods divided by the actual size of the population[56] Therefore, one can generalize this to

$$S_t = \frac{\sum_{j=1}^{t-1} L_{Hj}}{L_t} \Leftrightarrow S_t L_t = \sum_{j=1}^{t-1} L_{Hj}.$$

Since

$$S_{t+1} = \frac{\sum_{j=1}^{t} L_{Hj}}{L_{t+1}},$$

one can substitute $S_t L_t$ for $\sum_{j=1}^{t-1} L_{Hj}$. This results in the final law of motion for educational attainment

$$S_{t+1} = \frac{(S_t L_t + L_{Ht})}{L_{t+1}} \Leftrightarrow S_{t+1} = \frac{S_t}{1+n} + \frac{L_{Ht}}{L_{t+1}},$$

given the gross growth rate of population $L_{t+1}/L_t = 1 + n$. Multiplying the last term with L_t/L_t one gets

$$S_{t+1} = \frac{S_t}{1+n} + \frac{L_{Ht}}{L_t(1+n)},$$

and subtracting S_t from both sides yields

$$S_{t+1} - S_t = \frac{1}{1+n}\left(S_t + \frac{L_{Ht}}{L_t}\right) - S_t.$$

Finally, we have

$$S_{t+1} - S_t = \left(\frac{1}{1+n}\right)\left(\frac{L_{Ht}}{L_t} - nS_t\right).$$

Naturally, average educational attainment rises with share of population in school in a periodL_{Ht}/L_t, but falls with the growth rate of population, c.p..

Calculation of the Euler Equations

To solve for the centralized solution, we define a value function

$$V(S_t, A_t, K_t) = \max_{\{L_{Ht}, L_{At}, I_t\}} \frac{\left(\frac{A_t^{\xi}\left[e^{f(S_t)}(L_t - L_{Ht} - L_{At})\right]^{1-\alpha} K_t^{\alpha} - I_t}{L_t}\right)^{(1-\theta)} - 1}{1-\theta}$$

[56] The time spend in school is chosen after having decided on the time devoted to labor.

$$+\rho V\left[S_t+\frac{1}{1+n}\left(\frac{L_{At}}{L_t}-nS_t\right);A_t(1-\delta_A)+\mu A_t^{\phi}\left(e^{f(S_t)}L_{At}\right)^{\lambda}\left(\frac{A_t^*}{A_t}\right)^{\psi};K_t(1-\delta_K)+I_t\right]$$

Indeed, three functions are considered. First, we find the following derivatives $\frac{\partial V(S_t,A_t,K_t)}{\partial L_{Ht}}$, $\frac{\partial V(S_t,A_t,K_t)}{\partial L_{At}}$ and $\frac{\partial V(S_t,A_t,K_t)}{\partial I_t}$. I will exemplify the calculation procedure for the resulting Euler equations, taking the first equation. the other two are analogously derived. the second equation requires some more rearrangement work, the third is the most easiest one. Consider now the rearranged FOC for people in school

$$\left(\frac{A_t^{\xi}\left[e^{f(S_t)}(L_t-L_{Ht}-L_{At})\right]^{1-\alpha}K_t^{\alpha}-I_t}{L_t}\right)^{-0}(1-\alpha)$$

$$*\frac{A_t^{\xi}}{L_t}\left(e^{f(S_t)}(L_t-L_{Ht}-L_{At})\right)^{-\alpha}K^{\alpha}e^{f(S(t))}$$

$$=\rho\frac{\partial V(S_{t+1},A_{t+1},K_{t+1})}{\partial S_{t+1}}\frac{1}{1+n}\left(\frac{L_t-L_{Ht}}{L^2}{}_t\right)$$

$$\Leftrightarrow\left(\frac{C_t}{L_t}\right)^{-\theta}(1-\alpha)\frac{Y_t}{L_t}\frac{1}{L_{Yt}}=\rho\frac{\partial V(S_{t+1},A_{t+1},K_{t+1})}{\partial S_{t+1}}\frac{1}{1+n}\left(\frac{L_t-L_{Ht}}{L_t^2}\right)$$

We can now define a policy rule, assuming that the optimal decision depends solely on the one corresponding state variable. In the underlying case, $L_{Ht}=L_H(S_t)$. Therefore the value function is redefined. We substitute $L_H(S_t)$ for L_{Ht}. This function is differentiated by S_t

$$\frac{\partial V(S_t,A_t,K_t)}{\partial S_t}=\left(\frac{A_t^{\xi}\left[e^{f(S_t)}(L_t-L_H(S_t)-L_{At})\right]^{1-\alpha}K_t^{\alpha}-I_t}{L_t}\right)^{-0}$$

$$(1-\alpha)\frac{A_t^{\xi}K_t^{\alpha}}{L_t}\left(e^{f(S_t)}(L_t-L_H(S_t)-L_{At})\right)^{-\alpha}*\left[f'(S_t)e^{f(S(t))}(L_t-L_H(S(t))-L_{At})\right.$$
$$\left.-e^{f(S_t)}\frac{\partial L_H(S_t)}{\partial S_t}+\rho\frac{\partial V(S_{t+1})}{\partial S_{t+1}}\left(1+\frac{n}{1+n}+\frac{n}{1+n}\frac{1}{L_t}\frac{\partial L_H(S_t)}{\partial S_t}\right)\right. \tag{37}$$

We can plug in the RHS of the FOC into this derivative and then do a time shift. The LHS of this equation is substituted back into the FOC for schooling. Finally, this approach results in the following Euler equation

$$(\frac{C_t}{L_t})^{-\theta}\frac{(1-\alpha)Y_t}{L_{Yt}}$$

$$=\frac{\rho}{1+n}(\frac{C_{t+1}}{L_{t+1}})^{-\theta}\frac{(1-\alpha)Y_{t+1}}{L_{Y,t+1}}[1+f'(S_{t+1})(\frac{L_{Y,t+1}+L_{A,t+1}}{L_{t+1}})],$$

The other equations are derived similarly and stated in section 5.1.

Calculation of the Steady State Growth Path for Output, Consumption and Capital

Consider the aggregated production function given by equation (1). Taking the logarithm, one can also write

$$\ln Y_t = \xi \ln A_t + (1-\alpha) \ln e^{f(S_t)} + (1-\alpha) \ln L_{Yt} + \alpha \ln K_t.$$

Substituting in (3) and differentiating with respect to time then results in

$$\frac{d\,Y_t/d\,t}{Y_t} = \xi \frac{d\,A_t/d\,t}{A_t} + (1-\alpha)\frac{d\,H_{Yt}/d\,t}{H_{Yt}} + \alpha \frac{d\,K_t/d\,t}{K_t},$$

and in terms of growth rates,

$$g_Y = \xi g_A + (1-\alpha) g_H + \alpha g_K.$$

Using the facts that, in steady state, capital and output grow at the same rate and that labor grows exogenously at rate n and S is constant, we can rewrite this equation to get

$$g_{Y,ss} = \frac{\xi g_{A,ss}}{1-\alpha} + n.$$

Plugging in the steady state growth rate of technology finally yields to

$$g_{Y,ss} = \frac{n \xi \lambda}{(1-\phi)(1-\alpha)} + n.$$

We can now transform the growth rates into gross growth rates by applying the above-described rearrangements.

$$e^{g_{Y,ss}} = e^{\left(\frac{\xi g_{A,ss}}{1-\alpha} + n\right)} \Leftrightarrow e^{\ln G_{Y,ss}} = e^{\left(\frac{\xi \ln G_{A,ss}}{1-\alpha} + \ln G_{H_{Yt}}\right)}$$

$$\Leftrightarrow G_{Y,ss} = G_{A,ss}^{\xi/(1-\alpha)}(1+n)$$

However, we already know the steady state gross growth rate of technology (20) and can express the gross growth rate of output in terms of parameter values and exogenous population growth

$$G_{Y,ss} = (1+n)^{\lambda\xi/[(1-\phi)(1-\alpha)]} \tag{38}$$

Actually, this equation holds only for the assumption of identical technology growth rates, $g_{A^*,ss} = g_{A,ss}$.

Having found the gross growth rate of output means that we also have the rates for capital and consumption.

The Normalized System to Solve

Dividing consumption, capital and output by $A_t^{\frac{\xi}{1-\alpha}} L_t$ one obtains the transformed variables $\hat{c}_t$, $\hat{k}_t$ and $\hat{y}_t$. From the Euler equations (13, 14, 15) we get the following three normalized equations

$$\left(\frac{\hat{c}_{t+1}}{\hat{c}_t}\right)^{\theta} \left(\frac{u_{Y,t+1}}{u_{Yt}}\right) G_{At}^{\frac{\xi(\theta-1)}{1-\alpha}} \left(\frac{\hat{y}_t}{\hat{y}_{t+1}}\right) = \left(\frac{\rho}{1+n}\right) [1 + f'(S_{t+1})(u_{Y,t+1} + u_{A,t+1})] \tag{39}$$

$$\left(\frac{\hat{c}_{t+1}}{\hat{c}_t}\right)^{\theta} \left(\frac{\hat{y}_t}{\hat{y}_{t+1}}\right) \left(\frac{u_{Y,t+1}}{u_{Yt}}\right) = \left(\frac{\rho(g_{At} + \delta_A)}{G_{At}^{(\xi/1-\alpha)(\theta-1)+1}}\right) \left(\frac{u_{A,t+1}}{u_{At}}\right) *$$
$$\left[\frac{\xi\lambda}{1-\alpha} \left(\frac{u_{Y,t+1}}{u_{A,t+1}}\right) + \left(\frac{1-\delta_A}{g_{A,t+1} + \delta_A}\right) + (\phi - \psi)\right] \tag{40}$$

$$\frac{1+n}{\rho} \left(\left(\frac{\hat{c}_{t+1}}{\hat{c}_t}) G_{At}^{\frac{\xi}{(\theta-1)}1-\alpha}\right)\right)^{\theta} = \alpha \frac{\hat{y}_{t+1}}{\hat{k}_{t+1}} + 1 - \delta_k \tag{41}$$

The state variables are described by the laws of motion of the transformed former state variables. The law of motion for human capital is already known

$$S_{t+1} = \frac{S_t}{1+n} + \frac{L_{Ht}}{L_t(1+n)}.$$

It remains the same; S_{ss} is already a constant. The laws of motion for technology and capital, $\hat{k}_t$ are given by

$$T_{t+1} = T_t \left(G_{A^*t}/G_{At}\right)$$
$$\hat{k}_{t+1} = \frac{(1-\delta_k)\hat{k}_t + \hat{y}_t - \hat{c}_t}{(1+n)(G_{At})^{\xi/(1-\alpha)}}$$

10.3.3 Programs from Papageorgiou and Perez-Sebastian (2002)

The following original Gauss programs of the authors are on the CD-version of this Diploma-Thesis. I thank Chris Papageorgiou and Fidel Perez-Sebastian for sending me these files. This enabled me to work with the model. The file 'paramete.val' gives the underlying parameter values. Import these values into the file 'cyalog.1fs', in which the policy functions are approximated. This approximation is done with the help of the Chebyshev polynomial. Once implemented, the steady state values for the growth rates, constant average years of schooling, transformed capital per capita, steady state consumption and the labor shares are needed to calculate bounds for the distance towards the steady state path. To approximte the policy functions of the transformed system, values, that satisfy the Euler equation in several state space points are chosen. The three policy functions are then built up on the basis of the Chebyshev polynomial. The file 'timepath.1fs' then generates the simulation of the time paths. Therefore, you will need estimation results for the coefficients. The asymptotic speed of convergence is calculated, in Mathematica, with the file 'assymsta.nb'. There, the normalized system is calculated and transformed into matrix notation to finally compute the eigenvalues of the Hessian Matrix.

Erklärung zur Urheberschaft

Ich bestätige hiermit, dass ich diese Arbeit selbständig und nur unter Verwendung der angegebenen Quellen und Programme (Eviews4.1, Gauss) angefertigt habe.

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Berlin, 20. Februar 2004.