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An Investigation into the Sources of Economic Growth Differentials Among Nations

John Roppenecker
Wright State University - Main Campus

AN INVESTIGATION INTO THE SOURCES OF ECONOMIC GROWTH DIFFERENTIALS AMONG NATIONS

An internship report submitted in partial fulfillment
of the requirements for the degree of
Master of Science

By

JOHN ROPPENECKER
M.B.A., Wright State University, 2001
M.C.S., University of Dayton, 1989
B.A., William Paterson College, 1982
A.A., County College of Morris, 1979

2002
Wright State University

Wright State University

School of Graduate Studies

Department of Economics

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I hereby recommend that the internship report prepared under my supervision by John Roppenecker entitled An Investigation into the Sources of Economic Growth Differentials Among Nations be accepted in partial fulfillment of the requirements for the degree of Master of Science in Social and Applied Economics.

Dr. Robert Premus
Thesis Director

Dr. Stephen M. Renas
Faculty Reader

Dr. Leonard J. Kloft
Director, Social and Applied
Economics Program

ABSTRACT

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This study was conducted to comprehensively review established growth economics literature, analyze newly revised data sources, and reestimate generally accepted economic growth models using the revised data. Specific findings include the revalidation of the MRW model, discovery of a satisfactory alternative measure of human capital, sensitivity issues when performing Barro-style regressions, and data trends that may have an alarming impact on certain of the growth models.

Reestimation of the MRW model was found to be robust, and satisfactorily explains differences in productivity among nations. Additionally, human capital as measured by the literacy rate of the population was found to be as satisfactory as the secondary schooling participation rate used in the original investigation. Additional measures of human capital that were investigated including life expectancy and per capita educational expenditure were found to be unsatisfactory.

Reestimation of a Barro-style regression was found to be less satisfactory than the reestimation of MRW. The model was found to be highly sensitive to collinearity issues pertaining to sample and time selection. Barro-style models are an important addition to growth theory economics in that they attempt to extend the MRW model with the addition of certain other factors and should not be discounted. They are useful for

establishing economic policies when dealing with specific grouping of countries, rather than the broad generalizations regarding policy that may be derived from the MRW model. From this investigation higher rates economic growth were found among countries with lower fertility rates, lower rates of inflation, and higher, although not the highest levels of democracy.

While no reestimation of any of the endogenous growth models was performed in this project, one empirical finding relating to knowledge production is of concern to both the exogenous and endogenous treatment of technological change. The finding that the rate of per capita knowledge production is declining is a finding that has negative implications for the future. To subscribers to the MRW model of economic growth this means that the time between shifts in total factor productivity will become greater. To subscribers of models incorporating endogenous technological innovation this poses a reduction in the rate of increasing complexity of knowledge, discouraging to the realization of increasing returns to scale.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

I. Introduction

Following the seminal work of Adam Smith, *An Inquiry into Nature and Causes of the Wealth of Nations*, the question of what factors and policies significantly influence the long run growth rates of nations had been of great interest to economists and policy planners. The primary reason for this interest in identifying the economic growth determinants is so selective changes to policy can be made to improve the likelihood of positively affecting the long run growth performance of the nation's economy. Any nation, when presented with the universe of all policy choices, will likely elect to effectuate those policy changes that are forecasted to improve its economic long run growth rate. It is through this selfish pursuit of improving the lot of the nation, that government policy can complement the "invisible hand" to improve economic conditions of the nation's inhabitants.

Much work has been done in the area of economic growth research. There is still a great deal that needs to be done given that the explanatory power of some of the models is not as high as desired. In addition, there have been certain questions and inconsistencies regarding the structure and robustness of existing growth models. This paper was written as a product of a comprehensive investigation into previous and current economic growth literature.

It is an attempt to answer in part, what are the factors that affect the long run growth rates of nations and what are the policies that can be pursued to improve long run economic growth rates of nations, and what are the policies a nation could effect to

improve its long run economic growth performance. The paper is organized as follows. An introduction is presented in section I. Section II presents a historical perspective on the development of economic growth theory from the classical school through modern informal growth regressions. Section III presents the empirical results from regressions on neoclassical and latter models. In section IV, knowledge bases used in regression models and for hypothesis testing include the Penn World dataset, the World Bank's World Development Indicators, and the Freedom House index of freedom dataset. The analysis in this research effort consists of three different investigations. The first examines patterns in national and global levels of per capita GDP, growth in per capita GDP, the productivity level, and growth rate of productivity. The second reviews the levels and distribution of human and knowledge capital. The third assesses how per capita GDP and productivity growth rates are influenced by factors including government's share of GDP, the investment share of GDP, educational investment as a share of GDP, initial levels of per capita GDP, inflation rates, fertility rates, life expectancy, openness, democracy, and literacy.

Section V consists of two parts. The first examines the validity of the Augmented Solow Model by estimating the model with data from the new Penn World dataset. It also investigates various alternate measures of human capital. The second part consists of panel regressions using the factors examined in section IV. Comparisons are made with the regression results of prominent models found in the empirical literature. Finally, section VI consists of a summary and a discussion of the conclusions developed in light of the models' regressions'. A comprehensive annotated bibliography for the primary articles and books used for this project is presented for review.

II. Historical Perspective on Economic Growth Theories

Classical

Adam Smith paved the way for the development of formal classical growth theory as well as new classical economic growth economics when he published his seminal work: *An Inquiry into Nature and Causes of the Wealth of Nations*. Smith, an advocate of the free market system and minimal government intervention, proposed a model of economic growth as a function of physical capital, labor, land, and entrepreneurship[1]. Growth in investment, population, land area, and productivity determined growth in output[2]. Smith proposed that population growth was endogenous, depending on available food and necessities to support growth.[3] He also proposed that capital investment was endogenous, depending on the savings rate, and the entrepreneurial proclivity of businessmen in a profit-oriented economy.

"Every increase or diminution of capital, therefore, naturally tends to increase or diminish the real quantity of industry, the number of productive hands, and consequentially the exchangeable value of the annual produce of the land and labour of the country, the real wealth and revenue of all its inhabitants.... Capitals are increased by parsimony, and diminished by prodigality and misconduct."[4]

According to Smith, growth in land available depends on changes in technology to improve fertility of existing lands, or simply through expansion of available lands by conquest and exploration. Smith also explained how technological progress could improve rates of growth with his famous example of a pin factory employing division of labor as a means to increase productivity. Smith believed that through the specialization

of labor and division of labor economic growth is possible, and that this growth demonstrates increasing returns to scale.

David Ricardo modified the classical model of growth with the concept of diminishing marginal returns. An important difference from Smith's growth model was that the quantity of land was fixed. The consequence of this was that as more land was brought into productive use, the land being brought into cultivation was on the margin of already cultivated lands, hence the term "marginal returns."

The effects of increasing the marginal land utilization are several. First, landowners' rents will rise because of the increasingly limited supply of land, thus reducing the profits of capitalists. Second, wages as measured in goods from agriculture will increase in price over time cutting into profits because workers will demand higher wages to purchase the more expensive goods. It was through these mechanisms that growth is limited. Ricardo did believe that although the limiting process could be delayed through technological innovation, in the long run that growth would cease.[5]

In later publications Ricardo took a far more pessimistic view on machinery and technology. Ricardo stated that machinery and technological innovation, because of their labor saving characteristics, would free labor for employment elsewhere. The problem as he stated was that freed labor might not be readily absorbed in the system because capital would not be freed in a simultaneous fashion so as to match freed labor for productive output purposes. The effect of this unbalanced freeing of labor would be to create downward pressure on wages and income over time.[6] To prevent this process from happening it would be necessary to have increased levels of capital accumulation.

Ricardo's model as described makes no provision for offsetting capital accumulation so it predicts a decline in profits and savings.

Neoclassical Growth Theory

The early classical growth theory as proposed by Adam Smith and modified by other classical economists lost much of its significance in the hands of neoclassical growth economists in the 1950s. Neoclassical writers such as Solow and Swan went to great lengths to deinstitutionalize economic growth theory, developing models that Liu and Premus refer to as "institution free."[7] The Solow model (1956), takes the savings rate, population growth rate, and technological progress as exogenous. The model is represented using a Cobb-Douglas production function with constant returns to scale and diminishing returns to factor input of form

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

where Y is output, K capital, L labor, and A the level of technology. L and A are assumed to grow exogenously at rates n and g:

(2) $$L(t) = L(0)e^{nt}$$

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

A(t)L(t), the effective number of labor units, grows at rate n + g. The model assumes a constant portion of capital, s, is invested. With k as the stock of capital per effective unit of labor, k = K/AL, and y as the level of output per effective unit of labor, y = Y/AL, k's evolution is dictated by

(4) $$\dot{k}(t) = sy(t) - (n + g + \delta)k(t)$$

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

where δ is depreciation. Since the value $g + \delta$ is assumed to be constant at .05 across all nations, (4) implies that k converges to a steady state value k*, which is defined by $sk^{*\alpha} = (n + g + \delta)k^*$ or

(5) $$k^* = [s/(n + g + \delta)]^{1/(1-\alpha)}.$$

This shows that the steady-state capital-labor ratio relates positively to the savings rate and negatively to the population growth rate. Since a central prediction of the Solow model relates to the impact of savings and population growth on real income, we can substitute (5) into (1), take logs and find the steady-state growth in income per capita:

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

An important concept suggested by the neoclassical model is per capita income (output) convergence among nations; nations with lower initial levels of income per capita would approach and finally meet the level of income per capita (output) as the leader. Three types of convergence are possible; no convergence where the nations do not exhibit convergence, absolute convergence where all nations converge on the leading economy at a rate inversely related to their initial per capita income level, and conditional convergence where nations within like groups converge on the leader within that group at a rate inversely related to their initial per capita income level. The Solow model as normally posited does not predict convergence; rather it predicts that income per capita in a country converges to that country's steady-state value. Thus, it follows that nations having similar final steady-state values will exhibit convergence at rates inversely related to their original per capita income levels.

The Solow model as originally presented had poor explanatory power for wide variations in per capita output across nations, explaining only about 60 percent of the variation. Additionally, capital's share of output as suggested by the model was about 60 per cent, much higher than expected. A group of extensions to the Solow model were developed to address these issues. Most significant among these was the Menkiw, Romer, Weil model (MRW) which defines capital broadly to include both physical capital and knowledge, or human, capital. The model was also represented as a Cobb-Douglas production function with the addition of a term for human capital; the equation having form

(7) $$Y(t) = K(t)^{\alpha}H(t)^{\beta}(A(t)L(t))^{1-\alpha-\beta} \qquad 0<\alpha+\beta<1$$

where Y is output, H human capital, K physical capital, L labor, and A the level of technology. With s_k being the fraction of income invested in physical capital, s_h being the portion of income invested in human capita, the evolution of the economy is dictated by

(8a) $$\dot{k}(t)= s_k y(t) - (n + g + \delta)k(t)$$

(8b) $$\dot{h}(t)= s_h y(t) - (n + g + \delta)k(t)$$

where y = Y/AL, k = K/AL, and h = H/AL are quantities per effective unit of labor. This suggests that the economy converges to a steady state defined by equations

(9)

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

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

Substituting (9) into (7) gives an equation for income per capita similar to that developed for the original Solow model

$$(10) \qquad \ln\frac{Y(t)}{L(t)} = \ln A(0) + gt - \frac{\alpha+\beta}{1-\alpha-\beta}\ln(n + g + \delta) + \frac{\alpha}{1-\alpha-\beta}\ln(s_k) + \frac{\beta}{1-\alpha-\beta}\ln(s_h).$$

The explanatory power of this model was much better than the original Solow model. It explains approximately 80 percent of cross-country variations in income and growth rates. Additionally, physical capital's share of output in the model approximated one-third, much closer to its expected theoretical value.

Endogenous Growth Theories

A distinct set of models were developed in parallel with the neoclassical school called "endogenous growth theory". The augmented neoclassical growth explains growth and the income differentials fairly well but there were several criticisms. The most important criticism is that technology is treated as exogenous. Additionally, neoclassical growth theory imposes convergence to a steady state in per-capita income and output. Endogenous growth theories pose no such limitations, but rather suggest a steady-state growth rate of an economy. Models of this type can be divided into three different groups, rival human capital, non-rival human capital, and ideal model.

A. Rival Human Capital

Kenneth Arrow developed one of the earliest endogenous growth theories (1962) when he worked at the RAND Corporation. He noted that the direct labor requirement to build an airframe seemed to fall regularly as a function of cumulative output.[8] This regularity he called the learning curve. His model embodied the hypothesis that the experience of production carries with it an automatic improvement in technology that is known as technological progress. Arrow chose capital investment as the vehicle through

which technical progress occurs. His model concludes that productivity advances rapidly during times of high investment, and very little, if any, during periods of little investment. Even without research and development efforts, the time rate of change in productivity is endogenous because it depends on economic decisions like the decision to invest in capital equipment. The general format for the Arrow model is

(11) $Y = A(K)KL$

where A(K) is the level of technology which is a function of the level of accumulated capital, K = capital, and L = labor. With this function it is possible for capital to accumulate to keep the marginal product of capital from declining to zero.

Rebelo (1991) developed a different endogenous growth model that that is simpler in structure. He modeled economic agents as investing in all forms of capital including physical, human, and knowledge capital. The aggregate production function posited is:

(12) $Y = AK$

where Y = output, A = level of technology, and K = composite of physical, human, knowledge, and other forms of capitals. Because the production function exhibits constant returns to scale there exists no theoretical steady state at which the economy will arrive. Unlike the Solow models, Rebelo's model permits the persistence of long-term growth rates and their differentials among nations.

Romer introduced several different forms of endogenous growth theory. The first (1986) attempted to preserve competitive markets in modeling economic agents in society. He did this by treating new skills and knowledge as an outgrowth of the external economy. Individuals invest in the accumulation of human capital up to the point where

private returns equal private costs. Since people can acquire knowledge and skills from sources outside the firm as the economy expands, productivity increases. This enhancement to productivity Romer suggests could be sufficient to offset diminishing marginal returns to capital, allowing indefinite growth.

The various versions of endogenous growth theories hold the common premise that human capital is a rival good. Individuals are free to acquire the benefits of knowledge by working, or through activities external to the firm. Growth researchers can then assume competitive markets when modeling growth processes of individuals and firms. This implies the resulting equilibrium will be efficient and the endogenously determined economic growth rate will be optimal.

B. Non-rival Human Capital Models

An alternative to the rival capital models proposed by Lucas (1986) views the benefits from new knowledge as only partially excludable. This means that economic agents who invest in knowledge capital are able to capture only a fraction of their private investments in the development of new knowledge. Consequentially, that portion of knowledge that is not captured is disseminated to the remainder of society. The advantage to this model is that it preserves the incentive to invest, while allowing for the enhancing effect of knowledge formation to benefit other than those who invested. If the benefits from new knowledge were not excludable at all, then this would be a pure public good requiring the public sector to finance the education and training necessary to achieve economic growth. The production function that best describes the Lucas model is

(13) $$Y = KL$$

where Y is output, K the level of capital where capital is broadly defined to include human capital, and L is the labor force. It is interesting to note because knowledge is embodied in human capital, population in the Lucas model is not contrary to growth in per capita output and income, as it is in other models.

C. Ideas Models

Romer (1990) proposed an endogenous growth model free of the presumption of competitive markets. Economic growth is based on the notion that new ideas are the feedstock of technological progress. Technological progress consists of finding new varieties of capital goods. Economic agents invest in the production of new knowledge only to the extent that they can be certain that they can receive an adequate rate of return on their investment. This model assumes monopolistic competition and the private incentive to invest. This model supports the idea of a non-competitive equilibrium where on-going growth in per capita income is sustained through technological progress, with capital growing without limit along the equilibrium trajectory. The production function describing the 1990 Romer model is

$$Y = H_{\gamma}^{\alpha} L^{\beta} \sum_{i=1}^{N} x_j^{1-\alpha-\beta} \tag{14}$$

where Y is output, H_{γ}^{α} is the portion of human capital dedicated to producing output, L^{β} is the amount of raw labor, and the remaining term the sum of all varieties of output. It is through the increasing level of varieties of capital goods that the effects of diminishing marginal returns to capital are avoided.

A subsequent work by Sorensen (1999) extends the Romer model to explain economies in transition. His model is a takeoff on the 1990 Romer model that is extended with human capital accumulation. Designs for intermediate products are

developed in a research and development sector. Patents for these intermediate designs are sold to intermediate producers who issue shares to raise capital for production. Final goods are produced using the intermediate goods and human capital. The model's technology is such that the formation of higher levels of human capital creates increased demands for intermediate goods and larger intermediate markets. The model also includes a learning sector where skills are accumulated. It is through this continuous accumulation of human capital that research and development investments become attractive. The point at which the profitability of research and development activities becomes attractive is called a regime shift, explaining investing behaviors by firms in those economies.

Growth Regressions

Cross-country panel regressions have been estimated to explain the disparities in the distribution of growth rates across nations. This area of research has been of keen interest to economists since the early 1990s. Researchers have examined the influence of factors such as fertility, saving rates, rule of law, degree of openness, education and training, investment in R&D research, and others in terms of how they correlate to the growth process. The most significant of these investigations was performed by Barro (1991, 1997), Barro and Lee (1991, 1994), Barro and Sala-I-Martin (1992, 1995), and Barro and Spiegel (1994). The general format for the system of equations used in the regressions is

$$\Delta Y_1 = \beta_0 + \beta_1 X_{11} + \ldots + \beta_N X_{1N}$$

$$\vdots$$

(15) $$\vdots$$

$$\Delta Y_M = \beta_0 + \beta_1 X_{M1} + \ldots + \beta_N X_{MN}$$

where the ΔY terms represent the rate of growth in GDP for a set time frame, and the remaining independent variables are state variables representing factors under investigation as well as instrumental variables.

One criticism of this approach to identifying the determinants of economic growth is that it is too simplistic. Additionally, some of the regressions that have been performed have had serious issues with multicollinearity. A specific case of this is the issue raised in the Barro-Lee regressions that shows female education negatively correlated to growth in income levels. Lorgelly and Owen (1999) attribute this to the fact that several Asian nations having highly educated female populations do not provide the social structure so women can contribute effectively to production. In their regressions they use a dummy for Asian nations that were suspected of exhibiting this property, and the coefficients for education were no longer found to be statistically significant in determining economic growth.

Observations and conclusions

It seems that growth economics has gone full circle. Adam Smith posited an economy whose growth rate was determined by endogenous and exogenous factors. Later neoclassical models created elaborate mathematical frameworks that attempted to explain growth rates and convergence in income and output levels across nations simply as a function of saving and population rates' differences. Finding the neoclassical models insufficient, researchers developed the so-called endogenous growth models that enhanced the neoclassical model in a number of different ways. Even these endogenous

growth models have had their critics, specifically arguing that some do not properly model for the complementarity of human and physical capital[9] and they falsely predict a much higher than observed growth rate. It was to overcome these criticisms that the so-called panel regressions were developed to identify specifically which are the factors that affect levels of income and productivity.

III Review of Empirical Approaches

Neoclassical Models

The classic Solow model has been regressed many times by different investigators. Several different regressions of the classic Solow equation were performed using OLS, of which one is presented. The representative statistical results are provided in Table 1.

Table 1: Estimation of the Classic Solow Model[10]

Dependent variable: log GDP per working-age person in 1985	
Sample:	Non-oil
N:	98
CONSTANT	5.48
	(0.0008)
ln(I/GDP)	1.42
	(0.0000)
$ln(n + g + \delta)$	-1.97
	(0.0007)
F	70.79
	(0.0000)
$\overline{R}^2$	0.590
Restricted regression:	
CONSTANT	6.87
	(0.0000)
ln(I/GDP) - $ln(n + g + \delta)$	1.48
	(0.0000)
F	140.58
	(0.0000)
$\overline{R}^2$	0.59
Test of restriction:	
ρ-value	0.38
Implied α	0.60

Note: ρ statistics are in parenthesis. The investment and population growth rates are averages for the period 1960-1985. $(g + \delta)$ is assumed to be 0.05.

Note that the saving (*ln*(I/GDP)) and population ($ln(n + g + \delta)$) coefficients are of the expected sign and the anticipated magnitude. The estimated value for α is .60, which

implies that physical capital's share in output is approximately sixty percent. This is too high, which suggests that the textbook Solow model may be incorrect. Also important to note is that the adjusted R^2 value is less than 60 percent, showing that this model leaves more than 40 percent of the differences in output productivity unaccounted for.

The statistics presented for the augmented Solow model are from the 1992 Mankiw, Romer, and Weil paper "A Contribution to the Empirics of Economic Growth." Several different regressions of this model were performed using OLS, of which one is presented. The representative statistics being

Table 2: Estimation of the Augmented Solow Model[11]

Dependent variable: log GDP per working-age person in 1985	
Sample:	Non-oil
N:	98
CONSTANT	6.89
	(0.0000)
ln(I/GDP)	0.69
	(0.0000)
$ln(n + g + \delta)$	-1.73
	(0.0000)
ln(SCHOOL)	0.66
	(0.0000)
F	115.64
	(0.0000)
$\overline{R}^2$	0.780
Restricted regression:	
CONSTANT	7.86
	(0.0000)
ln(I/GDP) - $ln(n + g + \delta)$	.73
	(0.0000)
ln(SCHOOL) - $ln(n + g + \delta)$	.67
	(0.0000)
F	172.95
	(0.0000)
$\overline{R}^2$	0.78
Test of restriction:	
ρ-value	0.41
Implied α	0.30
Implied β	0.28

Note: ρ statistics are in parenthesis. The investment and population growth rates are averages for the period 1960-1985. $(g + \delta)$ is assumed to be 0.05.

Note that the saving (*ln*(I/GDP)), human capital investment (*ln*(SCHOOL)) and population (*ln*($n + g + \delta$)) coefficients are of the expected sign and of approximately the correct magnitude. The implied values for α and β are approximately 1/3, which much more closely approximates the expected share values for physical and human capital. The adjusted R^2 value is now almost 80 percent, much improved over the textbook Solow model. This shows that adding a broad definition of human capital has far better explanatory power than the classic Solow model.

Endogenous Growth Models

An endogenous growth model that was subjected to good empirical research and modeling on is the general model proposed by Lucas (1986). Specifically the model was used by Asteriou and Agiomirgianakis in their 2001 paper "Human capital and economic growth time Series Evidence from Greece" to show the effects of education on economic growth. The authors employ a technique of Johansen integration with a series of Granger causality tests to examine the validity of different hypothesis. The statistical findings are:

Table 3: Johansen Cointegration Procedure Results[12]

Tests for cointegration between education and GDP

		Trace test				
		Prim	Sec	Higher	Expend	
H_0	H_a	Statistical value				Critical Value
r=0	r>=1	42.66*	37.25*	41.88*	27.64*	13.75
r=1	r>=2	4.94	3.24	4.57	2.15	7.52

GDP=GDP Per Capita; PRIM=enrollment in higher education; SEC=enrollment in secondary education; HIGHER=enrollment in higher education; EXPEND=public expenditures in education over total expenditures.

* = Significant at the 5% level.

Table 4: Granger Causality Test Results[13]

Causality test results

Null hypothesis	Obs	F(4,30) Statistics
PRIM growth does not cause growth GDP	40	6.254*
GDP growth does not cause growth PRIM	40	0.001
SEC growth does not cause growth GDP	40	4.589*
GDP growth does not cause growth SEC	40	0.004
HIGHER growth does not cause growth GDP	40	1.073
GDP growth does not cause growth HIGHER	40	2.748*
TOTAL growth does not cause growth GDP	40	2.950*
GDP growth does not cause growth TOTAL	40	0.278
EXPEND growth does not cause growth GDP	40	3.218*
GDP growth does not cause growth EXPEND	40	1.789

GDP=GDP per capita; PRIM=primary school enrollment; SEC=secondary school enrollment; HIGHER=enrollment in tertiary education; TOTAL=enrollment in all levels of education; EXPEND=public expenditures in education over total expenditures.

* Denotes the rejection of the null hypothesis of causality. Critical value for F(4,30) being 2.69.

The Granger causality tests refute the null hypotheses that primary education, secondary education, total education, and educational expenditures do not cause GDP growth. Similarly, the null hypothesis that growth in GDP does not cause growth in higher education levels is refuted. The implications of these finding are that expenditures on education and total educational attainment -- specifically primary and secondary education -- are important contributors to economic growth. Similarly, higher levels of economic growth contribute to growth in educational attainment at the tertiary level.

Growth regressions

Barro and others have formulated a number of different models that are families of equations that attempt to correlate growth in GDP against numerous factors. The model presented in Table 5 is a family of three equations regressed using three stage least square with different instrumental variables for each equation. The signs of the

Table 5: Barro Cross-Country Panel Regression[14]

Dependent variables: growth rate per capita real GDP 1965-1976, 1975-1985, 1985-1990	
N	80, 87, 84
Constants	Not specified
ln (GDP)	-0.0225
	(0.0032)
Male secondary and higher education	0.0098
	(0.0025)
ln(life expectancy)	0.0418
	(0.0139)
ln (GDP)*male schooling	-0.0052
	(0.0017)
ln (fertility rate)	-0.0135
	(0.0053)
Government consumption ratio	-0.115
	(0.0270)
Rule of law index	0.0262
	(0.0055)
Terms of trade change	0.127
	(0.0300)
Democracy index	0.094
	(0.0270)
Democracy index squared	-0.091
	(0.0240)
Inflation rate	-0.039
	(0.0080)
Sub-Saharan Africa dummy	-0.0042
	(0.0043)
Latin America dummy	-0.0054
	(0.0032)
East Asia dummy	0.005
	(0.0041)
$\bar{R}^2$	.60, .52, .47

Note: s.e. values are in parenthesis beneath the applicable coefficient.
The instrumental variables include the five-year earlier value of log(GDP) as well as earlier values of all the independent variables except the inflation rate.

coefficients are as expected. The R^2 values are not as great as in other models, but that the regression analysis is being performed across and within countries over time. A criticism of Barro's research is that the correlation coefficient matrix is not presented for evaluation.

IV Data Analysis

This chapter introduces the various data sources used in this research investigation. Following the description of the data sources, detailed data analysis is presented with particular attention to identifying inter-country trends in real GDP per capita, human capital formation and distribution, and knowledge capital formation and distribution, as well as other factors.

Review of Data Sources

The sources of data used in this paper include the World Bank's World Development Indicator 2001 Dataset, the University of Pennsylvania's Penn World 6.0 dataset (1998), and the Freedom House organization's Index of Freedom (2001). From these sources a dataset consisting of 22 variables for 109 countries is constructed for the period 1960 through 1995.

A. The World Development Indicators Dataset

The 2001 World Development Indicators dataset by the World Bank is a comprehensive set of 559 variables for 209 countries for the period of 1960 through 1999. The dataset has a great deal of sparseness in its contents and thus can only provide continuous data for subsets of countries for certain years. This source proved to be useful to in evaluating trends in knowledge capital and human capital measures over time.

B. Penn World 6.0

The 1998 Penn World 6.0 dataset was constructed by the University of Pennsylvania and consists of 20 variables for 207 countries for the period of 1950 through 1998. The dataset also suffers from having a great deal of sparseness in its content and thus can only provide continuous data for subsets of countries for certain years. This source is used to evaluate trends in real per capita GDP levels, per capita GDP growth rates, degree of openness, and GDP shares of private consumption, investment, and government consumption. Earlier versions of this dataset (PWT 4.0, 4.5, 5.0, and 5.5) were used by Summers and Heston and Barro *et. al.* in their regressions. Since the original version's release measurement techniques have been improved and many of the earlier versions' values for the time series have been examined and in some cases substantially revised. It is because of the changes in measurement and the corrective processes that this version rather than the next latest Penn World version 5.6 is used in this study.

C. Freedom House Index of Freedom

The 2001 Freedom House Index of Freedom is a collection of time series on 207 nations from 1973 through 2001 that measures levels of political rights and civil liberties in those nations. Both measures are given numerical values with 1 indicating most free and 7 most repressive. This dataset is a continuation of the Gastil Index that has been used by earlier researchers in their investigations and the method of its derivation has changed little since the earlier Gastil publications. The Freedom House Index of Freedom is a good source to evaluate trends in real per capita GDP growth rates in relation to levels of democracy.

Data Trends

Four types of analyses were conducted. The first attempted to identify time trends in national and global real per capita GDP levels and the growth rates thereof. The second sought to identify time trends in national and global levels of worker productivity and the growth rates thereof. The third sought to identify time trends in human and knowledge capital formation and distribution. The last sought to identify trends in per capita GDP and worker productivity relative to other factors.

A. Patterns in Real Per Capita GDP

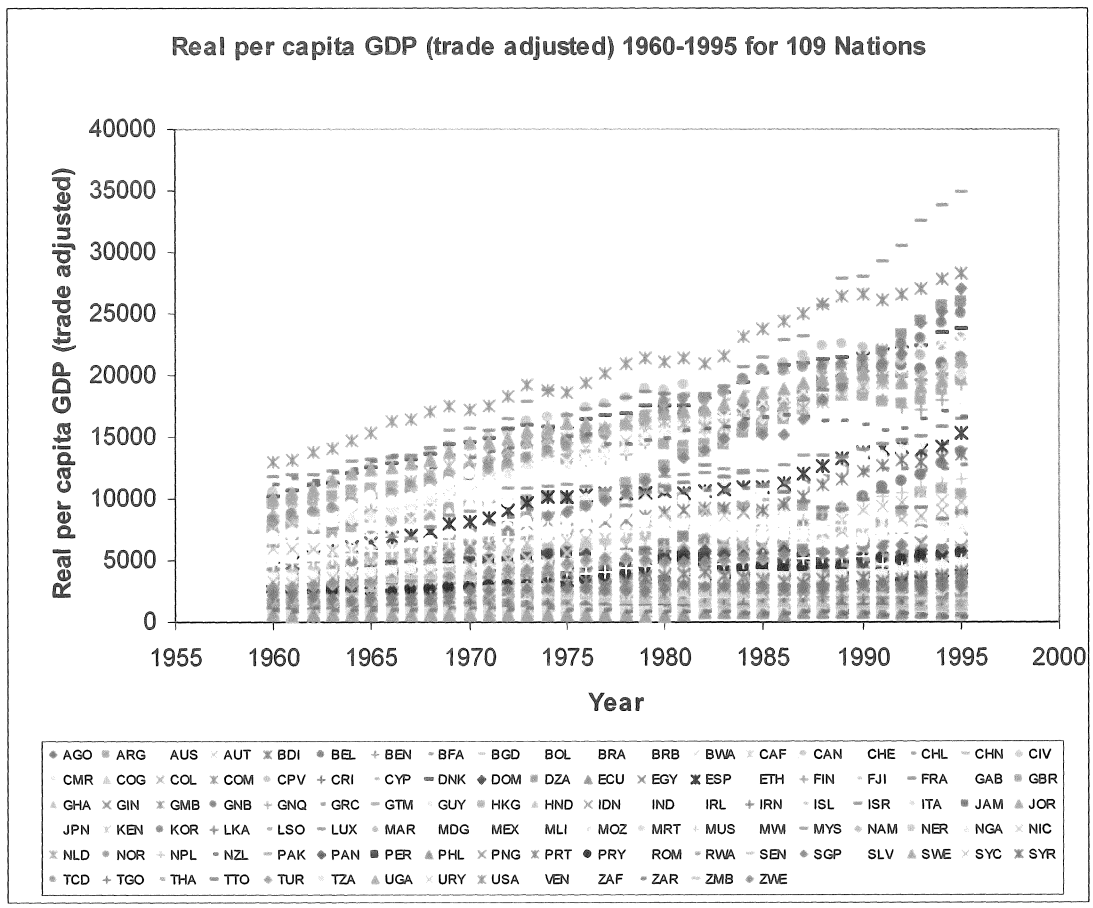
Several trends are explored with regards to real per capita GDP. Specifically, they are:

- the pattern of real per capita GDP by nation over time;
- the pattern of real per capita GDP growth by nation over time;
- the pattern of real per capita GDP globally over time;
- the pattern of real per capita GDP growth globally over time;
- whether conditional convergence as posited by the neoclassical model is demonstrated by the newer revised data.

Growth in the 109 countries in the Penn World 6.0 dataset that had continuous data for the real per capita GDP was examined for the period 1960 through 1995. The real per capita GDP variable RGDPTT is adjusted for changes in the terms of trade. This variable compares favorably with the PPP adjusted real per capita GDP provided in the World Development Indicators dataset.

Figure 1 presents trends in real per capita GDP for the period 1960-1995. No evidence was found of absolute convergence among the nations, but the pattern exhibited was suggestive of divergence within the group. Also to be noted is the sudden and rapid distancing movements made by Luxembourg in the mid 1980s that placed it in the lead position among the nations of study by 1990. Until the breakaway pattern by Luxembourg , Switzerland and the USA held for the lead position

Figure 1: Real per capita GDP 1960-1995 for 109 Nations



in per capita GDP.

Figure 2 presents nations with demonstrated growth rates of real per capita GDP of between –40 and 60 percent annually. The great majority of country growth rates were

in the range of –10 to 10 percent annually. The pattern and spread of growth rates by nations appears to be normally distributed within and across time periods.

Figure 2: Growth in real per capita GDP 1960-1995 for 109 Nations

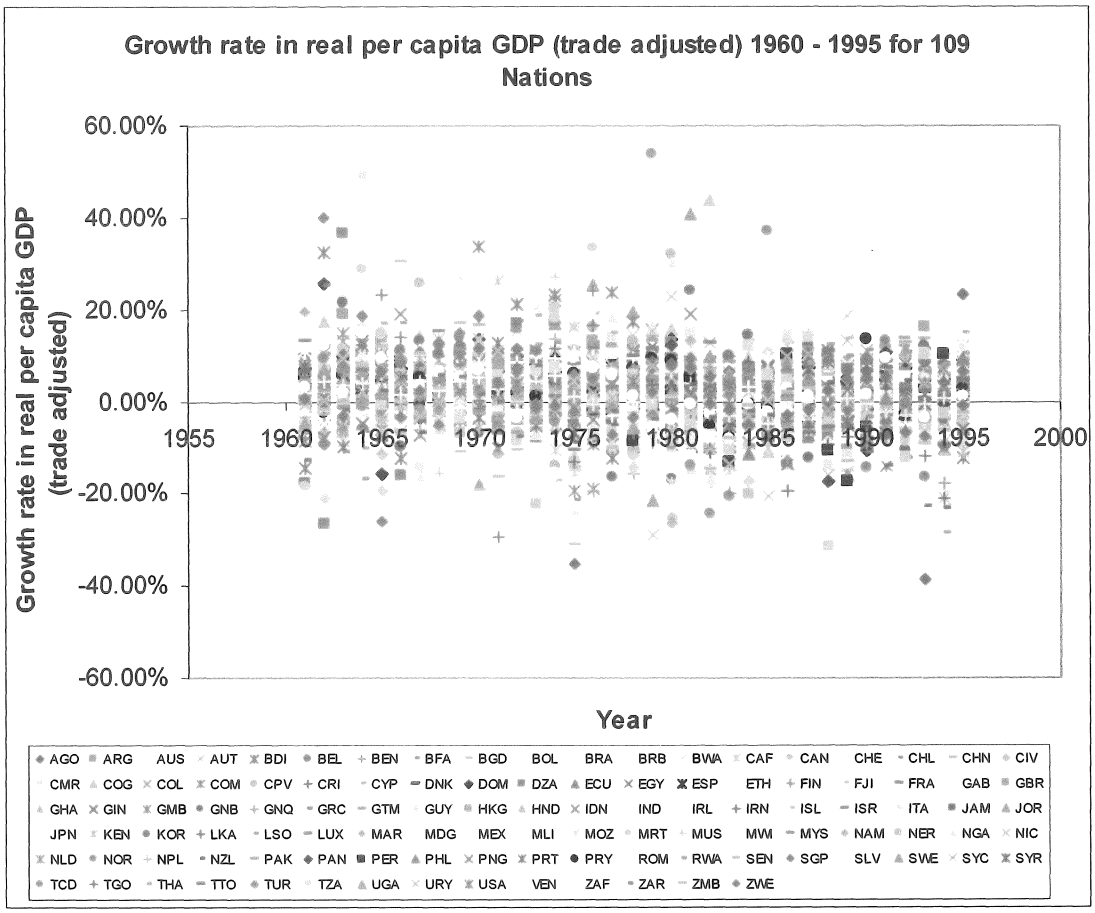
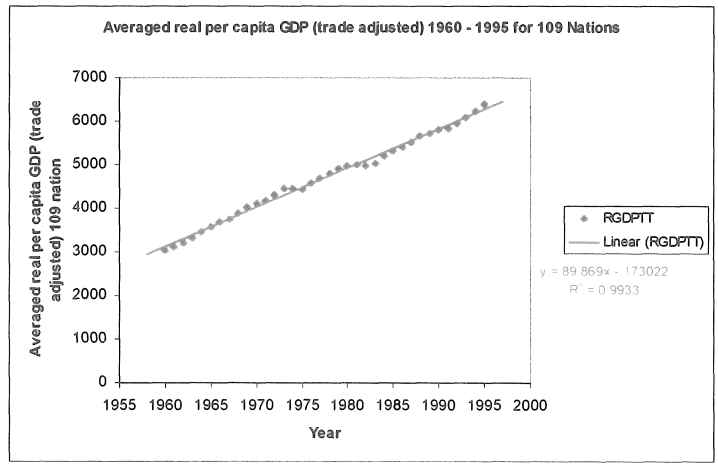


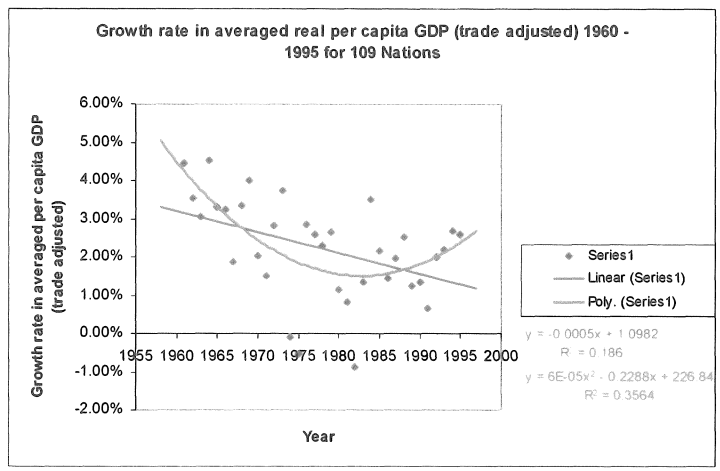
Figure 3, the averaged global real per capita GDP for the period 1960-1995, shows that world per capita real GDP more than doubled in 35 years. A linear trend line drawn through the data shows a positive slope and a high R^2 value. The annual rate of increase[15] in global real per capita GDP for the period was 2.16%.

Figure 3: Averaged real per capita GDP 1960-1995 for 109 Nations



An interesting change in the pattern of world economic growth was detected. Figure 4 showed the growth rate is best represented by a quadratic trend line[16] implying that the global slowdown in real per capita GDP after 1973 is beginning to reverse.

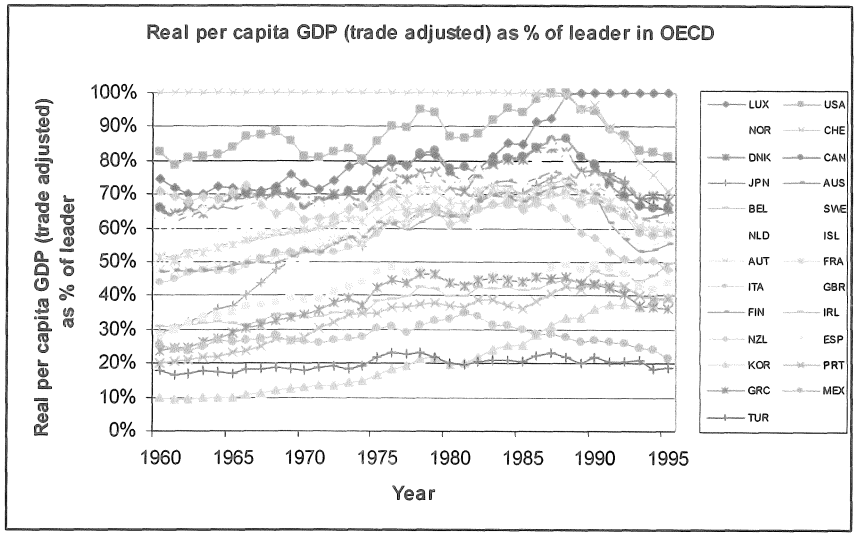
Figure 4: Growth rate in averaged real per capita GDP 1960-1995 for 109 Nations



Evidence of the neoclassical model's concept of conditional convergence is explored using evidence from 109 countries for which continuous GDP data for 1960-1995 are available. Specific groups of nations include the OECD countries[17], South American countries, and African countries. For each group of countries the ratio of a

country's real per capita GDP to the real per capita GDP of the leader in the group was calculated. OECD data in Figure 5 shows evidence of convergence among the OECD

Figure 5: Real per capita GDP as % of leader in OECD Nations



nations. However, data for South America, Figure 6, does not show evidence of convergence in real per capita GDP levels across the nations. Some nations converge and other nations diverge relative to the leader. The picture for Africa, shown in

Figure 6: Real per capita GDP as % of leader for South American Nations

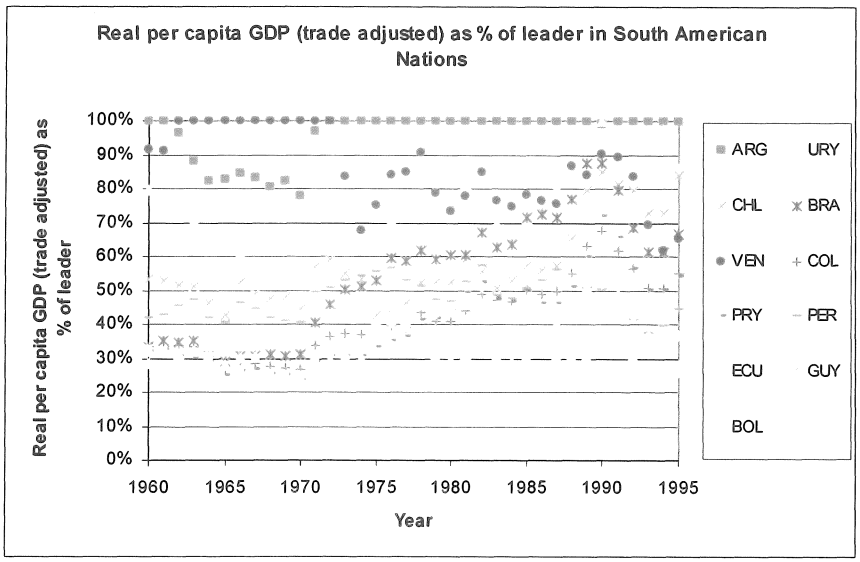
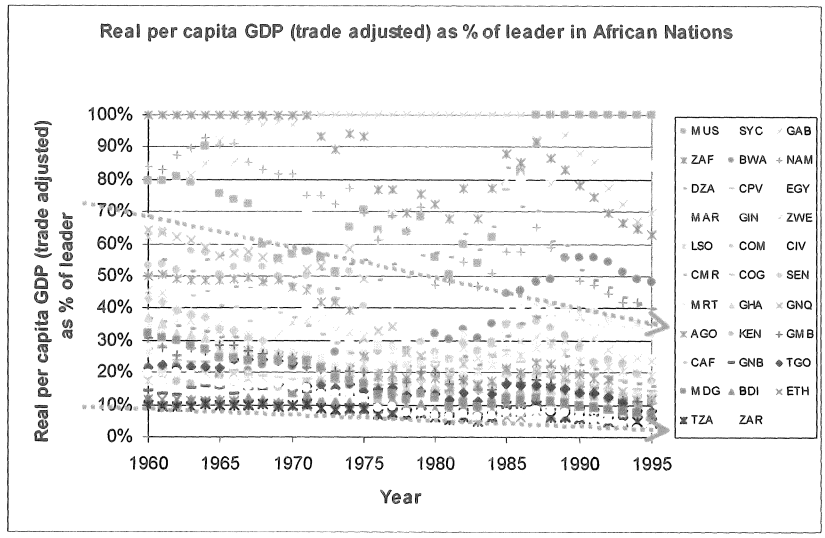


Figure 7, is considerably more complex. There is divergence in real per capita GDP levels. However, the chart shows that African nations exhibit a convergence among themselves.[18]

Figure 7: Real per capita GDP as % of leader in African Nations



B. Patterns in Productivity

This section attempted to document global trends in productivity growth. The most significant trends are:

- the level of productivity for each nation over time;
- the pattern of productivity growth by nation over time;
- the level of productivity globally over time;
- the pattern of productivity growth globally over time;
- conditional convergence as posited by the neoclassical model using the newer revised data.

The data examined in these investigations was for the 106 countries that had both real per capita GDP growth information as well as worker population information. The real per

capita GDP variable used is the RGDPTT from the Penn World 6.0 dataset. This was multiplied by the ratio of national population to national workers from the World Development Indicators dataset to arrive at a trade adjusted real GDP per worker.

Figure 8 presents the trends in real GDP per worker for the period 1960-1995 for 106 nations. No evidence was found of absolute convergence between the countries. A sudden, rapid distancing move by Luxembourg in the mid 1980s was observed. This placed it as the leader in 1990 eclipsing the previous leaders of Switzerland and the USA.

Figure 8: Real GDP per worker 1960-1995 for 106 Nations

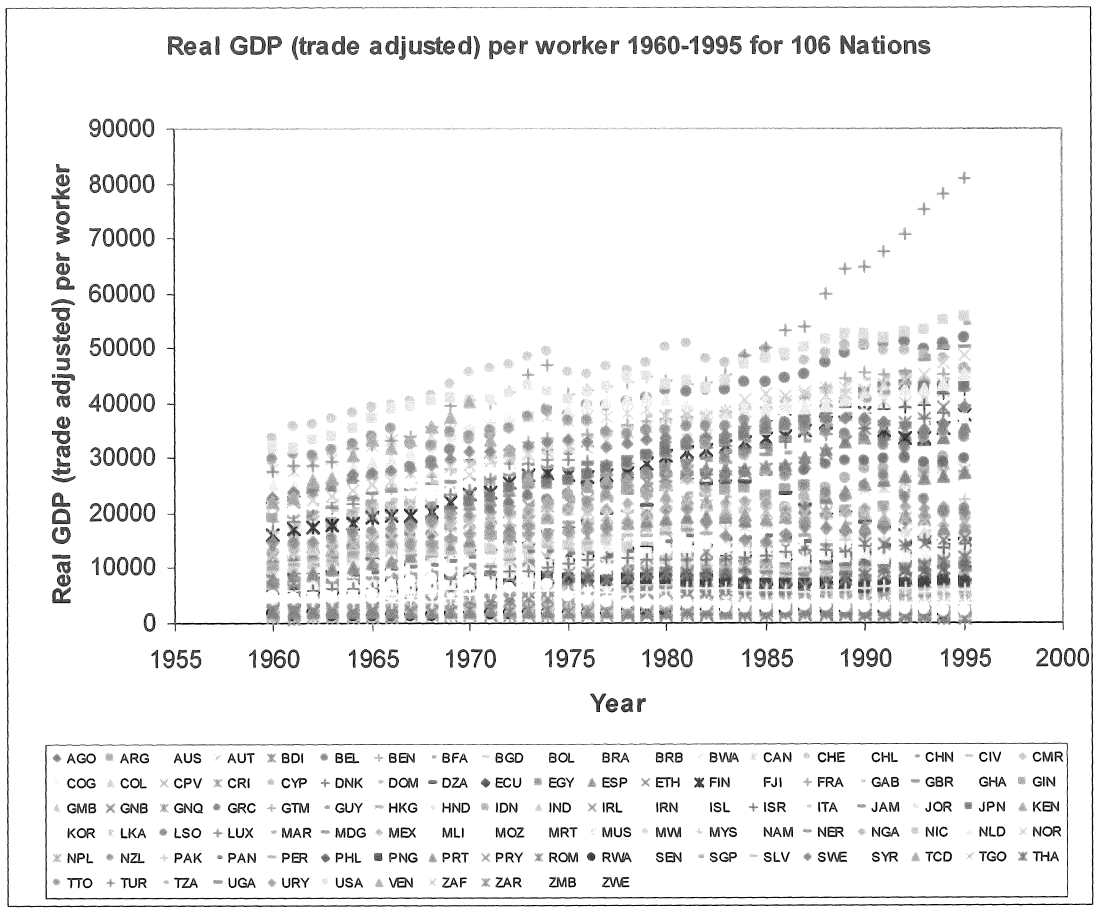


Figure 9 shows that the nations exhibited growth rates of real GDP per worker between –40 and + 60 percent annually, the majority being within –10 and 10 percent annually.

Figure 9: Growth in real GDP per worker 1960-1995 for 106 Nations

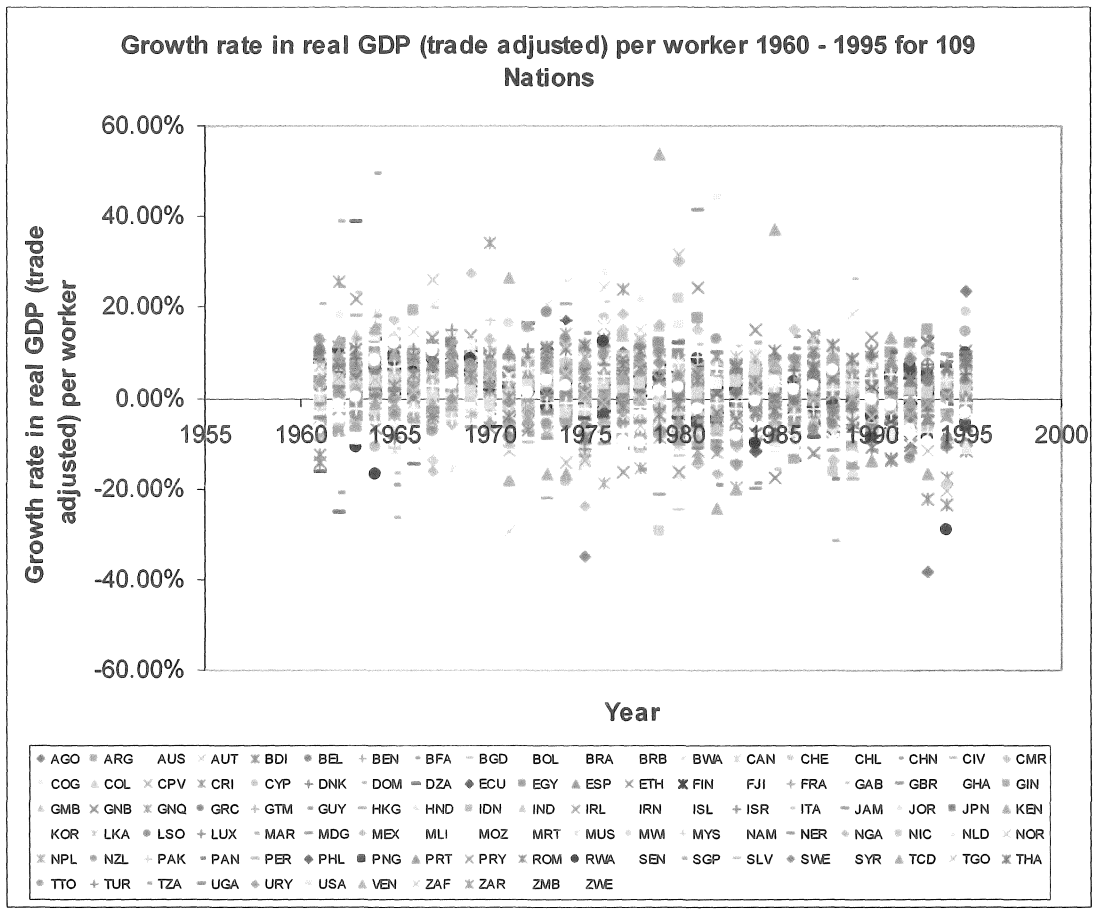
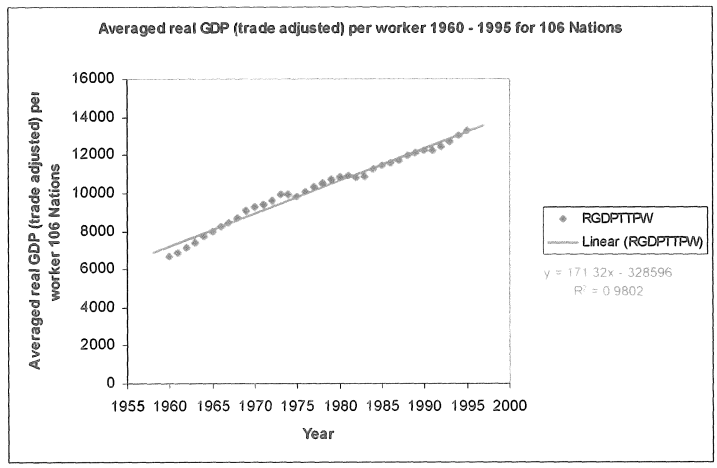


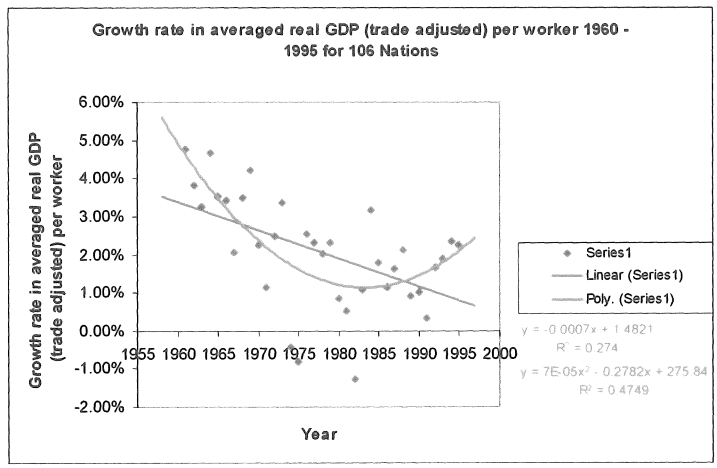
Figure 10 shows that the averaged real GDP per worker for the period 1960-1995 increased significantly, with global productivity almost doubling in 35 years. A trend line through the data shows a strongly positive slope with a very high R^2 value. The annual rate of increase in global real GDP per worker in the period is 1.98%.

Figure 10: Averaged real GDP per worker 1960-1995 for 106 Nations



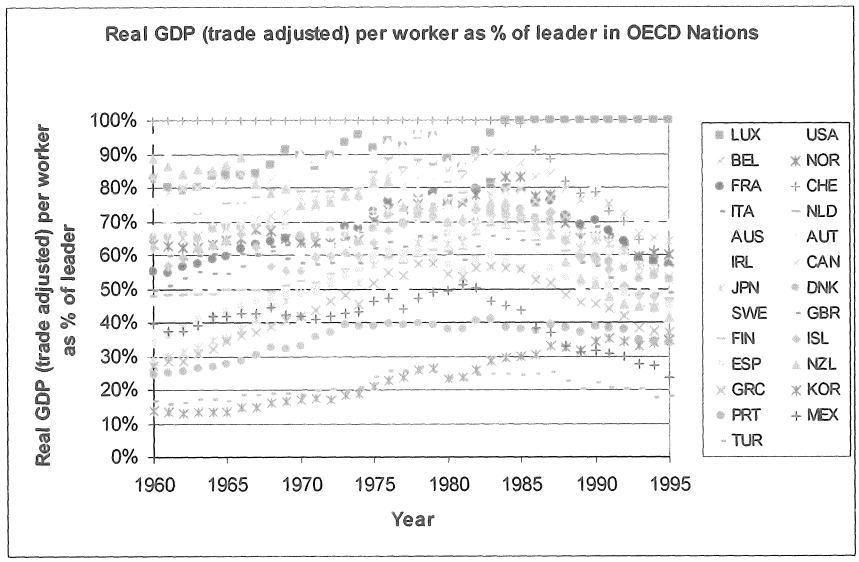
An important change in global productivity patterns was found. Figure 11 shows the growth rate is best fit by a quadratic trend line suggesting that the global slowdown in productivity growth that began after 1973 is beginning to reverse. Evidence of the

Figure 11: Growth rate in averaged real GDP per worker 1960-1995 for 106 Nations



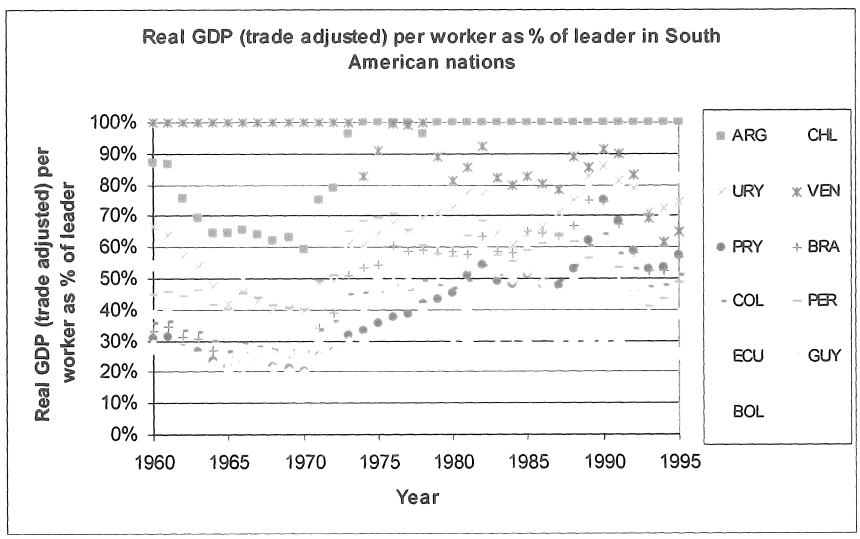
neoclassical model's concept of convergence is explored using information for the 106 countries with continuous data. The groups include the OECD nations, South American countries, and the African countries. The OECD group in Figure 12 shows convergence

Figure 12: Real GDP per worker as % of leader in OECD Nations



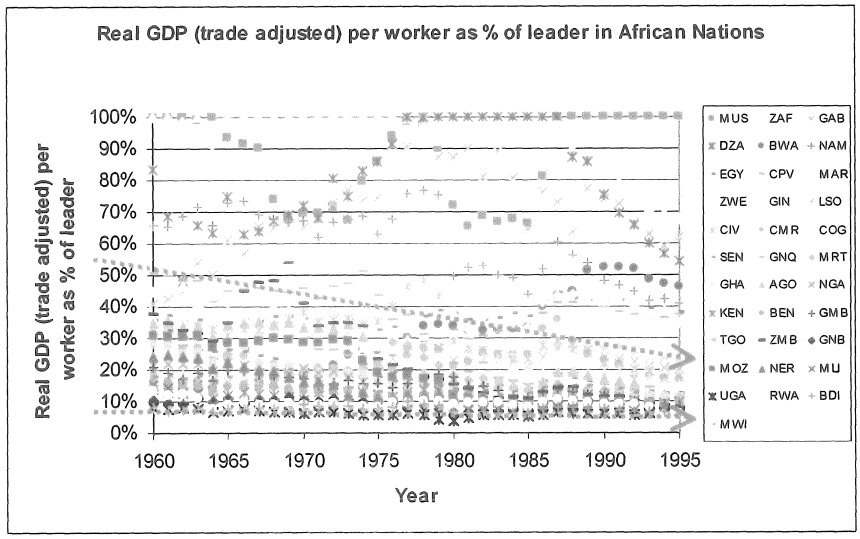
in productivity levels among the nations. However the South American nations, Figure 13, does not show convergence in real per worker GDP levels.

Figure 13: Real GDP per worker as % of leader in South American Nations



The picture for the African nations, Figure 14, is more complex. The nations show divergence in real per worker GDP levels. However, the bottom two thirds of the nations exhibit a declining convergence within themselves.

Figure 14: Real GDP per worker as % of leader in African Nations



C. Patterns in Human and Knowledge Capital

This section documents trends in human and knowledge capital growth and distribution over time. The significant trends investigated include:

- whether per capita human capital is increasing over time;
- whether there is a trend towards more uniform human capital distribution;
- whether knowledge capital is increasing;
- whether there is a trend suggesting more uniform formation rates of knowledge.

Several human capital and knowledge capital variables are available from the World Development Indicators dataset. Scientists and engineers per million population, and literacy rates where selected as measures of human capital. The number of scientific and journal articles was selected as the measure of knowledge capital.

Figure 15, scientists and engineers per million population, and Figure 16, smoothed literacy rates 1980, 1985, 1990, 1995 suggest human capital formation.

Figure 15: Scientists and engineers per million population 1980 - 1997

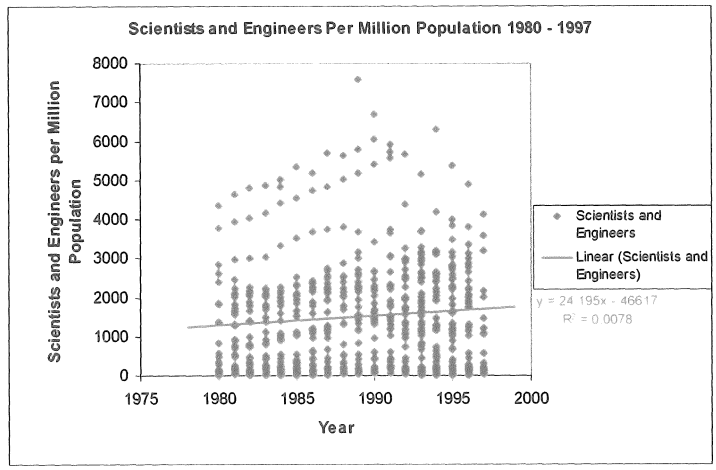
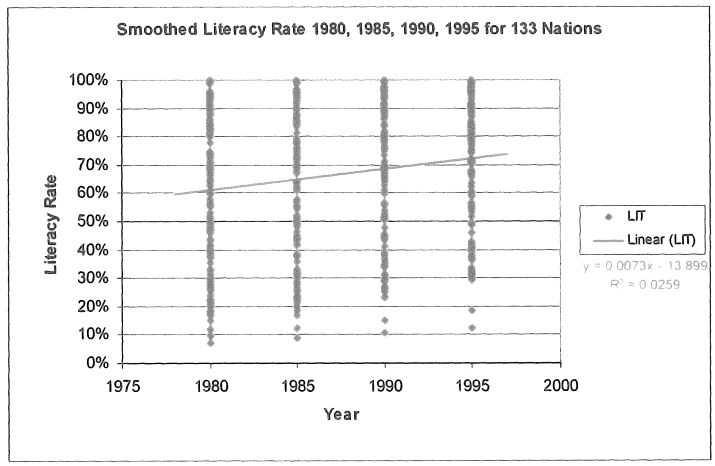
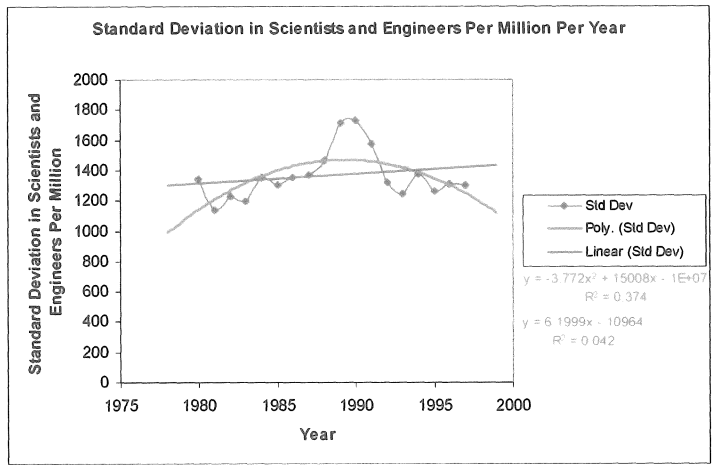


Figure 16: Smoothed Literacy Rate 1980, 1985, 1990, 1995 for 133 Nations



To identify if the distribution of human capital is becoming more uniform over time, annual standard deviations of the selected measures of human capital were calculated and plotted over their corresponding time periods. Figure 17 presents the standard deviation in scientists and engineers per million population by year. A quadratic trend line is the best fit for the data. This suggests that some process or event caused an irregularity in human capital distribution in the late 1980s. This perturbation has since abated, and the human capital distribution of human capital globally has become more uniform.

Figure 17: Standard Deviation in Scientists and Engineers per Year



The standard deviation of the literacy rate, Figure 18, is best fit by a linear regression line. The trend line shows a negative slope with a very high R^2 value. This suggests that human capital as measured by literacy rates is becoming more evenly distributed.

Figure 18: Stdevp(Smoothed Literacy Rate) 1980, 1985, 1990, 1995 for 133 Nations

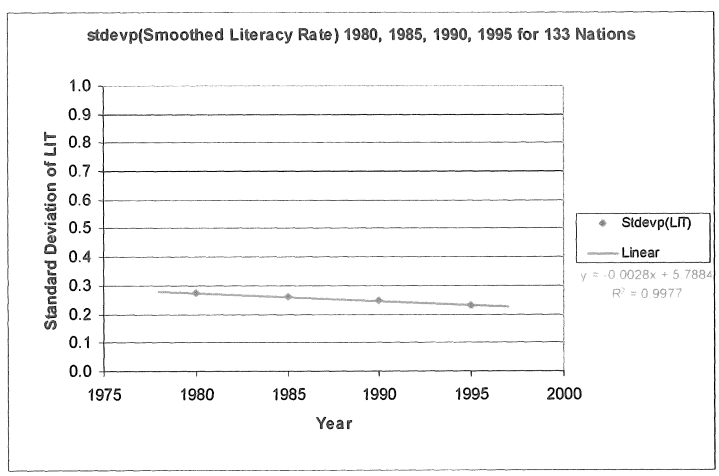
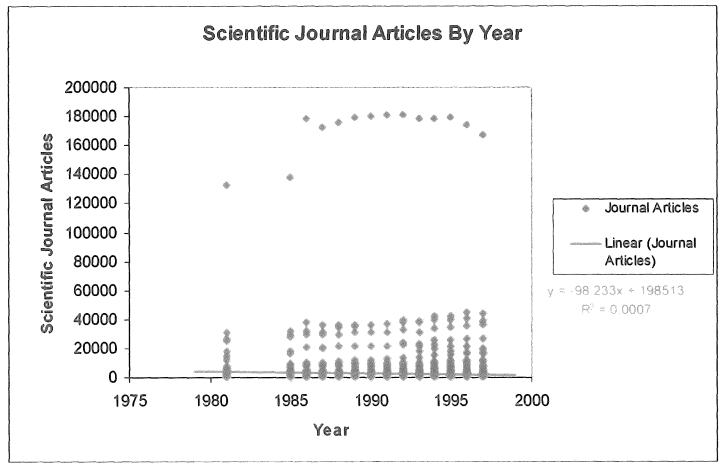


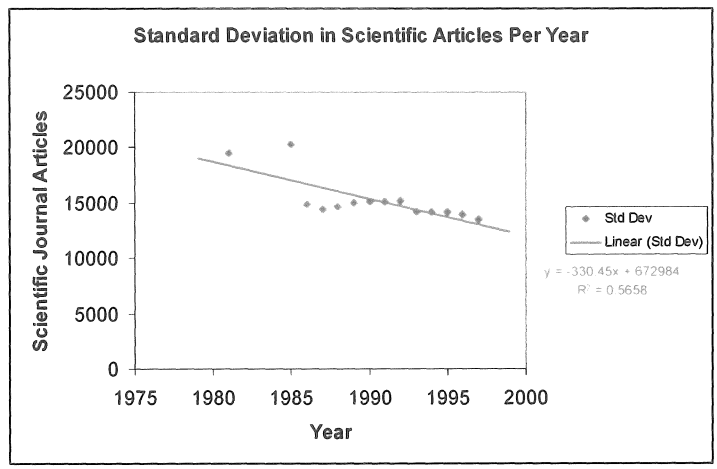
Figure 19 shows the number of scientific journal articles for 1981-1997. A negatively sloped linear trend line is the best fit for the data. This indicates that the levels of knowledge capital formation are declining among the nations. Analysis of the

Figure 19: Scientific Journal Articles by Year



distribution of knowledge capital is shown in Figure 20. A negatively sloped linear trend line is the best fit for the data. This suggests that the level of knowledge capital formation is becoming more uniform across all countries.

Figure 20: Standard Deviation in Scientific Journal Articles



D. Other Factors and Growth in Per Capita GDP and Productivity

This section details the influence of certain factors on real per capita GDP and productivity growth rates. Specific factors investigated include:

- government share of GDP,
- investment share of GDP,
- per capita educational investment,
- literacy rates,
- variability in literacy rates,
- initial per capita GDP levels,
- inflation rates,
- variability in inflation rates,
- fertility rates,
- life expectancy,
- openness, and
- democracy.

The real per capita and per worker GDP values are those that were discussed previously. The government shares, investment shares, and openness data are from the Penn World dataset. Democracy is measured by the GASTIL index, which is an average of the Political Freedom and Civil Liberties index values provided by the Freedom House dataset. All other data is from the WDI, or derived from the WDI.

Partial regressions of government share of GDP versus per capita/per worker GDP growth rates in Figure 21 and Figure 22 show the expected negative relationship.

Figure 21: Government share of GDP versus growth rate in real per capita GDP

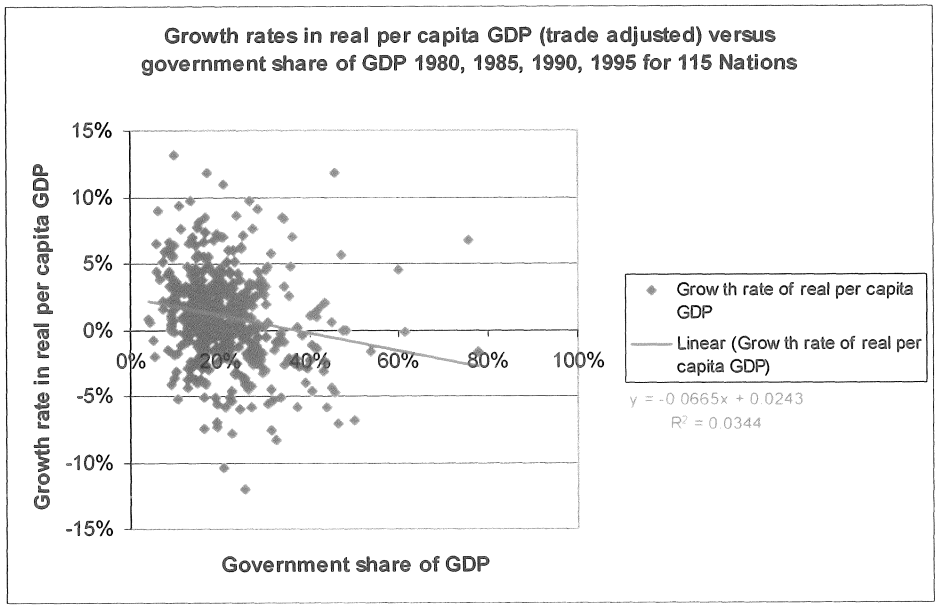


Figure 22: Government share of GDP versus growth rate in real per worker GDP

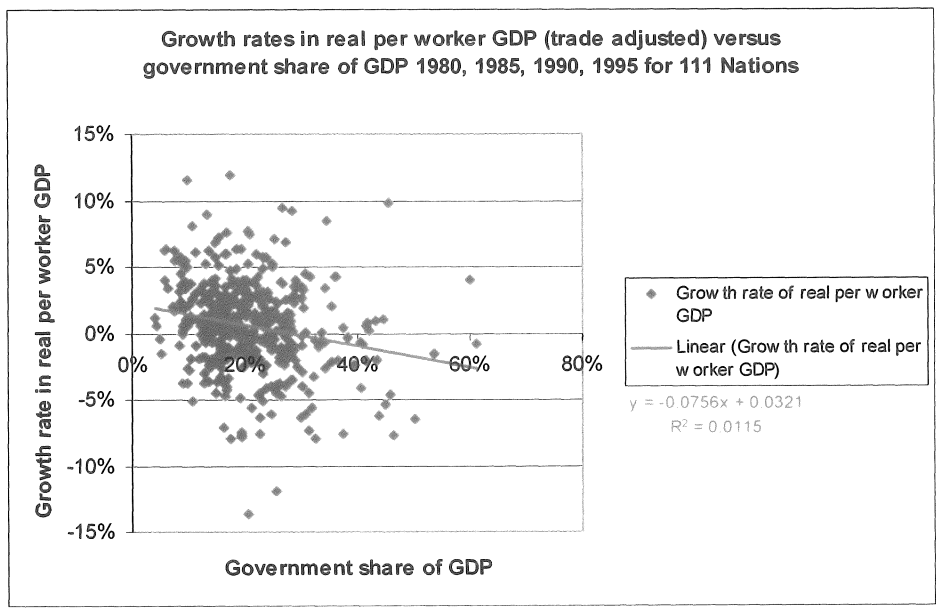


Figure 23 and Figure 24 present partial regressions of the investment share of GDP versus per capita/per worker GDP growth rates. They show a positive relationship between the investment share of GDP and per capita/per worker GDP growth rates.

Figure 23: Investment share of GDP versus growth rate in real per capita GDP

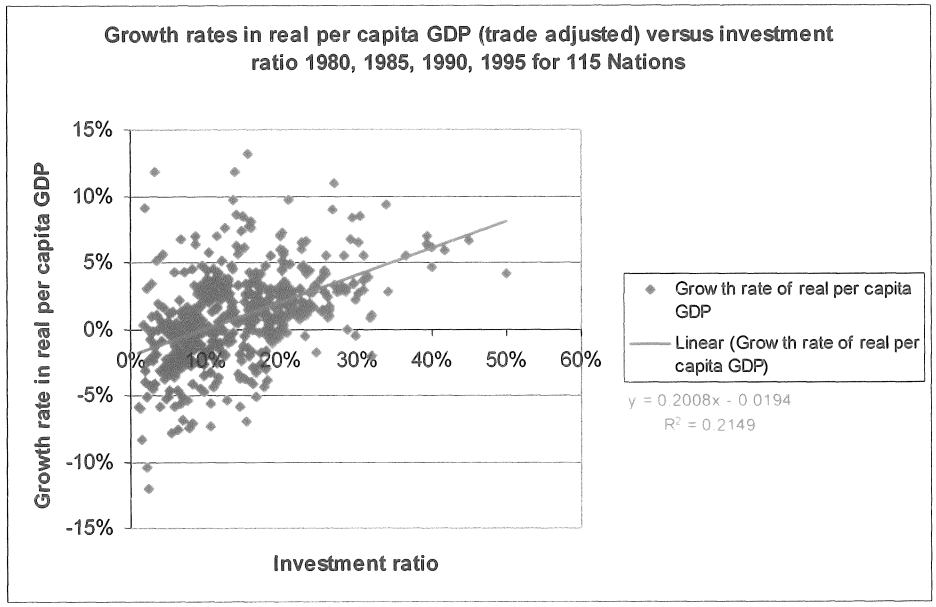
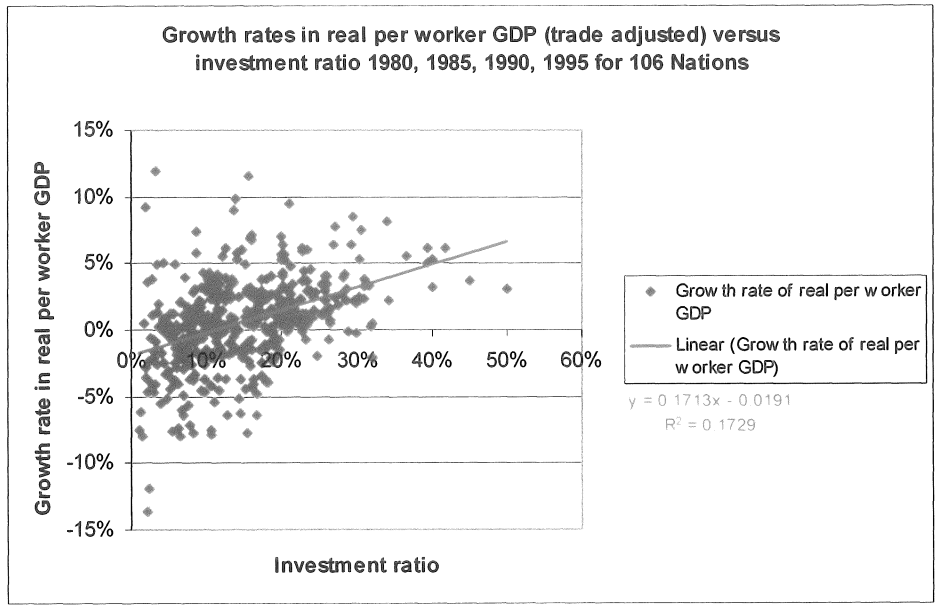


Figure 24: Investment share of GDP versus growth rate in real per worker GDP



Partial regressions of the per capita educational investment and per capita/per worker GDP growth rates in Figure 25 and Figure 26 show a quadratic relationship.

Figure 25: Per capita educational investment versus growth rate in real per capita GDP

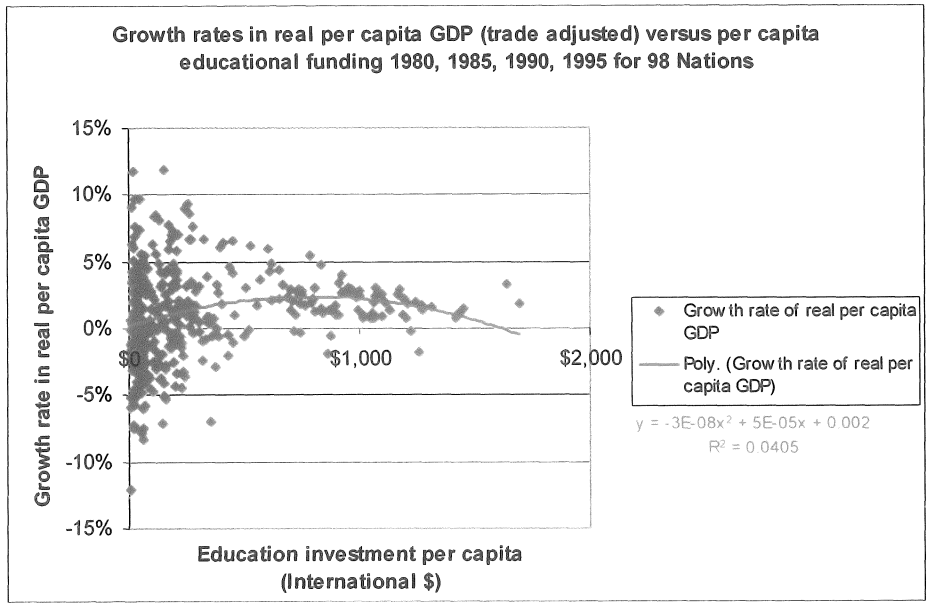


Figure 26: Per worker educational investment versus growth rate in real per capita GDP

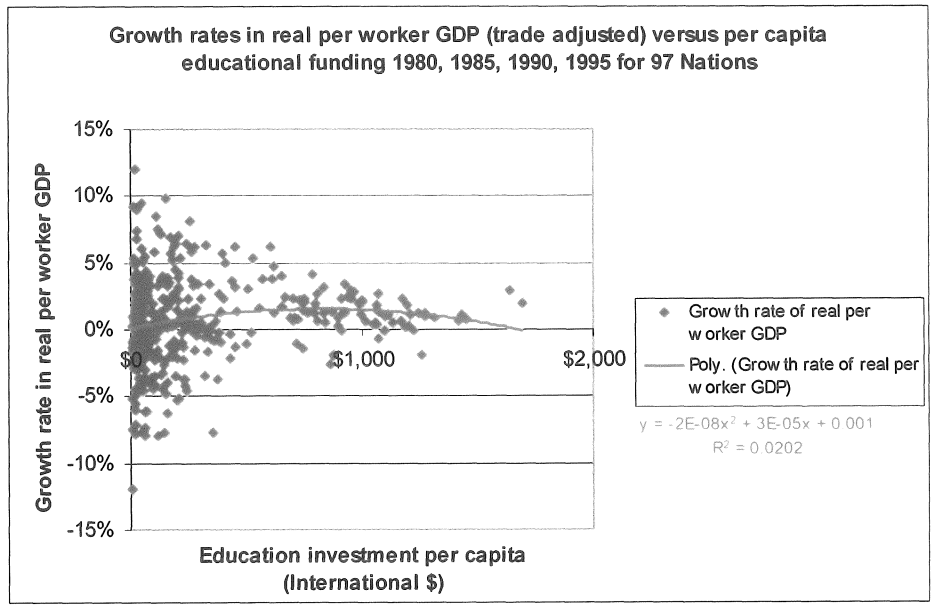


Figure 27 and Figure 28 present the literacy rate versus per capita/per worker GDP growth rates. A positively sloped linear trend line best describes the data relationship. Partial regressions of the standard deviation of the literacy rate and per capita/per worker

Figure 27: Literacy rate versus growth in real per capita GDP

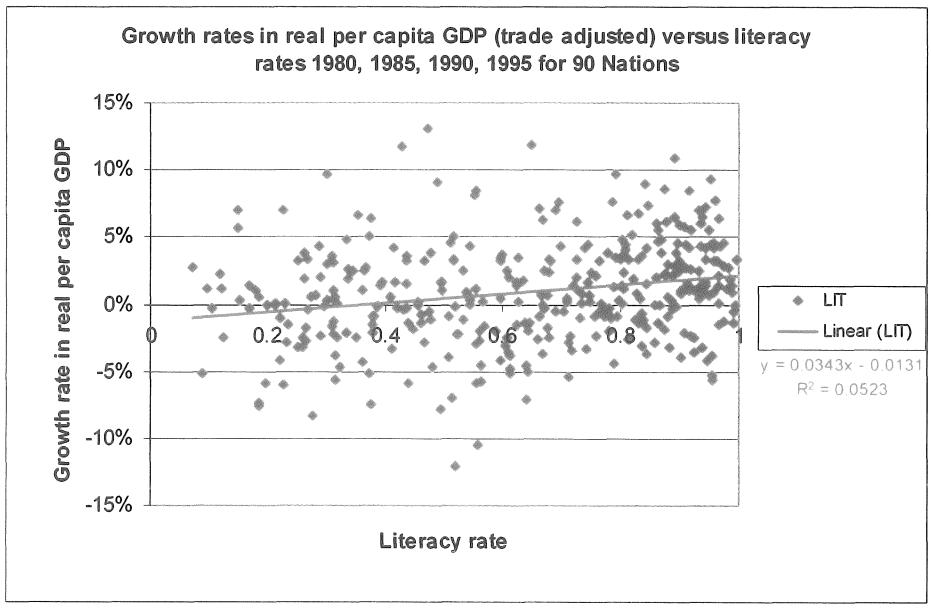
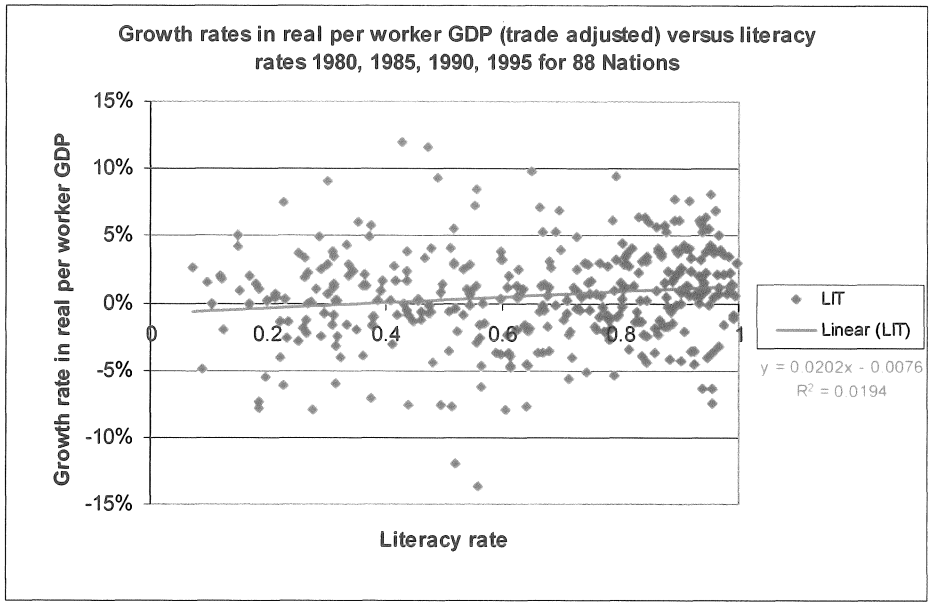


Figure 28: Literacy rate versus growth in real per worker GDP



GDP growth rates presented in Figure 29 and Figure 30 show a negative relationship. This suggests that policies that stabilize the literacy rates within nations are conducive to enhancing growth in national real per capita GDP and productivity.

Figure 29: Standard deviation of literacy rates versus growth in real per capita GDP

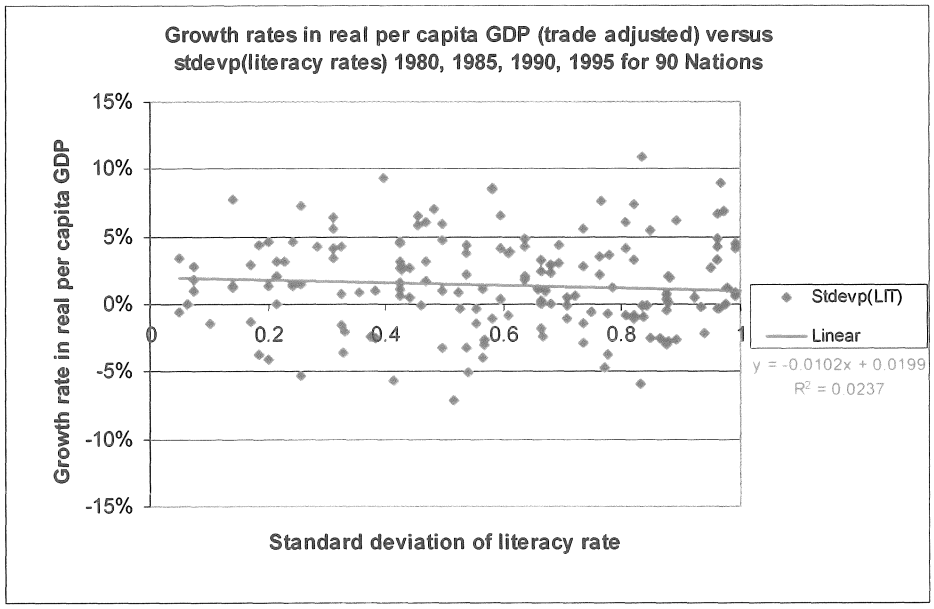
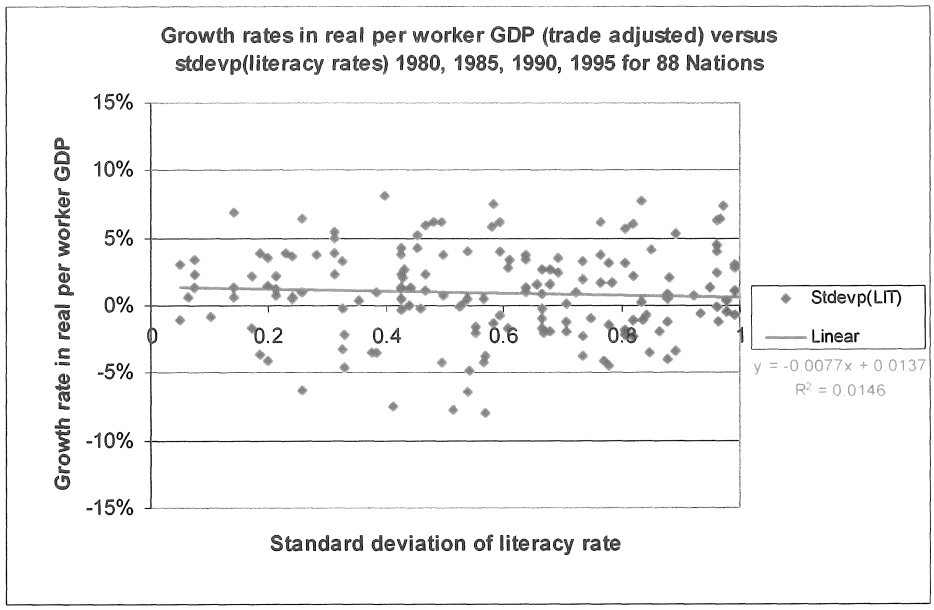


Figure 30: Standard deviation of literacy rates versus growth in real per worker GDP



Partial regressions of real per capita GDP levels and per capita/per worker GDP growth rates in Figure 31 and Figure 32 show a non-linear relationship that is contrary to the concept that poor countries grow faster than wealthier countries. The relation between

Figure 31: Real per capita GDP versus growth rate in real per capita GDP

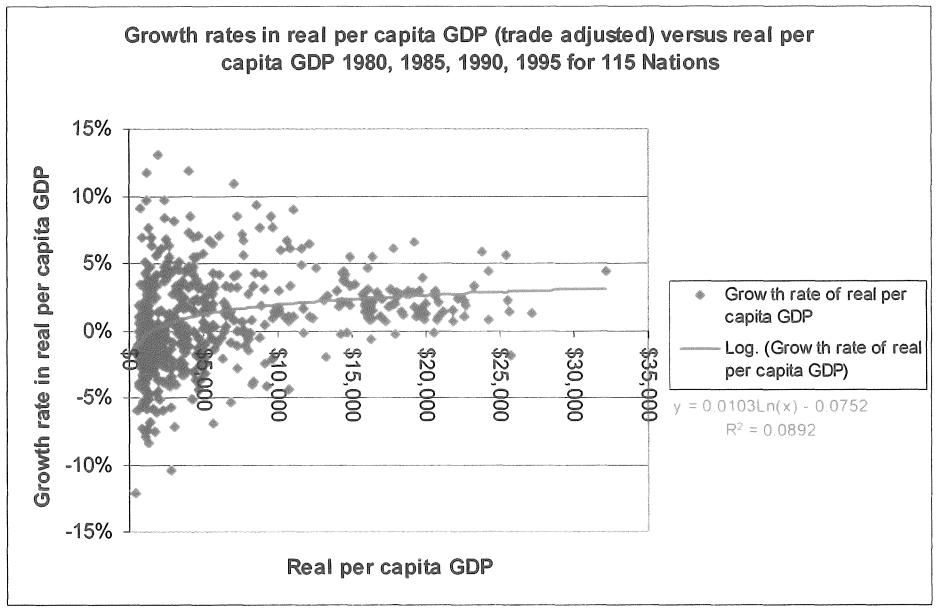
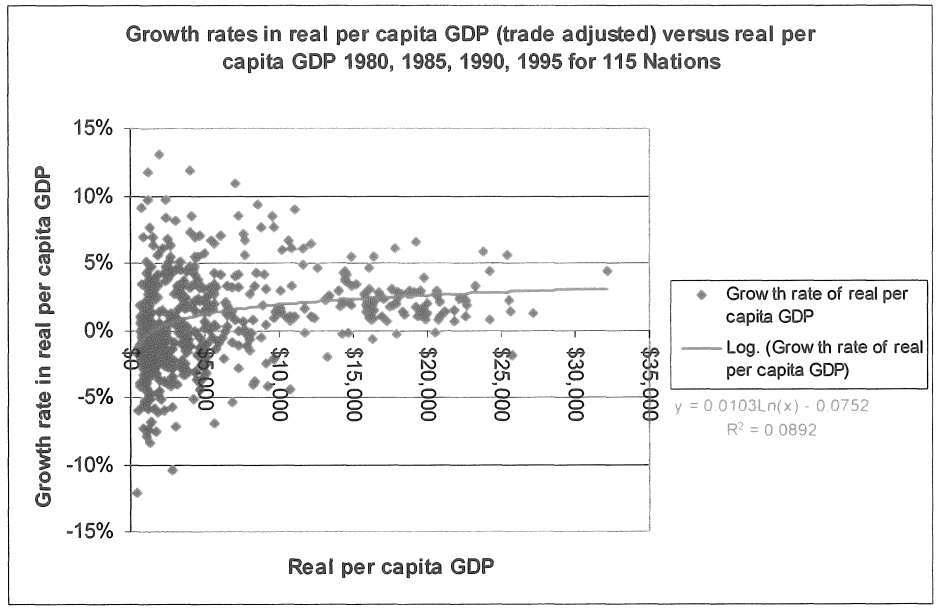


Figure 32: Real per worker GDP versus growth rate in real per worker GDP



the average inflation rate and per capita/per worker GDP growth rates in Figure 33 and Figure 34 show the expected negative linear relationship suggesting that higher levels of inflation are contrary to growth in per capita GDP and worker productivity. Partial

Figure 33: Inflation rate versus growth rate in real per capita GDP

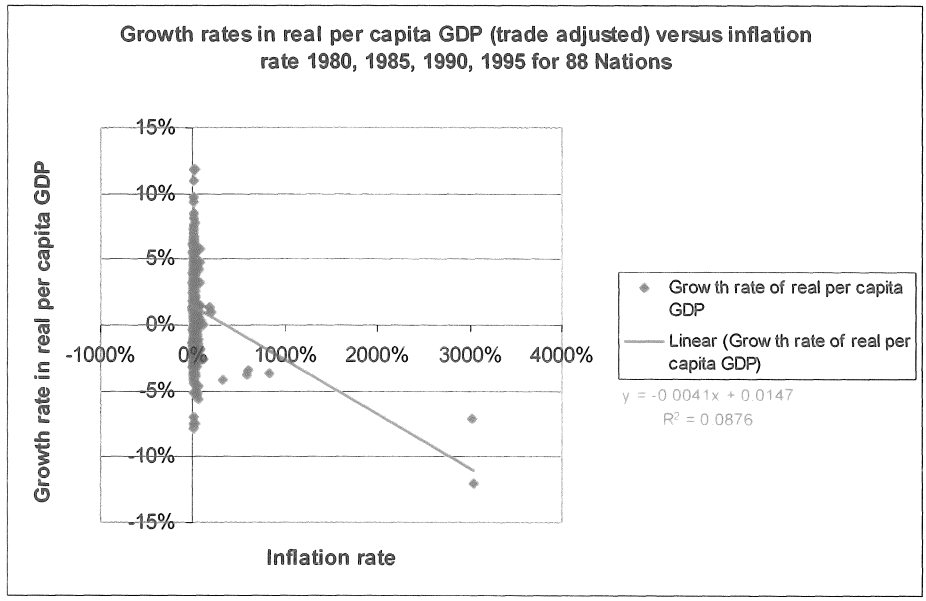
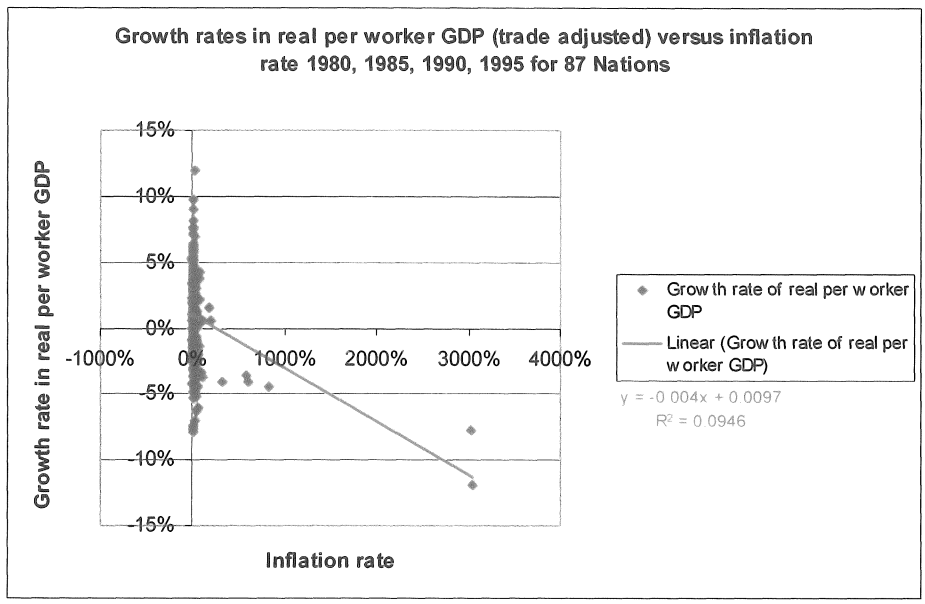


Figure 34: Inflation rate versus growth rate in real per worker GDP



regressions between the standard deviation of inflation rate and per capita/per worker GDP growth rates in Figure 35 and Figure 36 are best fitted by linear trend lines. The trend lines are negatively sloped which may suggest that greater variability in inflation rates is contrary to higher levels of real per capita GDP growth and productivity.

Figure 35: Standard deviation of inflation rate versus growth rate in real per capita GDP

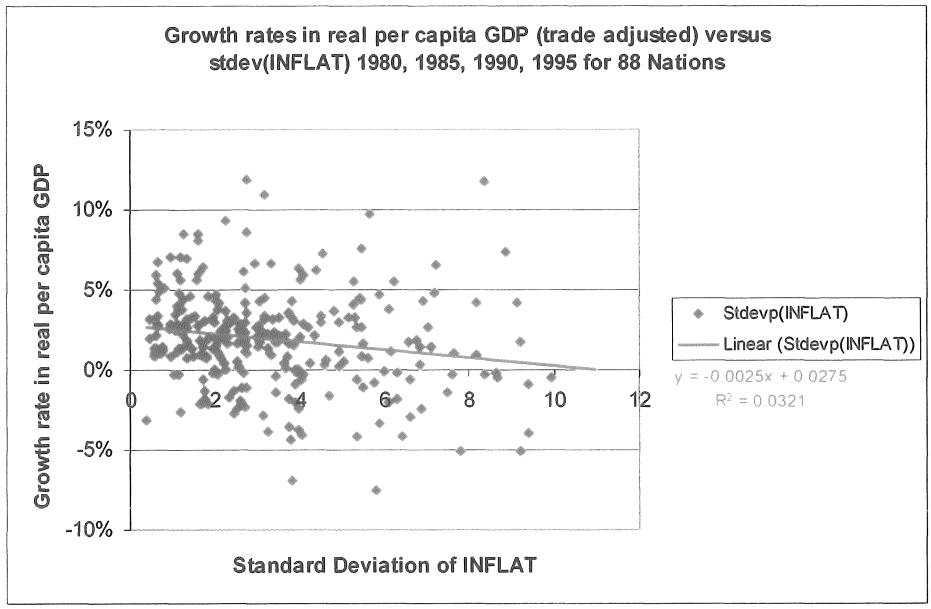


Figure 36: Standard deviation of inflation rate versus growth rate in real per worker GDP

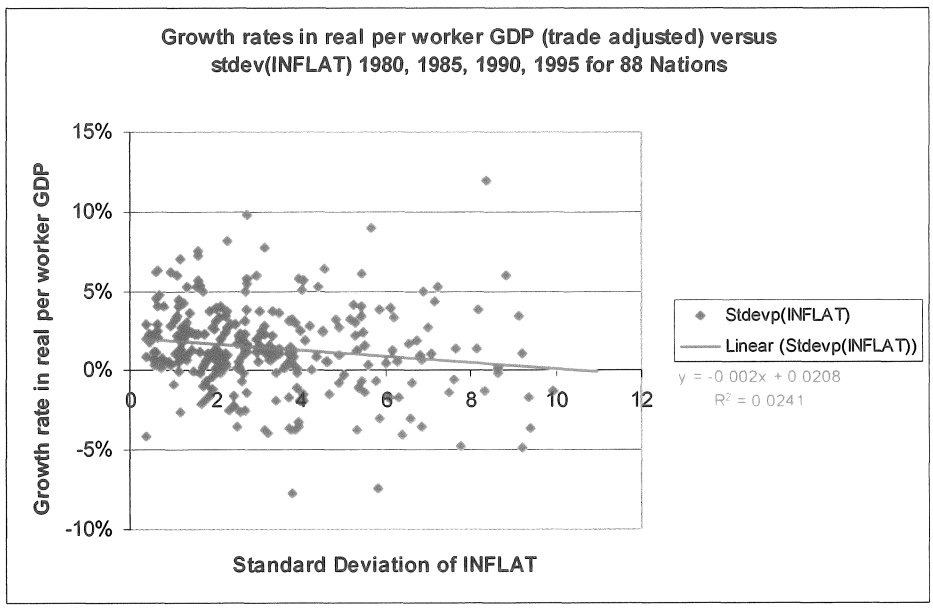


Figure 37 and Figure 38 present the average fertility rate versus per capita/per worker GDP growth rates respectively. The data are best fit by linear trend lines with a negative slope. This suggests that high fertility rates are contrary to growth in real per pita GDP and productivity growth rates. The relation between life expectancy at

Figure 37: Fertility rate versus growth rate in real per capita GDP

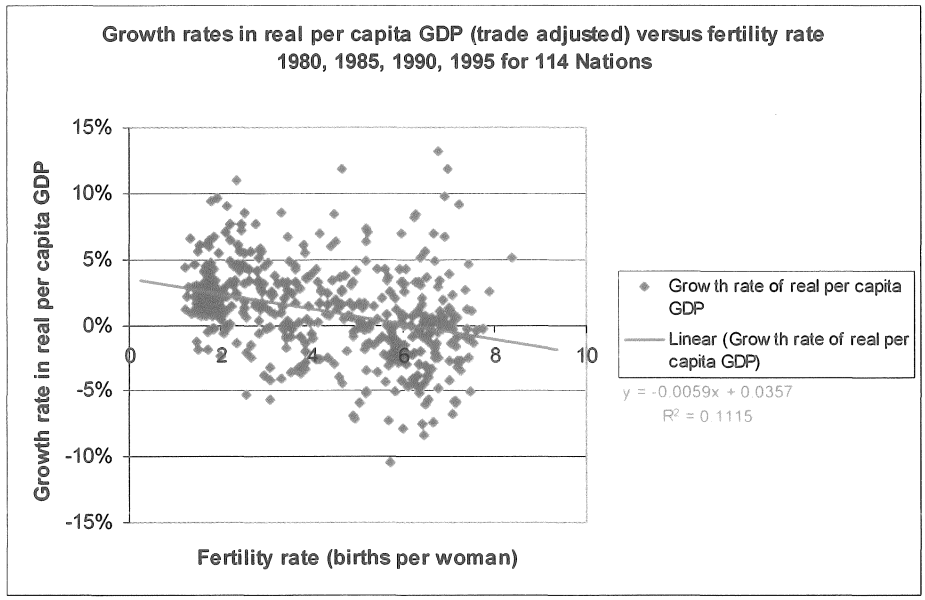
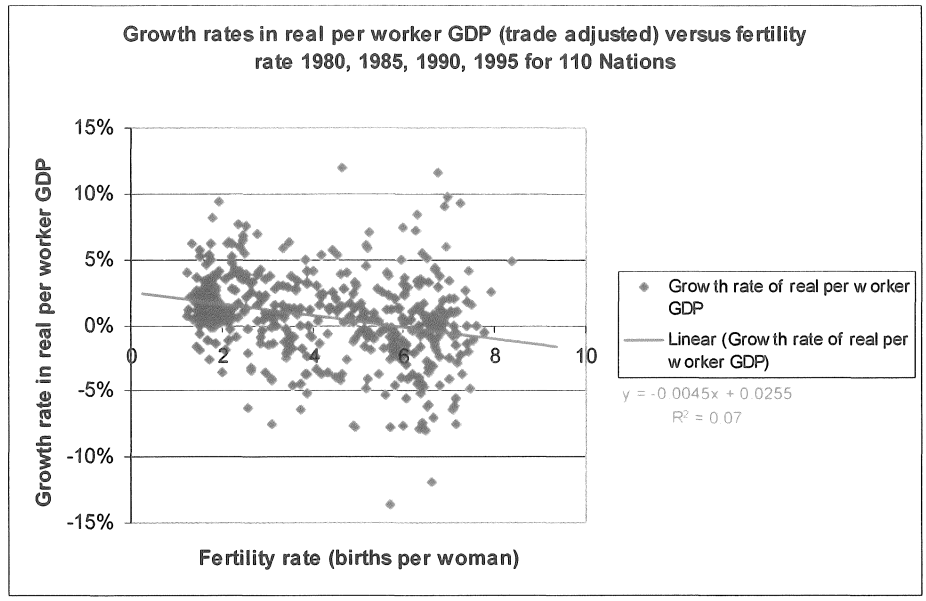


Figure 38: Fertility rate versus growth rate in real per worker GDP



birth and per capita/per worker GDP growth rates are given in Figure 39 and Figure 40. Both show the expected positive linear relationship between life expectancy at birth and per capita/per worker GDP growth rates. Partial regressions of the openness of markets

Figure 39: Life expectancy at birth versus growth rate in real per capita GDP

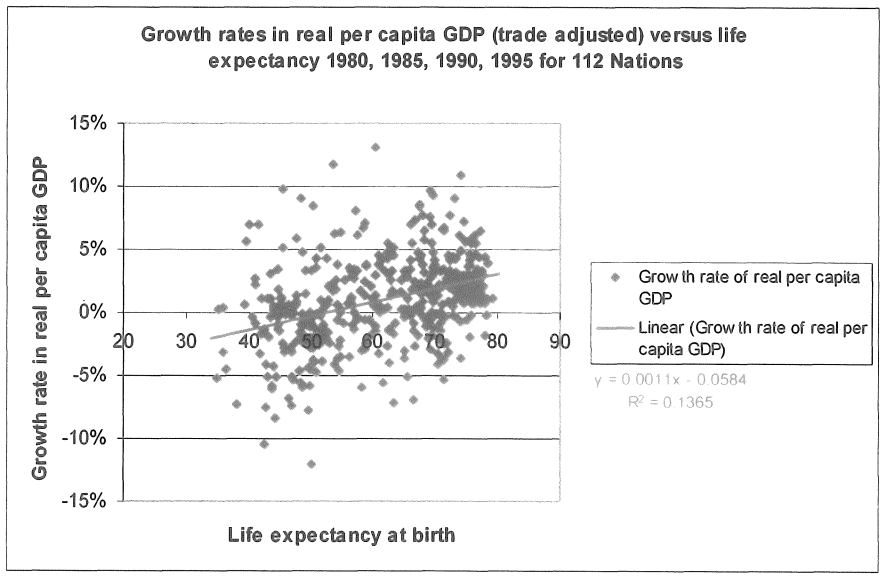
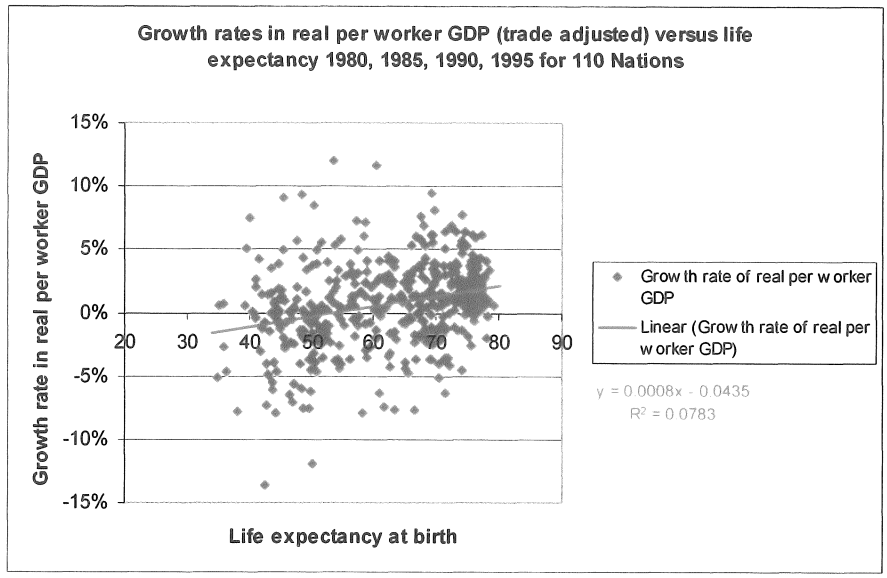


Figure 40: Life expectancy at birth versus growth rate in real per worker GDP



versus per capita/per worker GDP growth rates are presented in Figure 41 and Figure 42 respectively. Both are best fit by positively sloped linear trend lines suggesting that increases in market openness positively affect per capita/per worker GDP growth rates.

Figure 41: Openness versus growth rate in real per capita GDP

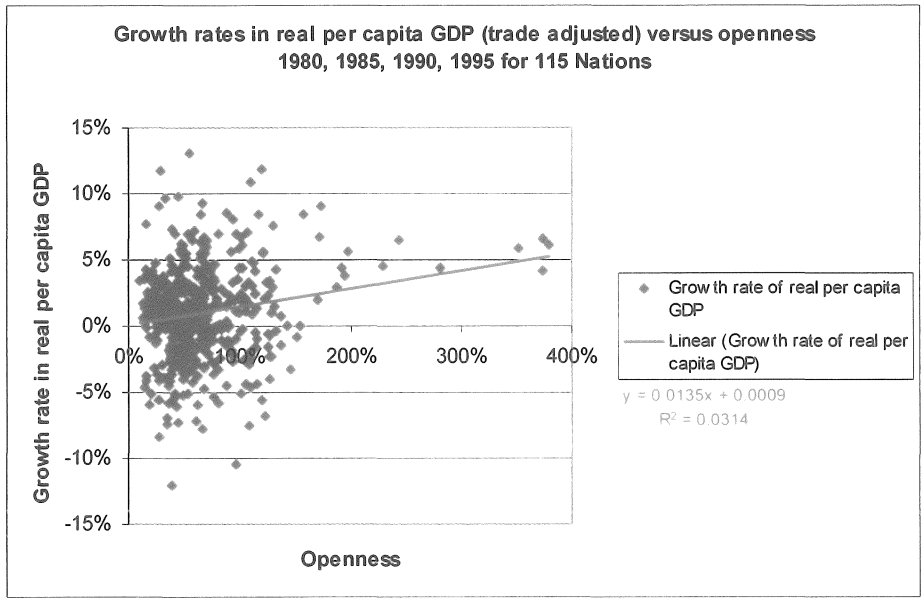
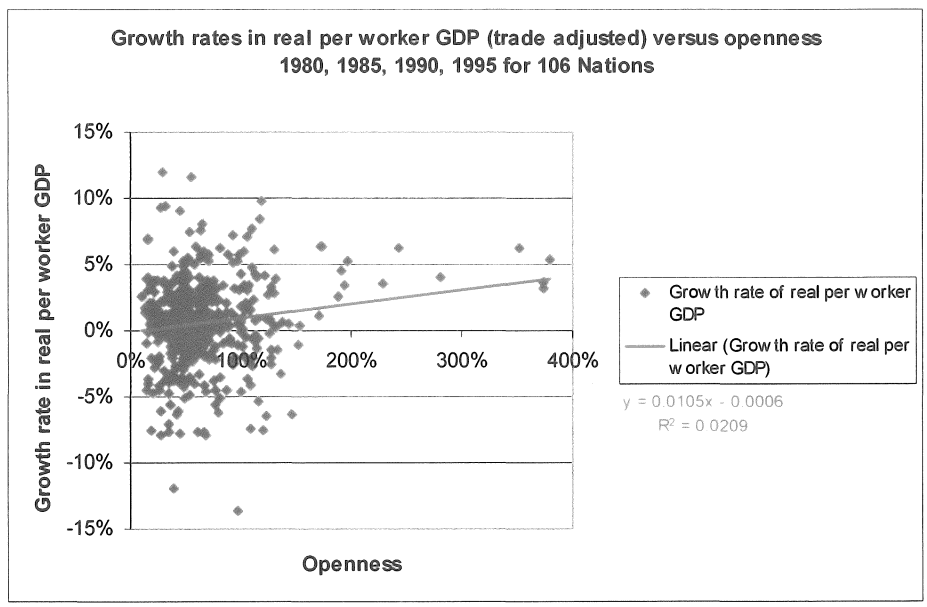


Figure 42: Openness versus growth rate in real per worker GDP



The relation between the averaged GASTIL index and per capita/per worker GDP growth rates in Figure 43 and Figure 44 shows the expected quadratic relationship. One important difference from the Barro evaluation of this factor is that the maxima of the

Figure 43: GASTIL index versus growth rate in real per capita GDP

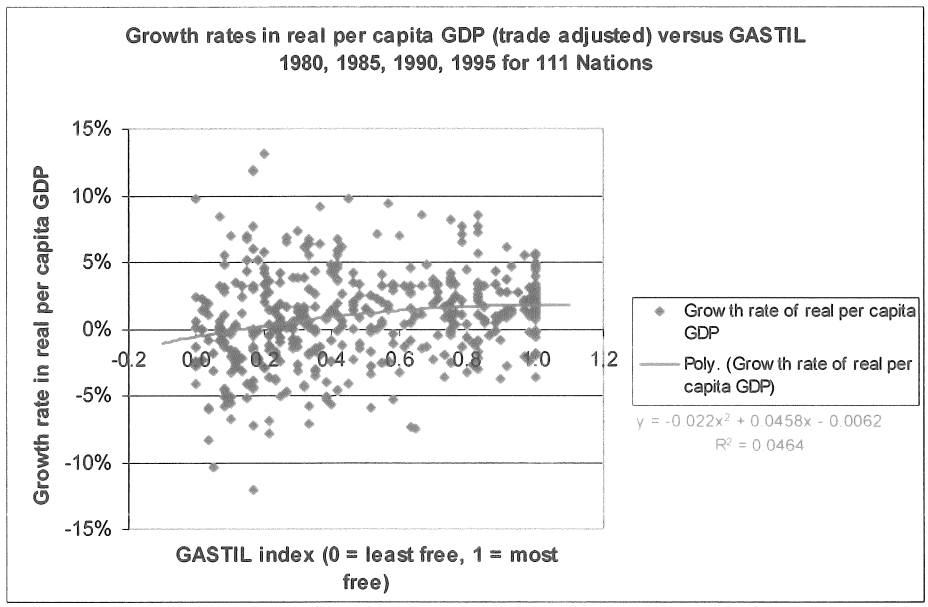
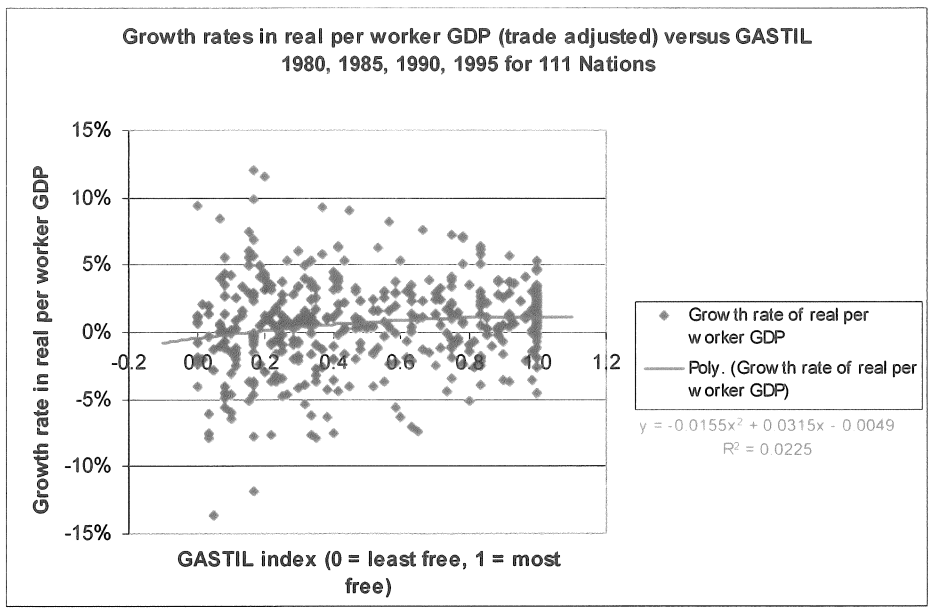


Figure 44: GASTIL index versus growth rate in real per worker GDP



implied function is shifted to the right towards higher levels of GASTIL. This can be explained by the fact that I am using a different time frame than the Barro evaluation, and that the world on average has grown more democratic in the years since the Barro evaluation.

Summary of Findings

There are several important findings as result of the analysis of the data. Real per capita GDP and worker productivity data show that absolute convergence does not hold, and that conditional convergence as posited by MRW is supported. Findings for global real per capita GDP and worker productivity are that the annual growth in these approximates 2 percent. This corroborates the findings by Barro in several of his cross-country empirical studies. An important additional finding in this area is that the slowdown in growth of per capita GDP and worker productivity that started in the 1970s appears to be reversing.

Evaluation of time trends in human and knowledge capital produced important findings. The level of human capital as measured by scientists and engineers per capita as well as literacy rates is increasing. The variability in the distribution of human capital global is decreasing. The level of knowledge capital as measured by scientific articles per year is decreasing. Variability in the distribution of knowledge capital formation is decreasing.

Investigation of other factors and their effects on growth in per capita GDP and worker productivity produced important results. Government share of GDP, inflation rate, and fertility rate were found to be negatively related to growth in per capita GDP and worker productivity consistent with several of Barro's studies. Investment share of GDP, life expectancy, and openness were found to be positively related to growth in per capita GDP and worker productivity consistent with several of Barro's studies. Higher growth rates in per capita GDP and worker productivity were found in countries with higher initial levels of per capita consistent with Barro, yet inconsistent with the neoclassical notion that richer countries should grow more slowly than poor ones.

Evaluation of democracy shows that there is a distinctly non-linear relationship between it and growth rates of nations. This finding is consistent with that found by Barro. Human capital as measured by per capita educational investment and literacy rates was found to be positively related to growth in per capita GDP and worker productivity. This finding is consistent with Barro's find for aggregate educational attainment.

V Model Development and Evaluation

This section of the paper is divided into two parts. The first is a reestimation of the augmented Solow model using new data available in the Penn World 6.0 dataset and alternative human capital measures. The last part is a Barro-style regression. The purpose of the section is to re-test the MRW and Barro-style regressions on an expanded data set and to introduce alternative measures of human and knowledge capital into the analysis.

Reexamining the Augmented Solow Model

The augmented Solow model presented by Mankiw, Romer, and Weil was prepared using the Real National Accounts data by Summers and Heston (1988). Since their investigation, numerous revisions to the data have occurred and are available in the Penn World 6.0 and World Development Indicators datasets. There have also been concerns about the authors' choice of education as a human capital measure. Mankiw, Romer, and Weil concede that their model has dimensional inconsistencies in its derivation.[19] Additional criticisms focusing on variable choice and measurement problems may explain why female educational attainment is not found to significantly affect growth rates.[20] Because social conditions vary among the nations different levels of schooling may have quite different influences on growth.[21] It is because of the changes in data as well as questions on the suitability of educational attainment as a measure of human capital that this investigation was conducted.

A. Model Development

The augmented Solow model presented in (16) is used to develop the regression model. The model predicts that the coefficients for physical and human capital are

$$(16) \quad \ln\frac{Y(t)}{L(t)} = \ln A(0) + gt + \underbrace{\frac{\alpha}{1-\alpha-\beta}\ln(s_k)}_{\text{Physical Capital}} - \underbrace{\frac{\alpha+\beta}{1-\alpha-\beta}\ln(n+g+\delta)}_{\text{Labor}} + \underbrace{\frac{\beta}{1-\alpha-\beta}\ln(s_h)}_{\text{Human Capital}}$$

positive and approximately equal. The coefficient for labor is predicted to be negative and of magnitude two, and that the coefficients for physical capital, human capital, and population sum to zero.[22] The augmented Solow model also predicts values for α and β of approximately one-third.[23]

The derived regression model with expected signs is:

$$(17) \quad \ln\left(\frac{Y}{L}\right) = \underset{(+/-)}{\beta_0} \quad \underset{(+)}{\beta_1\ln\left(\frac{I}{GDP}\right)} \quad \underset{(-)}{\beta_2\ln(n+g+\delta)} \quad \underset{(+)}{\beta_3\ln(\textbf{\textit{HUMAN CAPITAL}})}$$

where the sign and magnitude of the constant are irrelevant, the coefficients for savings and human capital are positive with approximate magnitude of one, and the labor coefficient is negative with approximate magnitude of two. The dependent variable is represented by the log of output per effective unit of labor. The physical capital variable is represented by the log of investment share of GDP; the labor variable by the log population growth rate plus .05, and the human capital variable by the log of the human capital variable. The difference between my version of the MRW regression model and the original form estimated by MRW is the human capital variable. We interpret human capital as any of the human capital measures under investigation, including educational participation at the secondary level (SCHOOL used in Mankiw, Romer, Weil), literacy rates, life expectancy rates, and per capita educational investment.

B. Regression Results

The regression of the model was performed on 69 countries using OLS. The regression results are presented in Table 6.

Table 6: Investigation of the Augmented Solow Model Using Alternative Human Capital Measures

Dependent variable: log GDP per working-age person in 1985				
Regression:	$SCHOOL_{85}$	$Literacy_{85}$	$Life\ Expectancy_{85}$	$Education\$_{85}$
N:	69	69	69	69
CONSTANT	4.94	6.56	-6.18	3.78
	(0.0004)**	(≈.0000)**	(0.0006)**	(0.0002)**
ln(I/GDP)	0.47	0.57	0.34	0.29
	(0.0001)**	(≈ .0000)**	(0.0009)**	(0.0011)**
$ln(n + g + \delta)$	-1.67	-1.51	-0.23	-1.16
	(0.0011)**	(0.0050)**	(0.6212)	(0.0001)**
ln(human capital)	0.45	0.57	3.76	0.59
	(≈.0000)**	(≈.0000)**	(≈.0000)**	(≈.0000)**
F	56.75	52.63	93.36	128.31
	(≈.0000)**	(≈.0000)**	(≈.0000)**	(≈.0000)**
$\overline{R}^2$	0.71	0.69	0.80	0.85
Restricted regression:				
CONSTANT	6.75	7.46	-3.54	4.41
	(≈.0000)**	(≈.0000)**	(≈.0000)**	(≈.0000)**
$ln(I/GDP) - ln(n + g + \delta)$	0.51	0.59	0.46	0.30
	(≈.0000)**	(≈.0000)**	(≈.0000)**	(0.0004)**
$ln(\text{human capital}) - ln(n + g + \delta)$	0.49	0.61	1.84	0.61
	(≈.0000)**	(≈.0000)**	(≈.0000)**	(≈.0000)**
F	82.97	79.49	96.01	193.66
	(≈.0000)**	(≈.0000)**	(≈.0000)**	(≈.0000)**
$\overline{R}^2$	0.71	0.70	0.74	0.85
Test of restriction:				
ρ-value	0.93	0.89	0.00**	0.02*
Implied α	0.25	0.27	0.14	0.16
Implied β	0.25	0.28	0.56	0.32

Note: ρ statistics are in parenthesis. The investment and population growth rates are averages for the period 1960-1985. $(g + \delta)$ is assumed to be 0.05.
*Indicates significance at the 5% level.
**Indicates significance at the 1% level.

The signs of the coefficients for all regressions are as expected. The magnitudes of coefficients for the life expectancy regression appear to be incorrect. All coefficients for all regressions are significant at the 1% level with the exception of the coefficient for labor in the life expectancy regression, which is not significant at the 5% level. All F

values are significant at the 1% level. The test of the restriction that the coefficients of physical capital, labor, and human capital sum to zero is not rejected in the SCHOOL and literacy regressions, and is rejected in the life expectancy and per capita educational investment regressions.

Testing the augmented Solow model with updated data and alternative measures of human capital revealed several important points. First, the augmented Solow model does not appear to have lost any robustness from its original presentation. Second, literacy appears to be as satisfactory a measure of human capital as the schooling measure used in the original investigation. Finally, two other measures of human capital, life expectancy and per capita educational expenditure, do not appear to be suitable proxies for human capital.

Barro-Style Panel Regression

The regressions performed by Barro and others in much of the empirical research have been of panel form. This section of the paper presents a panel regression of the numerous factors that have been reported in various studies in growth determinants. The purpose is to evaluate the suitability of this approach.

A. Model Development

The framework for the model is a system of equations of form

$$\Delta Y_1 = \beta_0 + \beta_1 X_{11} + \ldots + \beta_N X_{1N}$$

(18)

$$\Delta Y_M = \beta_0 + \beta_1 X_{M1} + \ldots + \beta_N X_{MN}$$

where the ΔY terms represent the rate of growth in GDP for a set time frame, and the remaining independent variables represent factors under investigation. The data used in

the regression are for the period 1976 through 1995. The regression model to be estimated is similar to the one used by Barro.[24] The differences are in the choice of human capital measures selected, the omission of the GDP and human capital interaction variable, rule of law, and terms of trade variables.[25] The human capital variable selected for use in the regression model is the literacy rate versus the years schooling used in the Barro regressions. The model consists of a system of three equations for growth rates in GDP for 1981 through 1985, 1986 through 1990, and 1991 through 1995. Model variables include the log of initial values of per capita GDP, initial levels of human capital as measured by literacy rates, log of the average life expectancy for the period, log of the average fertility rate for the period, the average government share of GDP for the period, the average democracy level for the period, the average democracy level squared for the period, and the average inflation rate for the period. The model is

$$GGDP_{81\text{-}85} = \beta_0 + \beta_1 \ln(GDP_{81}) + \beta_2 LIT_{81} + \beta_3 \ln(LEXP_{76\text{-}80}) + \beta_4 \ln(FERT_{81\text{-}85}) + \beta_5 KG_{81\text{-}85} + \beta_6 DEMOC_{81\text{-}85} + \beta_7 DEMOC^2_{81\text{-}85} + \beta_8 INFLAT_{81\text{-}85}$$

$$GGDP_{86\text{-}90} = \beta_0 + \beta_1 \ln(GDP_{86}) + \beta_2 LIT_{86} + \beta_3 \ln(LEXP_{81\text{-}85}) + \beta_4 \ln(FERT_{86\text{-}90}) + \beta_5 KG_{86\text{-}90} + \beta_6 DEMOC_{86\text{-}90} + \beta_7 DEMOC^2_{86\text{-}90} + \beta_8 INFLAT_{86\text{-}90} \quad (19)$$

$$GGDP_{91\text{-}95} = \beta_0 + \beta_1 \ln(GDP_{91}) + \beta_2 LIT_{91} + \beta_3 \ln(LEXP_{86\text{-}90}) + \beta_4 \ln(FERT_{91\text{-}95}) + \beta_5 KG_{91\text{-}95} + \beta_6 DEMOC_{91\text{-}95} + \beta_7 DEMOC^2_{91\text{-}95} + \beta_8 INFLAT_{91\text{-}95}$$

B. Regression Results

The regression of the model was performed on 85 countries using SUR.[26] The regression results are presented in Table 7.

Table 7: Barro-style Panel Regression

Dependent variables: growth rate per capita real GDP 1981-1985, 1986-1990, 1991-1995	
N	85, 85, 85
Constants	0.2173
	(0.1810)
ln (GDP)	-0.0183
	(0.0051)**
Literacy Rates	0.0016
	(0.9491)
ln(life expectancy)	-0.0006
	(0.9875)
ln (fertility rate)	-0.0570
	(0.0001)**
Government consumption ratio	0.0140
	(0.7504)
Democracy index	0.0827
	(0.0542)#
Democracy index squared	-0.0685
	(0.0667)#
Inflation rate	-0.0028
	(0.0011)**
$\bar{R}^2$	.29, .39, .37

Note: ρ statistics are in parenthesis.
#Indicates significance at the 10% level.
*Indicates significance at the 5% level.
**Indicates significance at the 1% level.

The coefficients for initial GDP level, log of average fertility rate, and average inflation rate are significant at the one percent level, and the signs of the coefficients are as expected. The coefficients for the democracy index and democracy index squared are significant at the ten percent level, and the coefficients' signs are as reported by Barro.[27] The coefficients for average government share of GDP, average literacy rate, and log of average life expectancy are not significant at even the ten percent level. Additionally, the signs of the coefficients for log of average life expectancy and average government share of GDP are not as expected. Sensitivity analysis of the model revealed a considerable

sample sensitivity affecting the collinearity of various variables in the model. This finding is similar to that identified by Lorgelly and Owen in their evaluation of the robustness of the Barro-Lee model.[28]

Our results estimating a Barro-style regression were not as expected. Several of the coefficients proved to be significant with the correct sign; whereas, others were not. Investigation of the model's sensitivity demonstrated moderate to high levels of multicollinearity among some variables. The cause of this might be due to using a different measure of human capital than Barro, having different time frames than those used by Barro, revisions of the data having invalidated the original model, or some other cause. The high degree of sample sensitivity suggests that Barro-style regressions do not lead to robust conclusions regarding the factors that explain inter-country growth rate differentials. While the approach leads to very important insights into the economic growth processes, the results of Barro-style regressions appear to be inadequate to predict a solid basis for growth policy.

VI Summary and Conclusions

Empirical review of revised data sources identified time related trends in per capita GDP and productivity growth rates, time related trends in socio-economic factors, and the effects of various factors on economic growth. First, the productivity slowdown that occurred globally in the 1970s appears to be reversing as of the 1990s. Second, the level of human capital is increasing globally and the distribution of human capital is becoming more uniform globally. Third, the level of per capita knowledge capital is declining globally, and the distribution of knowledge is becoming less variable. Finally, the concept of absolute convergence is not supported by the data; whereas, the neoclassical concept of conditional convergence receives empirical support.

Investigation of the augmented Solow model with revised inputs and possible alternate measures of human capital revealed three important points. First, the augmented Solow model appears to have lost none of its robustness in explaining the disparity of wealth differentials among nations. Second, the use of literacy as an alternative measure of human capital is supported by experimentation, with regressions using literacy rather than the contrived schooling human capital performing satisfactorily. Finally, life expectancy and per capita educational expenditure are unsatisfactory measures of human capital.

Investigation of a Barro-style model using different inputs and model time frames revealed several issues. First, the statistical significance for all the coefficients could not

be supported at the ten percent level. Second, the sign for all the coefficients were not as predicted or reported by Barro. Finally, the Barro-style model is highly sensitive to collinearity issues as corroborated in other investigations, with influential outliers seriously affecting the predictive powers of the model.

In conclusion, this researcher has completed a comprehensive review of established growth economics literature, analyses of newly revised data sources, and reestimation of generally accepted economic growth models using revised data. Specific findings include the revalidation of the MRW model, discovery of a satisfactory alternative measure of human capital, sensitivity issues when performing Barro-style regressions, and data trends that may have an alarming impact on certain of the endogenous growth theories. These findings have important implications for economic policy formulation.

Upon reestimation, the MRW model is found to be robust and satisfactorily explains differences in productivity among nations. Additionally, human capital as measured by the literacy rate of the population is found to be as satisfactory as the secondary schooling participation rate used in the original investigation. MRW explains that a nation's level of productivity relates positively to the rates of investment and human capital savings, and negatively to its population growth. Policies designed to maximize the level of output productivity would affect any or all of the model variables. To encourage an increase in investment, tax policies such as accelerating the depreciation on new capital equipment should be considered. To increase the level of human capital several strategies are possible depending upon the specific measure of human capital that policy is expected to effect. If human capital is measured by the schooling variable as

used in the original regression, is selected, policies that reward school districts for having high levels of completion of secondary schooling, and provide incentives for individuals to complete their education through high school, should be implemented. For the human capital variable measured by literacy, several policy approaches are also available. To the schooling and educational systems responsible for development of our resources, financial incentives to improve the literacy rates of students at all levels should be implemented. For the public, providing ready access to free literacy development programs through community outreach centers would be helpful. To private industry, providing tax credits to encourage the creation of on-the-job and after work programs that focus specifically on improving employee literacy rates should be considered. To decrease population growth several strategies are available. One is to increase the availability of birth control and counseling to the populace. Another is to discourage families from having more than three children by curtailing the number of personal exemptions to be at a level to just allow for replacement. This would likely be a difficult policy to implement, and those already established large families would likely need to be exempted.

Reestimation of a Barro-style regression proved to be less satisfactory than reestimation of MRW. The model was found to be highly sensitive to collinearity issues pertaining to sample and time selection. Barro-style models are an important addition to growth theory economics in that they attempt to extend the MRW model with the addition of certain other factors and should not be discounted. They are useful for establishing economic policies when dealing with specific grouping of countries, rather than the broad generalizations regarding policy that may be derived from the MRW

model. From this investigation higher rates economic growth are found among countries with lower fertility rates, lower rates of inflation, and higher, although not the highest levels of democracy. Policies to encourage economic growth among nations are those that would lower fertility rates, inflation rates; and would stimulate political changes to foster democracy.

The MRW model does an adequate job at explaining disparities in productivity and growth rates among nations in transition. Because of diminishing returns to physical and human capital, all countries are predicted to converge to some final steady state unless some event happens to change their total factor productivity. Empirical analyses revealed that there indeed is some convergence within similar groups of countries, however growth is found to occur even after nations are predicted to have converged. This is because that there are technological innovations occurring that do affect total factor productivity. One criticism of the MRW model is that technological change is viewed as exogenous, endogenous growth theories were developed in an attempt to endogenize technology. In endogenous growth theories, the synergy of various factors allows for increasing returns to scale, permitting growth to continue ad-infinitum.

While this research report did not reestimate any of the endogenous growth models, one empirical finding relating to knowledge production is of concern to both the exogenous and endogenous treatment of technological change. The finding that the level of per capita knowledge being produced is declining, is a finding that has negative implications for the future. To subscribers to the MRW model of economic growth this means that the time between shifts in total factor productivity will become greater. To subscribers of models incorporating endogenous technological innovation this poses a

reduction in the rate of increasing complexity of knowledge, discouraging to the realization of increasing returns to scale. Policies that would be favorable to increase the rate of knowledge formation are those that encourage private investment, and provide for the protection of new technology. Since knowledge has characteristics of a public good, private agents are unable to fully capture the returns on their investment. The development of markets to foster knowledge creation requires that these private agents be able to more fully realize the returns on their investment. Increasing intellectual property rights protection through increased enforcement and penalties domestically and internationally is a reasonable policy change.

Notes

1. Goncalo L. Fonseca and Leanne J. Ussher, The History of Economic Thought: Classical Growth Theory From Smith to Marx. <http://homepage.newschool.edu/het/>.

2. Ibid.

3. Ibid.

4. Adam Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations;* Modern Library Edition, New York, 1937; p. 10.

5. Goncalo L. Fonseca and Leanne J. Ussher, The History of Economic Thought: Classical Growth Theory From Smith to Marx. <http://homepage.newschool.edu/het/>.

6. Ibid.

7. Lewis-Guodo Liu and Robert Premus, *Global Economic Growth: Theories, Research, Studies, and Annotated Bibliography, 1950-1997* (Greenwood Press, Westport, CT, 2000), 4.

8. Robert M. Solow, *Learning from 'Learning by Doing': Lessons for Economic Growth* (Stanford University Press, Stanford, CA, 1997), 4.

9. Albelo Alvarez and D. Carmen, "Complementarity Between Physical and Human Capital, and Speed of Convergence." *Economic Letters* 64 (1999): 357.

10. James D. Hamilton and Josefina Monteagudo, "The Augmented Solow Model and the Productivity Slowdown." *Journal of Monetary Economics* 42 (1998): 414.

11. Ibid., 420.

12. D. Asteriou and G. M. Agiomirgianakis, "Human Capital and Economic Growth Time Series Evidence from Greece." *Journal of Policy Modeling* 23 (2001): 486.

13. Ibid., 487.

14. Robert J. Barro, *Determinants of Economic Growth: A Cross-Country Empirical Study* (The MIT Press, Cambridge, MA 1997) 13.

15. This is actually the geometric mean of growth of real per capita GDP for the time period under consideration.

16. Several trend lines were tested with the quadratic form having the highest adjusted R-squared value.

17. Only 25 of the 30 OECD nations were included because of insufficient information on the Czech Republic, Slovakia, Germany, Hungary, and Poland.

18. The convergence of the African subset is shown between the two bold red dashed lines.

19. N. Gregory Mankiw, David Romer, and David N. Weil, "A Contribution to the Empirics of Economic Growth." *The Quarterly Journal of Economics* 102.2 (May 1992): 419.

20. Paula K. Lorgelly and P. Dorian Owen, "The Effect of Female and Male Schooling on Economic Growth in the Barro-Lee Model." *Empirical Economics* 24 (1999): 542.

21. D. Asteriou and G. M. Agiomirgianakis, "Human Capital and Economic Growth Time Series Evidence from Greece." *Journal of Policy Modeling* 23 (2001): 487.

22. N. Gregory Mankiw, David Romer, and David N. Weil, "A Contribution to the Empirics of Economic Growth." *The Quarterly Journal of Economics* 102.2 (May 1992): 417-418.

23. Ibid., 417.

24. Robert J. Barro, *Determinants of Economic Growth: A Cross-Country Empirical Study* (The MIT Press, Cambridge, MA 1997) 13.

25. The interaction of GDP variable with human capital was highly collinear. The rule of law index variable was not available for the time periods being investigated. The terms of trade variable is unnecessary as the GDP variable being evaluated is the terms of trade corrected GDP.

26. Seemingly unrelated regression (SUR), also known as joint generalized least squares (JGLS) or as the Zellner estimation, is a generalization of OLS for multi-equation systems. Like the OLS method, SUR assumes that all the regressors are independent variables, but SUR uses the correlations among the errors in different equations to improve the regression estimates. SUR requires an initial OLS

regression to compute residuals. The residuals are used to estimate the cross-equation covariance matrix.

27. Robert J. Barro, *Determinants of Economic Growth: A Cross-Country Empirical Study* (The MIT Press, Cambridge, MA 1997) 13-15.

28. Paula K. Lorgelly and P. Dorian Owen, "The Effect of Female and Male Schooling on Economic Growth in the Barro-Lee Model." *Empirical Economics* 24 (1999): 552.

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3. Asteriou, D., and G. M. Agiomirgianakis. "Human Capital and Economic Growth Time Series Evidence from Greece." *Journal of Policy Modeling* 23 (2001): 481-489.

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5. De la Croix, David, and Philippe Monfort. "Education Funding and Regional Convergence." *Journal of Population Economics* 13 (2000): 403-424.

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9. Lorgelly, Paula K., and P. Dorian Owen. "The Effect of Female and Male Schooling on Economic Growth in the Barro-Lee Model." *Empirical Economics* 24 (1999): 537-557.

10. Mankiw, Gregory N., David Romer, and David N Weil. "A Contribution to the Empirics of Economic Growth." *The Quarterly Journal of Economic* May (1992): 407-437.

11. Nussbaum, Martha. "Globalization Debate Ignores the Education of Women." *The Chronicle of Higher Education* 47.2 (Sept 2000): 16-17.

12. Rangazas, Peter. "Schooling and Economic Growth: A King-Rebelo Experiment with Human Capital." *Journal of Monetary Economics* 46 (2000): 397-416.

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14. Sorensen, Anders. "R&D, Learning, and Phases of Economic Growth." *Journal of Economic Growth* 4 (December 1999): 429-445.

15. Stewart. Francis. "Globalisation and Education." *International Journal of Educational Development* 16.4 (1996): 327-333.

16. Wolf, Alison. "Education and Economic Growth." *New Economy* 6.1 (March 1999): 33-37.

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SELECTED ANNOTATED BIBLIOGRAPHY

Articles

1. Alvarez, Albelo, and D. Carmen. "Complementarity Between Physical and Human Capital, and Speed of Convergence." *Economic Letters* 64 (1999): 357-361.

This article is an examination into the seeming discrepancies in rates of conversion between one and two sector models, and that which is found in empirical studies. The authors open with an introduction into the seeming discrepancy between models hypotheses and empirical results. Subsequently, a model is proposed that incorporates a variation of the Uzawa-Lucas framework as an effort to reconcile theory with reality. This framework is then used to assess the speed of convergence to the steady state as well as establishing long-term growth rates.

The one- and two-sector economic growth models presented by King and Rebelo in 1993 and Ortigueira and Santos in 1997 suggest a much higher rate of convergence than the two percent found empirically. The one-sector models get annual convergence rates of seven percent, and the two-sector models get annual convergence rates of twenty percent. The one-sector models reconcile theoretical results with empirical ones by assuming a broad definition of capital, which includes by physical and human capital. The two-sector models allow for the existence of adjustment costs, costs associated with capital installation. The authors propose that the reason the wide discrepancy is the existence of complementarities between physical and human capital.

The model that is proposed is a two-sector model of endogenous growth. Formal education and investment in physical capital are viewed as perfect substitutes for each other in human capital production. Additionally, investment is assumed to be measuring learning by using the new technology embodied in new capital goods. With this assumption the economy accumulates much more physical capital per unit of labor efficiency than in models that consider education as the only factor in the human capital production function. The model is a version of the Uzawa-Lucas model's theoretical framework. The significant difference is that human capital accumulation is additive in two different components, learning by using and formal education.

To identify the speed of convergence in this model appropriate numerical simulation techniques were used. Simulations revealed that the rate of convergence increases with the productivity parameter of education, and decreases with the learning by using productivity parameter. Additionally, it showed that the rate of convergence did not depend on parameters relating to social preferences, but only on the technological parameters of the model. The convergence rates between the regions approximated the empirical results. Additionally, the long-term growth rate demonstrated by the model was about two percent.

2. Asteriou, D., and G. M. Agiomirgianakis. "Human Capital and Economic Growth Time Series Evidence from Greece." *Journal of Policy Modeling* 23 (2001): 481-489.

The authors attempt to reproduce some of Barro's works, but with a special evaluation of certain factors. The article is an extensive examination into the significance that education plays in the formation of human capital, and its impact on long-term growth rates in Greece. Specific areas of concentration that are included in the article consist of the reasons for evaluating contributions of education to human capital

formation and economic growth, the types of models that were evaluated in the investigation, the statistical methods employed in the investigation, and the results of the investigation.

The authors elected to conduct this investigation because of several reasons. First, they are Greek citizens with a desire to improve their nation's lot among all nations. Second, because of increasing pressures of globalization there is the possibility that Greece may not be able to meet its demands for human capital resources; consequently the nation will have to either import human capital from abroad or opt to produce at a sub-optimal output level. Third, Greece has had universal education available to its citizens at the primary, secondary, and post secondary levels. The post-secondary levels have been available only upon passing appropriate examinations, and the educational authorities are considering dropping this examination requirement and would like to know if this will likely contribute to Greek economic growth.

The type of model that was employed is an endogenous growth model with a formulation similar to the Lucas production model. The significant difference from the Lucas model from 1988 is that the utility function that is formulated is a family utility function that also includes the household characteristics as well. Constraints are provided relating to the accumulation of both capital and knowledge, where the constraint on knowledge accumulation includes ability and leisure time. The system of equations is solved. The main conclusion is that the driver of the economy is the production of human capital.

The statistical methods that were employed did not use traditional OLS methods. First, tests for stationarity were performed on the data using an augmented Dickey-Fuller

(ADF) test, with stationarity occurring at one lag. Second, the variables were cointegrated using the Jahansen cointegration method that produces a cointegrating vector. Finally, the null hypothesis formulations were tested using Granger causality tests. A total of ten hypotheses were tested, including the null hypotheses as follows:

- growth in primary education levels does not cause growth in GDP,
- growth in secondary education levels does not cause growth in GDP,
- growth in higher education levels does not cause growth in GDP,
- growth in all education levels does not cause growth in GDP,
- growth in primary education investment does not cause growth in GDP,
- growth in GDP does not cause growth in primary education levels,
- growth in GDP does not cause growth in secondary education levels,
- growth in GDP does not cause growth in higher education levels,
- growth in GDP does not cause growth in all education levels,
- and growth in GDP does not cause growth in primary education investment.

The results of the hypotheses testing are interesting. The results for the following null hypotheses being:

- growth in primary education levels does not cause growth in GDP is refuted,
- growth in secondary education levels does not cause growth in GDP, is refuted
- growth in higher education levels does not cause growth in GDP is not refuted,
- growth in all education levels does not cause growth in GDP is refuted,

- growth in primary education investment does not cause growth in GDP is not refuted,
- growth in GDP does not cause growth in primary education levels is not refuted,
- growth in GDP does not cause growth in secondary education levels is not refuted,
- growth in GDP does not cause growth in higher education levels is refuted,
- growth in GDP does not cause growth in all education levels is not refuted,
- and growth in GDP does not cause growth in primary education investment is not refuted.

3. Ballot, Gerard, and Erol Taymaz. "Training Policies and Economic Growth in an Evolutionary World." *Structural Change and Economic Dynamics* 12 (2001): 311-329.

This paper examines the role of training and human capital accumulation as the source of innovation and growth within an evolutionary microsimulation model. The paper opens with a discussion on whether or not training policies play a role in influencing the growth of firms, and thus the economy. Subsequently the discussion proceeds to a debate on training. The model that is used in the simulation is then presented. From this, three different alternative training strategies are discussed. The simulations are then performed, and the results of these discussed.

The issue on whether training plays a significant role in improving a firms output productivity and thus economic growth has been a central issue for several years. Most world governments, and academicians believe that it does. Many instruments are used by governments to encourage investment in human capital such as tax subsidies to firm-

sponsored training activities, the creation of public training institutions, and various apprenticeship schemes. Becker in 1964 demonstrated conclusively that training has a direct and positive effect on productivity. The issue is not whether training works, but how and when to implement a training program.

The debate on training that exists is why should a government intervene in a firm's decision on training. Leaving the issue of training to the whims of the market results in many market failures. First, a firm cannot sponsor general training because of the issue of poaching by rivals. This lack of sponsoring does not imply under investment in training since workers can borrow on capital markets and finance their own training. The capital markets are imperfect, which will likely result in severe rationing of the workers. Second, there is the issue of a large number of skilled workers competing for the high-skill jobs. In this case, there is a lowered incentive for workers to invest in training. Third, there is the polar case where so few workers are highly skilled that industries have little incentive to invest in advanced technologies and create skilled positions. It is because of these types of market failures that government remedies are justified. The type of remedy that may be selected will depend upon the nature of the market failure.

The model used in the investigation is the Model of the Swedish Economic System (MOSES). It was constructed primarily to analyze industrial evolution on the basis of firms' decisions, to reproduce the effects of this on macro accounts as well as on some distributional patterns of the firms. The growth that is demonstrated by the model is micro-based endogenous growth. Modeling of manufacturing is done at the firm and sector levels. Other sectors, including agriculture/forestry/fishery, mining, building,

electricity/gas/water, services, government, and household are modeled at the sector level. Four industries constitute the manufacturing sector. Each of the industries creates a homogenous product and consists of a number of real and synthetic firms. Firms in the industries make decisions on the product, labor, and capital markets. The decisions made by the forms are based off of adaptive expectations.

The model was calibrated to examine the effects of three different alternative training strategies. The first is a government subsidy where the government offers the firms a subsidy set as a percentage of the firm's expenditure on training. The subsidy is funded by the general tax system. The second is based off of the French system of minimum training requirements. All firms have to spend some set percentage of the wage bill, with the percentage varying between zero and five percent. The third strategy was designed to reduce levels of unemployment. Here the government has a two-step plan. It pays for the social security for a newly hired unemployed person for a year, and it pays for the part of training that raises the level of human capital for the unemployed to the firm's average level.

The simulations performed included 101 simulations over 50 years each for each of the training systems. The simulations included variations in the levels of subsidy, duration of training, and frequency of training, and early/late subsidies to training. There are several different results of the simulations. First, subsidy and minimum training schemes have opposite effects on the firm's budget constraint. The minimum training scheme results in an inefficient allocation of resources on the firms, canceling any gains in productivity as a consequence of the training. Second, timing of the training subsidy is important for growth. Any training should occur before, or coincidental within a period

of technological change. Third, subsidies should not favor a particular type of training but include general and specialized training since they are complements. Finally, subsidies for hiring the unemployed are efficient for stabilizing unemployment. The effect on productivity is low, probably because of its narrow scope of focus.

4. Anonymous. "Economic Growth." *Occupational Outlook Quarterly* 45.4 (Winter 2001): 30-35.

This is an annually issued statement by the Bureau of Labor Statistics. It consists of a comprehensive set of economic definitions, and classifications. The article presents year 2010 projections for demand of the general categories of purchase items as their percentage share of total GDP, as well as projections in growth rates of the general categories of purchase items for the period 2000-2010. Conjectures as for causes of changes in trends of consumption are given as needed.

From the perspective of general information and definitions, the article presents to the reader a generalized definition of what GDP is, as well as explanation of the five categories of purchase items. The first category consists of personal consumption expenditures, that is the set of goods and services that are purchased by individuals for personal consumption. The second category is gross private domestic investment and consists of major business purchases such as buildings, factories, machinery, and software. The third category consists of purchases of goods and services by the Federal, State, and local governments. The forth category consists of exports of goods and services to individuals, businesses, and governments in foreign countries. The last category consists of imports of goods and services manufactured abroad by individuals, businesses, and governments domestically.

The 10-year projected change in personal consumption expenditures is projected to grow slightly from 67.8% to 68.5%. The 10-year projected change in gross private domestic investment is projected to grow substantially from 19.2% to 23%. The 10-year projected change in exports is expected to grow substantially from 19.2% to 23.0%. The 10-year projected change in imports is expected to grow substantially from 16.6% to 25.6%, showing a growing dependence and taste for imports in the domestic market. The 10-year projected change in government consumption is expected to fall slightly from 17% to 15.1%. Noteworthy comment is included that the growth in the services component of personal consumption is projected to average a healthy 3.5% annually until 2010. It is also important to note that the growth in the goods component of personal consumption is projected to average a very healthy 5.1% annually until 2010. Business investment in computer software, hardware, and services is projected to grow substantially from 2000 to 2010. Significant to note is that the annual rate of increase of business investment in computer hardware is projected to decline from 35.2% to 15.2% for year 2000 to year 2010. Additionally, the annual rate of increase of business investment in computer software is projected to decline from 15.1% to 12.6% for the same time period.

5. De la Croix, David, and Philippe Monfort. "Education Funding and Regional Convergence." *Journal of Population Economics* 13 (2000): 403-424.

This article is an examination of the process of regional convergence in a growth model where the engine of growth is the accumulation of human capital. The authors open the paper with an introduction of the groundwork for their model. The model is then proposed and formulated. Results of the simulations executed against the model are

discussed. From this, a strategy for choosing the right funding strategy for education is developed.

The authors begin the discussion on the formulation of the model by noting that perfect capital mobility is a powerful engine to enforce convergence across countries or regions. However, for immobile region-specific variables including land and human capital there is significant room for temporary discrepancies between regions. For human capital, the discrepancies are significantly impacted by the way in which education is funded. It is this investigation into the funding strategy that is the basis of the model development.

The model that is proposed is an overlapping generations model similar to one proposed by Diamond in 1965 that features endogenous growth fueled by the accumulation of human capital at the regional level. The model assumes that there are two different regions that share a common capital market and federal government. There are three different funding schemes being evaluated for the model. The first system is one where the local authorities in a region fund the education in their region by a local levy. The second funding scheme is one where the federal government levies nation-wide taxes to finance education in both regions. The third funding scheme is market funding where individuals borrow to finance their education.

The results of the model simulation are a series of propositions. First, assuming that the initial levels of human capital differ between the regions, for regional and market funding schemes there is absolute convergence in human capital levels if and only if there is knowledge spillover between the regions. Additionally, the speed of convergence increases with the degree of knowledge spillover. Second, with a positive level of

knowledge spillover the equilibrium for the federal funding scheme displays a higher rate of convergence than the equilibrium for the market funding scheme which has a higher rate of convergence than the equilibrium for the regional funding scheme. Third, with a positive knowledge spillover between regions, the equilibrium for federal funding has the same long-run growth rate as the equilibrium for regional funding. Forth, when altruism is zero, the growth factor for regional and federal funding is zero. This growth factor is a positive function of regional altruism for low levels of funding, with higher levels of altruism having a negative effect on growth. Fifth, if the degree of altruism maximizes long-run growth, the equilibrium for regional or federal funding has a higher log-run growth rate than the equilibrium with market funding. Sixth, if the level of altruism is sufficiently low, the equilibrium with market funding has a higher long-run growth rate.

For choosing the right funding strategy for education it is necessary to note that all of the equilibria described in the model are sub-optimal as knowledge spillover is not internalized. The question then becomes what is the second-best solution on the basis of what is known. Initially it appears that a nationwide source of funding by either the federal funding method or a market funding scheme enhances regional convergence as opposed to a funding scheme involving regional funding. From the perspective of long-run growth rates, federal and regional funding systems have the same result, with the market funding scheme having different growth rates. Additionally, from the perspective of a social planner, the regional funding system will never be chosen because it features the same growth rate as the federal funding system with a slower rate of convergence. The market funding system is optimal if the following conditions are met: (1) altruism is low, (2) the dispersion of capital across regions is low and, (3) the initial capital stock is

high. The choice of a particular funding strategy incorporates a trade-off between long run growth and short run convergence that is influenced by the initial level of capital for a specific regional discrepancy.

6. Hamilton, James D., and Josefina Monteagudo. "The Augmented Solow Model and the Productivity Slowdown." *Journal of Monetary Economics* 42 (1998): 495-509.

The article is an examination of an augmented Solow model for suitability to explain economic growth, with particular attention to the productivity slowdown that occurred in the middle 1970s. The authors open the paper attempting to answer the question as to why some countries are rich while others are poor. Subsequently, the Mankiw et al. model from 1992 is introduced. The model is then extended to evaluate its suitability to explain the productivity slowdown that occurred in the 1970s. Following this the data used in the regression, and the empirical results are described.

The question as to why some countries are rich whereas others are poor has fascinated economists since the time of Adam Smith. By being able to identify those characteristics and or policies that enhance the growth rate of a nation's economy, social planners will be able to position their nation's favorably among the others of the world. The authors in this article postulate that the augmented Solow model proposed by Mankiw et al. provides just this capability.

The Mankiw et al. model extends the 1956 Solow model and extends it to include human capital investment. The form of the model is $Y(t) = K(t)^{\alpha}H(t)^{\beta}[A(t)L(t)]^{1-\alpha-\beta}$, where Y(t) is aggregate output at time t, K(t) is the stock of physical capital at time t, H(t) is the human capital at time t, A(t) is the level of technology at time t, L(t) is the level of employment at time t, and α and β are constants. This model shows that the economy's steady-state path for the logarithm of output per person follows a linear time trend. The

intercept of this regression line reflects the rate of population growth and the shares of output devoted to investment in physical and human capital. The slope of the regression is exogenously determined, and is related to the rate of technological progress.

The model presented is then extended to offer an explanation of changes in growth rates over time. The revised model has form $Y(t) = K(t)^{\alpha}H(t)^{\beta}[A(t)L(t)]^{1-\alpha-\beta}$ with the difference from the original Mankiw model being that Y(t) is the growth of productivity from the previous period. Specifically the authors attempt to evaluate the causes of the productivity slowdown that occurred after 1970. The Mankiw et al. model predicts that this will happen because of convergence within country groups. The main concern is that there are certain countries that buck the trend and actually accelerated their growth rates while others were declining. It is the characteristics of those outliers that were of particular interest to the researchers, specifically what characteristics of those nations allowed them to escape the productivity slowdown?

The data used in this regression was from various sources. First, the Mankiw et al. regression relied on data from the Penn World dataset Mark 4. In addition, variables related to the growth rate of the working age for populations for the nations were obtained from the World Bank's World Tables and World Development Report. Other variables used in the model were constructed from these sources. The model regressions revealed coefficients for physical capital investment, population growth, and the initial level of output, being positive, negative, and negative respectively. All of the regression coefficients were statistically significant at the .01 level. Curiously, the regression results show that the coefficient for the human capital variable is negative, but not significant at

the .05 level or greater. This leads the author to conclude that investment in physical capital is the single most important factor in economic growth.

7. Judson, Ruth. "Economic Growth and Investment in Education: How Allocation Matters." *Journal of Economic Growth* 3 (December 1998): 337-359.

This is an interesting article that examines how the allocation of resources affects the returns on education. The author contends that it is allocative efficiency that makes a critical difference, rather than shear magnitude alone. The author covers the groundwork for the formulation of the model, the actual model formulations, and the results of regressions.

For the formulation of the model the author starts with the contention that education is a primary determinant in the formation of human capital. Also, there is the contention that education at the primary level provides an important filter function, in that it shows the suitability of higher education for people because without that single step the person's potential remains an unknown. From there the author provides that education in the model should be allowed to work two different ways. First, education provides increasing productivity with decreasing marginal product. Second, education functions as a source of information about the ability of an individual to translate education into skills. With this in mind a model is proposed that builds around four stylized facts. First, ability across individuals varies and affects educational attainment. Second, the rates of return to investment in education diminish at higher levels of education. Third, test scores are a noisy indicator of ability that grows less noisy with advanced levels of education. Forth, for the proposed model the education budget is exogenously defined, and that government can set the levels of students at each level of education.

The models proposed are simple variations of each other. The author first proposes a general form of the model that incorporates heterogeneous ability, progressive revelation of ability with training, and diminishing rate of returns to education in all levels. For the first variation, a two-level of education model is proposed with varying individual ability, education levels of 0, 1, or 2, screening of candidates to verify ability to proceed to the next level, and lumpy returns on education. The second version of the model is more complex with ability being normally distributed, n levels of education, partial screening with improving ability with each levels, and lumpy returns on education similar to the simple model.

The regression results are impressive. First, it does appear that allocation does indeed matter. Human capital accumulation is correlated strongly with allocation. Also, it was noted that for nations that do not allocate their investments in education wisely that educational investment might act as an antagonist to economic growth. Specifically, the author notes that several of the very poor nations have top-heavy investment in education; as a consequence they do not develop the broadest set of less-qualified individuals.

8. Lee, Doo Won, and Tong Hun Lee. "Human Capital and Economic Growth: Tests Based on the International Evaluation of Educational Achievement." *Economics Letters* 47 (1995): 219-225.

The authors in this paper examine models of economic growth involving human capital. They open the paper with an inspection of a subset of the various cross-country studies that have been performed, with several criticisms on those. Subsequently, they propose the Barro model for endogenous growth with different measures of human capital. Regressions are then performed and conclusions drawn.

The cross-country studies examined in the article include Barro in 1991 and 1992, Levine and Renelt in 1992, Levine and Zervos in 1993. The 1991 Barro model, the Levine and Renelt model, and the Levine and Zervos model all use school-enrollment rates as the proxy of human capital. The 1992 Barro model uses years of schooling as its proxy for human capital. The authors note that the variables used to represent human capital in those are unsatisfactory.

The model proposed by the authors is a Barro closed-form endogenous growth model of formulation $y = \alpha + \beta GDP_0 + \gamma H_0$ where y alternatively represents growth rates in GDP per worker, shares of the physical investment in total output, or fertility rates; and where explanatory variables GDP_0 and H_0 are initial levels of GDP per worker and human capital per worker, respectively. The major difference from Barro in this model is the selection for the measure of human capital for the explanatory variable H_0. They propose that a better measure of human capital would be a direct measure of scientific ability and achievement at the secondary education level. Specifically they identify a dataset for this information that was developed by a number of countries under the auspices of the IEA (International Education Association) that provides several different measures of educational ability. This dataset provides one key explanatory variable $SSCORE_0$ that is the science achievement scores for secondary school students in the years 1970-1971 that the authors use for their measure of human capital. Additional differences from the original Barro regressions exist in the selection of data sources for the remaining variables, with most of the data being obtained from the Summers and Heston Mark 5 dataset and the 1989 U.N. Demographics Year Book.

The first regression performed was of growth rates in GDP (GR) per worker against initial levels of GDP (GDP_0) per worker and human capital per worker (H_0). The coefficients for both GDP_0 and H_0 were negative and positive respectively as expected, and statistically significant at the .01 level. The second regression was of growth rates in physical investment in total output (I/Y) against initial levels of GDP (GDP_0) per worker and human capital per worker (H_0). The coefficients for both GDP_0 and H_0 were negative and positive respectively as expected, and statistically significant at the .01 level. The third regression was of growth in fertility rates (FERTNET) against initial levels of GDP (GDP_0) per worker and human capital per worker (H_0). The coefficients for both GDP_0 and H_0 were both negative as expected, and statistically significant at the .01 level.

Several conclusions were drawn. First, a higher initial stock in human capital results in a higher per worker GDP growth rate, a higher ratio of physical investment to GDP, and a lower fertility rate. Second, they corroborated the existence of conditional convergence, nations having a lower per-capita GDP endowment grow more rapidly than those with higher initial GDP endowments.

9. Lorgelly, Paula K., and P. Dorian Owen. "The Effect of Female and Male Schooling on Economic Growth in the Barro-Lee Model." *Empirical Economics* 24 (1999): 537-557.

The Barro-Lee model was formulated to posit a set of hypotheses for the sources of economic growth. The model was important in that it showed what factors contribute to economic growth, although it caused tidal wave of controversy by demonstrating that female education was statistically significant yet negatively related to economic growth. The authors in this article make a direct attack on the formulation of the Barro-Lee model. They first examine the model as proposed citing errors in model formulation.

They then proceed to make their own models that are variants of the Barro-Lee model, which they regress and evaluate.

Regarding the soundness of the Barro-Lee model the authors cite several issues. First, the panel sizes that are used for the various time periods are not uniform, with some time periods using 85 countries, while other periods using 95 countries. The authors contend that it is because of this disparate arrangement that certain facts are being presented in the statistics that should not be. Second, there is the issue of multicollinearity in Barro-Lee that renders suspect the conclusions drawn from its regression. The degrees of multicollinearity that are detailed in the authors' regressions are very high, making it appear that this was not properly controlled for when the model was originally formulated. Third, there is the issue that certain nation groups that do not support and advocate the equal treatment and schooling of women may contribute too significantly to the model weightings, thus making it appear that education of women does not contribute significantly to economic growth. The authors contend that if these nations were omitted from the regressions that the negative and statistically significant coefficient for female education would cease to be significant. A final issue that the authors had with the Barro-Lee model is that some of the data elements appear to be incorrect, thus casting even more suspicion on the soundness of the Barro-Lee model as formulated.

The models that the authors tested consisted of a set of variations of the Barro-Lee model. Their first variation was to make the panel groups for the various timeframe identical in size. This they did by reducing the panel set to 85 countries each. The regression on this augmented model still showed female education statistically significant

and negatively related to GDP growth, yet at a lower degree of confidence. The next formulation of the model consisted of identify nations that do not afford women equal educational rights and eliminating those nations from the regression. The eliminated nations consisted of a number of Asian nations. The effects of this action on the model were very important. First, the coefficient for female education was not statistically significant anymore. Second, the coefficient for male education lost much of its significance. The authors conjectured that it would be possible to omit the educational factors totally from the models and seeing what if any changes occurred.

10. Nussbaum, Martha. "Globalization Debate Ignores the Education of Women." *The Chronicle of Higher Education* 47.2 (Sept 2000): 16-17.

This article is a narrative on the effects of globalization. Specifically, issues regarding the treatment of women are focused on in particular with the effects of creeping globalization. The importance of the education of women is identified and discussed. Lengthy details are provided on the consequence of having education for women at all levels in a country.

Regarding the treatment of women, the author is without critical reservation. She states that women in less developed nations are treated very unequally with their male counterparts. She also states that as a consequence of globalization, that many of the third, forth, and fifth world nations are growing more distant from the leading nations of the globe, and that the women in those nations suffer disproportionately the consequence of the reduced levels of relative wealth. She notes that in the trailing nations, women frequently suffer physical abuse, rape, and murder during difficult times. Nussbaum additionally notes that having the women in those countries endure these levels of physical and mental torment not only endangers their lives, but also reduces their ability

for participation in output production. This situation produces a never-ending cycle of abuse, and reduction of the human capital stock of the nation because of reduced effectiveness of the victimized women and emotionally damaged children. Nussbaum implores the nations of the world to take notice of this situation, to explore ways to reduce violence against women, and to intervene directly in countries that do nothing to disrupt the cycle of violence and decline.

On the education of women, Nussbaum states that providing this beacon of light provides women a path to escape their plight in the victimizing nations by reducing or reversing the downward cycle of violence and economic decline. Specifically, Nussbaum states that providing education for women provides benefits in three different ways. First, women who are educated can increase their levels of production output, and consequently allow their nation to compete more effectively with other nations. Second, having a more educated female workforce allows the nation to compete more advantageously with its peers for foreign investment. Third, providing educational opportunities for women allows those women to impart some degree of their gained knowledge to their offspring, thus acting as an enhancing agent to the later human capital development of those offspring. All three benefits of the education of women are attractive because they suggest that economic growth and competitiveness of a nation are possible through this investment. Sadly, Nussbaum notes that many nations are not aware of the fortifying effects of educating women on growth, and that during hard times in those nations that women frequently are victimized further by disproportionate funding.

11. Rangazas, Peter. "Schooling and Economic Growth: A King-Rebelo Experiment with Human Capital." *Journal of Monetary Economics* 46 (2000): 397-416.

This article is an extension to the neoclassical growth model that incorporates human capital as measured by education. The article opens with a brief review of the neoclassical model developed by King and Rebelo in 1993 along with discussion on the extension of their model. Subsequently, a general theoretical framework for examining transitional growth is posited. This is then used to provide two different model variations that relax certain of the constraints of the original model. Numerical simulation of the models was performed and conclusions drawn.

The King and Rebelo model from 1993 presents a convincing critique of the neoclassical idea that growth s primarily due to the transitional accumulation of physical capital. Numerical simulations show that growth driven by physical capital investment requires initial returns to capital that are dramatically higher than observed in U.S. history. It is this peculiarity that is the foundation for work in this paper. This paper follows the King and Rebelo article in two ways. First, human capital is added to a standard neoclassical model. Second, quantitative analyses performed by King and Rebelo are repeated on this extended model.

The theoretical framework that is proposed is one for transitional growth. Specifically, the framework is a standard overlapping generations model augmented with intergenerational altruism. First, individuals in households are assumed to live for four periods, childhood, young, middle, and old. Each individual works a fixed number of hours in the first two periods of adulthood and retires in the third. Second, individuals are assumed to be altruistic toward their children. Human capital expenditures are made in-kind on behalf of their dependent children during the first period of the adult's life.

The first model is an investigation into whether human capital accumulation can generate a reasonable growth simulation if perfect intergenerational loan markets are assumed. Results of the model simulation are unsatisfactory. First, the expectations that capital-intensity and interest rates will remain constant are not realized, with interest rates remaining too high during the simulation. Second, the pattern of education GDP shares does not make sense. Instead of starting at about one percent and trending upwards as historically has occurred, the share of GDP is about two percent with a very weak upward trend. This poor performance of the school spending suggests that attempts to reduce lower interest rates will not improve the model; lower interest rates will encourage the high levels of school spending to rise further.

The second model is similar to the first with the constraint that there may be limits to the amounts that household can bequeath to their children. It is the binding of this bequeath that changes the patterns of investment. Results of the model simulation are better than in the first model. First, the interest levels generated in the model are close to the historical values for the United States. Second, the level of school spending starts at one percent, and rises rapidly to about two percent.

There are several conclusions drawn in the article. First, the standard infinitely lived agent model is inconsistent with historical data. An infinitely lived agent model implies that school spending is independent of parental wealth, generating counterfactual predictions about the level and growth of school spending and the level of interest rates. Second, binding non-negativity constraint on transfers to future generations eliminates the inconsistencies of the first model particularly interest rate concerns, generating a smooth pattern of growth over the transition.

12. Ranis, Gustav, and Frances Stewart. "Economic Growth and Human Development." *World Development* 28.2 (2000): 197-219.

This article presents a systems approach to ideas relating to human development and economic growth. The authors open the paper with a discussion into the subject areas of human development and economic growth. They then propose a two-chain model that is a system including both economic growth and human development. Following this, they test a series of hypotheses on their model. They then analyze the nations of the world as two their development level in the model that they developed, and propose specific strategies for nations to improve their position.

The position that the authors take is that human development is a subject that is advanced as the ultimate objective of human activity in place of economic growth. Their definition of human development is enlarging people's choices in a way that enables them to live longer, healthier, and fuller lives. They state that it is obvious on its face that simply extending human life and health conditions enables people to contribute more towards output productivity, hence significant towards continuous economic growth for a nation.

The model that is proposed is a two-chain model linking economic growth to human development. The first chain, chain A, links economic growth to human development. GDP contributes to human development mainly through household activities, government activities, and activities of non-governmental organizations. The same level of GDP can lead to different performance on human development according to its allocation among and within the various institutions. The second chain, chain B, links human development to economic growth. Higher levels of human development affect the economy directly through enhancing productivity and creativity.

The hypothesis testing was performed on the links comprising both chains. For chain A, the dependent variable selected to measure human development was life expectancy shortfall reduction from a maximum of 85 years. The explanatory variables selected included the lagged GDP per capita growth rate as a measure of economic growth, public expenditure on education and health as a percentage of GDP, several different measures of income distribution, female primary school gross enrollment, and regional dummies. The results of the regression show that GDP per capita is strong and significant, with higher levels of per capita income leading to better human development performance. Additionally, public expenditure on education and health as a percentage of GDP is strong and significant, with higher values leading to better human development performance. The income distribution measure surprisingly did not have the right sign, and was not significant in determining human development performance. The female primary education variable had a very small but significant value. And the regional dummies were negative and significant for Africa and Latin America, and positive and significant for Asia. For chain B, the dependent variable chosen was GDP per capita growth. The explanatory variable chosen included the log of GDP per capita in 1960 to test for convergence, initial levels of human development using a combined index of life expectancy and literacy, changes in human development over time, gross domestic investment as a percentage of GDP, income distribution lagged, and the regional dummies from chain A. All the explanatory variables were found to be significant and of the correct sign, except the gross domestic investment that was not significant when regional dummies were included.

Following the model formulation the authors collected the nations from the study and arranged them according to the relative effectiveness of the human development and economic growth chains. They found that the nations fall into any of four categories. There are nations with virtuous cycles where the mechanisms of both chains enhance each other. There are nations with vicious cycles where the mechanisms of both chains tend to interfere with each other. There are nations with human development lopsidedness where the human development chain disproportionately enhances the economic growth chain. And there are nations with economic growth lopsidedness where the economic growth chain disproportionately enhances the human development chain. The ideal state for any nation is to be in the virtuous cycle group, with the effects of both chains reinforcing each other.

13. Sorensen, Anders. "R&D, Learning, and Phases of Economic Growth." *Journal of Economic Growth* 4 (December 1999): 429-445.

This article is a review of the stages of development that a nation goes through from a condition of having poor capital endowments through a mature economy. The author initially looks at the conditions at various times inside Germany, Great Britain, and the United States. Subsequently the author develops a model that explains economies in transition. The model is then simulated using appropriate numerical techniques and observations are noted.

The article opens with an examination of the significance of investment in research and development on output in Germany, Great Britain, and the United States. The author notes that in these nations that investment in research and development as a fraction of net output rose from less than a percent to almost five percent in the period 1934 through 1989. The author concludes that the shift in the investment in research and

development is the consequence of the growing probability of research and development for profitable returns. The author states that for economies with very low levels of human capital that research and development is not profitable, and that market size is important for research and development because agents have the option of investing in human capital. In economies with very low levels of human capital the return to innovation will be lower than the return to investing in learning. As the level of human capital increases because of the investment in learning there is a point where investment into research and development becomes more profitable than investment in learning alone.

The model that the author develops is a takeoff on the 1990 Romer model that is extended with human capital accumulation. Designs for intermediate products are developed in a research and development sector. Patents for these intermediate designs are sold to intermediate producers that issue shares to raise capital for production. Final goods are produced using the intermediate goods and human capital. The model's technology is such that the formation of higher levels of human capital creates increased demands for intermediate goods and larger intermediate markets. The model also includes a learning sector where skills are accumulated. It is through the continuous accumulation of human capital that research and development investments can become attractive. The point where the profitability of research and development activities becomes attractive is called a regime shift.

The validity of the model itself could not be verified because of a lack of statistical information. The author instead elected to simulate the model's operation using various techniques. The first observation made of the model is that improved

learning technologies lead to a higher threshold level of human capital and a lower trigger point in time. The second observation made is that improvements in technologies of other sectors lead to a lower threshold level of human capital and a lower trigger point in time. The final observation made is that a less patient representative household results in a lower threshold level of human capital and a higher trigger point in time.

14. Stewart. Francis. "Globalisation and Education." *International Journal of Educational Development* 16.4 (1996): 327-333.

The author links growth, globalization, and educational investment. The primary focus of the article is the impact that globalization plays within national economies, and what the impact of education will have on a nation's ability to survive in the growing global environment. The author presents to the reader a narrative on the evidences found for globalization, the impacts that this has on a nation, what effects that education can play in providing a competitive advantage for a nation, and the issue of outliers and anomalies.

The author finds several examples to support the notion of a continuous trend towards globalization. First, he finds that there is a greater rate of investment in developing countries by other nations than in developed countries than there has ever been previously. Second, he notes that there is acceleration in the rate of trade by trans national corporations (TNCs). Finally, Stewart shows that there is an increasing trend in human capital migration than has ever existed before.

The effects of globalization on nations are many. First, there is the prospect of increased trade. With lesser-developed nations being attractive to foreign investment, the differences in attractiveness may not only lie with the actual wages paid but the capability and availability of their human capital. Thus it is advantageous to the less developed

nations to try to improve their stock of human capital through investment in education and training. Second, for nations with decreased opportunities available for their citizens, those with higher levels of human capital are more likely to migrate to areas where they can earn competitive wages. Those nations must either strive to improve the lot of their citizens, or must enact legislation to interfere with human capital mobility. Third, globalization makes the conditions of the very poor in a nation even worse as they must compete against more highly trained and less expensive foreign talent.

With regards to the role that education can play in a nation in the globalization of a nation, the author is optimistic. Stewart contends that education alone is the primary formative agent of human capital. The training of local talent is beneficial is two distinct ways. First, it makes the nation more attractive to outside investment because of the improved human capital stock. Second, the improved human capital stock improves the productivity of local industries, hence augmenting productivity.

On the issue of outliers and anomalies there is one important point made. The point is that there exist several fifth world nations whose ability to benefit by increased education of its citizens cannot be demonstrated statistically, and may actually diminish the levels of output. This is attributable to severe structural issues in those nations including rule-of-law. Stewart maintains that for the productivity gains that can be realized by improved human capital formation through education, it is imperative that structural issues need to be addressed and remedied first.

15. Wolf, Alison. "Education and Economic Growth." *New Economy* 6.1 (March 1999): 33-37.

This article is an evaluation of the significance of education on economic growth. Wolf examines the conditions of education in Great Britain with particular attention to

the affects that education plays in increasing productivity levels. The areas investigated include the effectiveness of allocation of educational resources in the nation, the creation of a self-fulfilling prophecy by employers who stress credentials and not primary skills, and the returns of productivity increases for educational investment at the primary, secondary, and post-secondary levels.

On the allocation of educational resources, Wolf cites several concerns. First, there is an ever-changing playing field that is presented to the student making it difficult for the student to ascertain the proper path to take. Second, there is the issue of institutional inefficiencies. With significant portions of the educational investment going to maintain an ineffective infrastructure the system strays from providing the best education possible to its students.

On the issue of employers creating a self-fulfilling prophecy by stressing credentials over primary skills, Wolf examines several issues. First is the apparent fact that education seems to contribute to the production of its own demand curve. This the author contends is due to the fact that people are presented with the fact that on average more highly educated people earn more than their counterparts, which creates a desire in the populace to pursue additional studies. Second, the author notes that there may be two different candidates for a position made available to a business. The business will most likely select the candidate with the stellar credentials, rather than the other even it the other is more capable. The consequence of this winnowing process is to encourage young people to pursue a higher degree of education then they might ordinarily pursue, thus driving the demand for education up and the salaries paid to educated people up. Additionally, this winnowing effect has the undesired effect of potentially throttling

growth by diversion of capable human capital. Wolf cites that this type of resource diversion is destructive to the growth of Great Britain's economy, and business should focus on the selection of qualified people on the basis of skills, not credentials solely.

On the empirical evaluation of the returns to investment in education at the primary, secondary, and post-secondary levels, the author finds significant difference between the investment choices. The author finds that investment in primary education contributes significantly to growth in output productivity rates, with every dollar invested at the primary level having a greater than a dollar in increased output levels. For the returns of investment in secondary education, Wolf finds that the returns in increased output levels just barely match the increased costs at this level. For the returns in postsecondary educational investment, the author finds that each dollar invested in higher education does not make up for itself in increased levels of output productivity, probably due to human capital diversion activities. Wolf suggests that the studies suggest that Great Britain needs to examine carefully its choices of investments in education, with a particular attention to the efficiency of education in the secondary and post secondary areas. The author contends that there is great inefficiency in the creation of human capital in these investments that can be optimized through proper evaluation and management.

Books

1. Aldcroft, Derek H. *Education, Training and Economic Performance 1944 to 1990.* New York, N.Y.: Manchester University Press, 1992.

This book is a tedious, long-winded piece that takes a great time to state principles and conclusions. The author examines British educational system and its long string of failures in its ability to meet the demands of domestic industry for qualified

personnel. Specific topics discussed include the impact of education and the economy, the failure of compulsory education, the role of vocational training, the success of higher education, the training of management, and the economic consequences of the failure in the several categories.

On the impact of education and the economy, the author cites a number of studies that associate the significance of having an educated workforce and growth of the economy. The author provides example of studies showing that there is a significant relationship between economic growth and type "type" of education. Engineers and scientists are shown to contribute the greatest to growth in GDP. And of the scientists, those involved in pure research and "hard" sciences are shown to affect GDP greater than the other scientists.

For the failure of compulsory education, the author demonstrates that the British system is lagging in its ability to produce educated manpower in sufficient quantity to meet demand. As a consequence, the domestic industries are unable to expand. Additionally, the author notes that the type of educated individual produce is not necessarily of the "right" type, and that the educational system is unable to encourage those with potential to stay focused. Also, the author notes that quality in education has been adversely affected because of rapid changes in qualification systems. The qualifying system in the schools made it far simpler for people to graduate, without having to really learn the tougher, more disciplined subjects. The consequence of this was that the students produced were growing more illiterate and innumerate.

The role of vocation training in Great Britain the author views more favorably. Specifically he states that the system operates more efficiently than the ordinary school

system. He does however state that the system is still not as well run as its German counterparts. He blames this on the fact that in Great Britain that the people who ordinarily attend the vocational school are those individuals that the regular school system found unacceptable. He believes that for the British vocational school system to reach the level of capability of the German system that the bar needs to be raised on admission and continuous testing.

The success of higher education in Great Britain is less than its German counterparts. The author attributes this to the fact that many of the students in the British system do not stay in their area of expertise. It is not uncommon practice for scientists and engineers in Great Britain to switch to a different non-technical field. Additionally, the author notes that the British system is not skilled at producing sufficient engineers, but rather is more capable of producing "well-rounded" people. This is attributed to the British system's focus on the production of gentlemen.

Of the training of management in Great Britain, the author notes this has grown from bad to worse. First, the people selected to manage may not be well suited to manage the people that they are in charge of. In Great Britain it is not uncommon to have a liberal arts graduate manage engineers, a seeming mismatch. In contrast, in Germany who leads Great Britain in output per capita as well as growth rates, it is common practice to have a senior scientist to manage the less senior colleagues. And second, there is a tendency for greater bureaucracy of organizations in Great Britain versus Germany, so those people selected to manage may have good organizational skill and a want of technical expertise.

Of the economic consequences of failure the author sounds a very concerned, fatalistic view. First, he states that by not being able to produce sufficient skilled manpower for the industry that British industry is declining, or having to import skilled talent from elsewhere. Second, by not keeping trained people in their areas of expertise that there is a net loss of capability. And third, by not having strict, rigorous competency examinations at all levels within the educational system, the manpower that is produced is deficient needing extra training.

2. Barro, Robert J. *Determinants of Economic Growth: A Cross-Country Empirical Study.* Cambridge, MA: The MIT Press, 1997.

This is a work that attempts to answer Adams Smith's question, "What determines the long-term economic growth rate, and therefore the prosperity of nations?" The book examines three different areas of interest to economists. These are the idea of economic growth and conditional convergence, the relationship between economic and political development, and the relationship between inflation and growth rate.

On the investigation into the question of economic growth and conditional convergence Barro develops a number of statistical models. One model is used to show that the conditional convergence theorem as suggested by the extended neoclassical growth model holds. He then proceeds to examine the significance of certain factors including education, life expectancy, fertility, rule of law, etc. on the rate of growth in GDP. Subsequently a table of projected growth rate for the nations in the study is developed. The investigation is then completed with a look at whether adjustments in public policy can be used to improve the non-stellar growth rates of leading nations. Barro concludes that since most of the imperfections in the leading nations have been

worked through, that being able to obtain a sustained long-term growth rate of greater than 2% is not possible for them.

For the investigation into the relationship between economic and political development Barro examines a number of statistics correlating economic growth to democracy, and he concludes that the Lipset hypothesis, that where there is economic growth there is a propensity to democracy, holds. Additionally he develops statistical models that correlate rate of growth in GDP to degree to democracy and finds an inverted quadratic relationship holds. The relationship suggests that GDP growth rates are maximal halfway between the extremes of degree of democracy. He attributes this to that in an extreme dictatorship any increase in political rights increases growth and investment because the benefit from government power is key, and for moderate democracies increases in political rights impair growth and investment because the dominant effect is income redistribution.

The investigation into the relationship between inflation and economic growth examines a few interesting models. The first set of models shows significant negative correlation between inflation rate and growth rate of GDP for countries with a 20% or higher inflation rate, an insignificant correlation between inflation rate and growth rate of GDP for countries with a less than 20% inflation rate, and a significant negative correlation between inflation rate and growth rate of GDP for all countries. He then examines the relationship between the variability of inflation rates and the rate of growth of GDP for the same groups and finds no statistical significance. He then examines the sources of inflation in countries and determines that there is a correlation on whether a nation has historically been a colony of another and whether it has a higher than expected

inflation rate. He then examines those countries that have been colonies and the country that was their last colonizer, and found significant differences between the nations on the grouping by last colonizer. Barro attributes the differences of the nations according to who their colonizer was to the degree of financial discipline that they were instilled with, and cites the financial control boards that they were members of. The last model that Barro evaluates relates the rate of growth in GDP to the degree of independence of the central bank. He finds that no statistically significant relationship exists.

3. OECD. *Education and the Economy in a Changing Society.* Paris, France: OECD, 1997.

The book is a collection of workshop write-ups for the OECD organizational conference of 1989. The OECD (Organization for Economic Cooperation and Development) is an international organization that helps its 30 member governments cope with the economic, social, and governance challenges of a globalized economy. There are 5 significant workshop discussions that are covered in the book. These consist of the new relationships between education and the economy in a changing society, initial education and the preparation of youngsters for active life, the further education and training of adults, the role of higher education in strengthening the scientific and technological potential for social and economic development, and the strategies for change.

On examining the new relationships between education and the economy in a changing society it is proposed that this is always changing, and that education and economic growth are more related than ever before. Four significant points are made on this topic. The first point is that in society fuller, more accessible personal development opportunities must be present for sustainable economic growth. The second point is that

the development, application, dissemination, and mastery of advanced technologies are necessary for economic growth in advanced societies. The third point made is that the definition of being "active" is changing, and that education is crucial for providing more than working skills as it helps towards personal fulfillment. The final point made is that the distinction between education and economy is becoming less distinct, and that greater levels of human capital are being formed through labor market programs and through corporate training.

On the initial education and the preparation of youngsters for active life, the author makes two significant observations. The first is that there appears to be a strong relationship between the quality of primary education, the individuals' results and standardized tests including the SATs, and their ability to be significant contributors to the economy later on in life. The second is that many of the OECD countries are failing to this end. Suggestions are then raised as to the solutions to this decline including curriculum revisions, increased classroom time, and increased inclusion of technology in the classroom.

On the further education and training of adults several observations are made. The first observation is that there are two tendencies that characterize the development of training and educational systems, the increasing involvement of enterprises in the skill formation of young people and adults, and the gradual redistribution of learning opportunities in favor of adults. The second observation made is that strong differences exist between the training efforts of different enterprises. First, training tends to be provided for capital-intensive rather than labor-intensive activities. Second, training tends to be provided for large enterprises rather than small enterprises. And finally, that

training tends to be provided for developing sectors of business, rather than those that are in decline.

On the role of higher education in strengthening the scientific and technological potential for social and economic development, several important issues are raised. The first is that when considering the correlation between higher education and technological development, it is important to consider the development of strategic sciences and technologies when formulating policy. A second issue that is noted is that because of the rising costs of research and development in higher education, there is a tendency for this type of research to be performed at fewer schools; this is a move that the OECD committee concludes is counterintuitive and will likely lead to lowered levels of knowledge capital formation. The final issue that there is a strong need for effective technology transfer and knowledge diffusion. The comment is made that the full economic benefit of innovation occurs only once the new technologies have been absorbed by all the components of manufacturing and service centers; that the significant political and managerial changes require increasing technological assistance.

The strategies for change consist of four separate recommendations. The first suggestion is to establish a new dialogue between education and the economy. The second suggestion is a strong impetus on achieving change in the classroom, as measured by improved skill levels and results and quantified by standardized testing procedures. The third recommendation is to improve the marketplace for training and education, to incentivize the training and continuing education of employees by the business enterprises, as well as through traditional higher education. The final recommendation is

to develop ways to effectively recognize and transfer competencies developed on the jobs and in life to other members of the workforce.

4. Liu, Lewis-Guodo, and Robert Premus. *Global Economic Growth: Theories, Research, Studies, and Annotated Bibliography, 1950-1997.* Westport, CT: Greenwood Press, 2000.

This is well-written work that examines the theories of economic growth. The authors took considerable care to focus on providing an easy to understand narration of collected works. The topics discussed include the historical perspective on economic growth, the Solow model of economic growth, endogenous growth studies in the 1980s, technological spillovers and rate of return studies, informal growth regressions, and a summary accompanied by public policy conclusions. The authors then complete the book with a comprehensive annotated bibliography for the years 1950-1997 consisting of works for the worlds and individual regions.

The historical perspective on economic growth starts with the emphasis that economic growth has been a focus of economic research since Adam Smith wrote his seminal work An Inquiry into the Nature and Causes of the Wealth of Nations. Elaboration is made of Smith's example of a pin factory to show that specialization in labor and capital can increase productivity. Discussion then proceeds to note that the focus of economists shifted to issues of resource allocation, macroeconomic stability, and growth. Subsequently a brief description of the various schools of economic thought is presented with the conclusion drawn that economic growth literature has gone full circle.

For the Solow model, the authors present the model and provide narration of it. Specifically, the Solow model provides that output is a function of labor, capital, and technological progress. The Solow model is significant in that it claims that the amount

of output not due to labor or capital inputs is significant at about 80%. Additionally, the Solow model is important in that technological progress is exogenously defined. The authors provide significant narration on growth accounting, the convergence theorem, and an extended MRW Solow model.

The endogenous growth studies from the 1980s include those that are rival human capital models, nonrival human capital models, and ideal models. For the rival human capital models, the authors provide the famous Kenneth Arrow learning by doing model, as well as a models posited by Rebelo and Romer. For the nonrival human capital model the authors present the Lucas model, where the benefits of new knowledge are only partly excludable. Finally, the ideal model Romer's 1990 model is presented where on-going growth in per-capita income is sustained by endogenous technological progress.

For the discussion on knowledge spillovers, the authors provide elaboration of this for Romer, Lucas, and Delong and Summers. The discussion on Romer and Lucas states that technological spillovers play a prominent roll in their models. First, it is through spillovers that the effect of diminishing returns to capital are negated and growth continues forever. Second, technological spillovers suggest that the economy's long-term equilibrium rate is likely to be sub optimal. The important point suggested by Delong and Summers is that investment in capital equipment provides the mechanism for diffusion of technological innovation throughout society.

The informal growth regressions discussion notes that this area of research is large, and continuously growing. An important point is made about researchers Klenow, Rodriquez-Clare, Levine, Renelt, and Jones that there are many problems with model

formations as posited by researchers. The authors then note several of the growth regression models including Barro-Lee.

For the summary and public policy conclusions the authors note the irony that both the neoclassical growth models, as well as the endogenous growth models seem to offer important basis for growth. The authors note that the neoclassical approach provide the bases for investment into human and physical capital as a means to increase the overall steady-state equilibrium. The endogenous growth theories are important in that they stress the investment in human capital as the basis for long-term economic growth.

5. Scherer, F. M. *New Perspectives on Economic Growth and Technological Innovation.* Washington, D.C.: Brookings Institution Press, 1999.

This book examines the relationship between economic growth and technological innovation. A number of different theories are presented in an evolutionary processional of growth economic theories through present day, followed by a focus on how to assure sustainable growth. The specific topics discussed include the traditional views of economic growth, the transition to new paradigms, investing in technological innovation, and the nature of human capital development.

On the traditional views of economic growth, the author introduces ideas on growth as presented by Smith, Ricardo, Malthus, Domar, and Solow. Smith's example of the pin factory and the division of labor therein is explained; citing that growth in output arises from a further refinement of the division of labor and machines that facilitate this end – an invisible call to R&D for continuous growth. For Ricardo and Malthus, we are introduced to the concepts of diminishing marginal returns through explanation of the land resource example; increases in the population will lead to the increase of cultivation of lands until all arable land has been placed into service and the laborer are forced to

work at the subsistence wage – a truly miserable state of poverty. Domer's ideas on continuous expansion are introduced; if growth were to proceed along an equilibrium path, the rate of saving had to be in balance in the growth rate of the demand for capital. For Solow we are introduced to the Solow model of form Y = Y(K, L, residual) where Y is real output, K is physical capital invested, L is labor input, and the residual is a measure of technological progress.

The transition to the new paradigms introduces us to the more current theories using older economic theories proposed by Marx and Schumpeter. Marx is used as the springboard for the justification for investment in research and development; it is the never-ending quest by the capitalist to reduce labor that prompts the investment in finding newer labor-saving technologies, and this causes growth in output. Schumpeter is used to introduce his concepts of creative destruction and technological waves. The new economic growth theories that are proposed and demonstrated include the concept of human capital as a factor of product, and the effects of knowledge spillovers.

On investing in technological innovation, the author introduces the issue of appropriability in innovation, the costs and risks of technological innovation, the sources of private funds, and public policy towards investing. The issue of appropriability in innovations traces the path of legislative actions to protect the fruit of innovation in both the United States and Canada. The discussion of the costs and risks of technological innovation assesses the costs and risks associated with managing a number of research and development projects. The commentary on the sources of private funding details the evolving group of consortiums available to provide funding for research and development. The public policy towards investing commentary describes policy changes

that have occurred to increase the rate of investment in research and development including direct spending and subsidies, and the use of tax policy to allow expensing of investment costs immediately, use of patent policy to protect the fruit of investment.

For human capital a number of evaluations and recommendations are presented. First, a ranking of the nations is performed along a number of criteria including the level of skilled engineers and technicians. The observation is made that there does indeed appear to be a correlation between this measure of human capital and the output level of a nation. Additional analyses are performed that evaluate the relative conversion rates of degrees in science and engineering and the final destination of the person, in academia, in an alternative field, or in their original field of study. Policy recommendations made include finding ways of increasing the rate of individuals staying within their original field of study, finding ways of increasing the number of individuals that choose science and technology as their field of study, and identifying ways of improving the flow of talented technicians from overseas to the United States.

6. Smolny, Werner. *Endogenous Innovations and Knowledge Spillovers: A Theoretical and Empirical Analysis.* Heidelberg, Germany: Physica-Verlag, 2000.

This is an excellent work that examines technological innovations and their effects on growth through spillover within the firm, between firms within a sector, between different sectors in a nation's economy, and within sectors internationally. The main topics discussed include the sources of productivity at the sector level, the effects of international sector spillovers, innovations prices and employment, endogenous innovations in the model of the firm, and the sources of productivity at the firm level. The author makes extensive use of statistical methods to develop and prove several pertinent hypotheses from the topics discussed.

On the issue of productivity at the sector level several ideas are introduced. The reader is first presented with the neoclassical Solow growth model of form Y = Y(K,L,Residual) where Y is real output, K and L are inputs of physical capital and labor respectively, and the residual is a measure of technological progress that varies over time and is exogenous. The author notes that the residual is very significant and likely explained through other unmeasured factors of production. To this he introduces new factors of production into the production function, human capital, knowledge, and an indicator of the business cycle. The newly revised production function that is developed here is $Y = Y(K,L,HK,U,K^N)$ where Y is real output, K and L are inputs of physical capital and labor respectively, HK is human capital, U is an indicator of the business cycle, and K^N is a measure of the stock of knowledge. Building on these newly introduced factors of production the author proceeds to show that with these that scale economies can occur, specifically that levels of knowledge rise with the level of human capital and from this scale economies arise from the human capital factor. The author then proceeds to analyze a number of time series datasets and proceeds to show that the extended Solow model as developed does hold.

Regarding international sector spillovers, the impact of this on the convergence of output is examined. Two separate experimental paths are followed. The first, a stationary analysis on production differences in Germany, is performed to assess the impact of productivity in the following country. The second, a complex analysis of catching up and convergence between Germany and the United States, uses two different production function formats; the first being the neoclassical growth model which assumes that there are constant returns to scale and that technological progress is external; the

second being an endogenous growth model that relies upon knowledge spillover and scale economies at the aggregate level. The stationary tests performed show that relative labor productivity and relative total factor productivity are stationary, and that this implies unconditional and conditional convergence applies between the nations. The second complex set of regressions reveled that both models appeared to properly define output growth depending upon the time frame. During the period of war reconstruction in Germany capital deepening was the primary source of productivity increases. In later decades this became a less significant source of changes in productivity, and that a greater portion of increases in productivity arose from knowledge spillovers.

On innovations, prices, and employment the author proceeds to develop a theoretical model that explains the impact of innovations on output, capacity utilization, employment, and prices. Several assumptions are made in the model including a delayed adjustment of prices and employment to disentangle short-run demand-induced adjustments, presumption that innovation affects the demand curve, innovation affects production costs, and that the firm affects the market structure through its innovations. Regression of the micro data for German firms reveals that there is a positive correlation between capacity utilization rate, prices, and employment. Secondly, firms having higher rates of product innovation tend to increase prices and have higher levels of utilization, output, and employment growth. Process innovations tended to correlate positively with higher levels of utilization, output, and employment growth. The author then answers the question of why if innovative firms tend to have higher levels of utilization and output that more firms don't innovate. This he states is because it is frequently easier to acquire already created products and processes than to innovate, and that there are other

determinants of the propensity to innovate. Regarding the issue of market structure the author notes that innovation significantly affects this by lowering the price elasticity of demand, lowering the volatility of prices, and raising the volatility of employment.

To evaluate endogenous innovations, the author develops a theoretical model of the innovation and investment behaviors of the firm. He provides a clear classification of innovations into two distinct categories, product, and process. He proposes the idea that product innovations tend to change the demand curve for the product, and that process innovations are more likely to reduce the firm's costs through the more efficient allocation of resources. A number of regressions are performed that show policies promoting stable macro environments lend themselves to higher levels of growth, the firm's size and market power affects its innovativeness, the innovations of competitors spark and increase of innovativeness within the firm, and that inter-firm and inter-sector knowledge spillovers contribute significantly to sustained growth.

The author evaluates microeconomic data for German manufacturing firms to identify sources of productivity growth. He first develops his own augmented growth accounting approach based on a production function that has output growth changes attributed to conventional inputs and total factor productivity, which is treated as an endogenous variable. Results of the regression indicate a significant correlation between the Solo residual and capacity utilization, that innovative firms exhibited significantly higher productivity growth rates, that the higher productivity rates of larger firms indicate scale economies, the productivity of process innovations are higher at smaller firms, and that firm size positively correlates to productivity.

7. Solow, Robert M. *Growth Theory: An Exposition, 2nd Ed.*. New York, NY: Oxford University Press, 2000.

This work is a revision of the original Growth Theory: An Exposition that presents the contents of that work in a more formalized manner. Solow performs a review of the past and current theories of the sources of economic growth. The significant difference with this edition of the work is the emphasis on the evolutionary development of economic growth theories, as well as the new models emphasizing endogenous growth that have been developed since the 1970 publication. Specific topics that are discussed include narration on the Harrod-Domar consistency condition along with various permutations of exogenous growth models, the standard growth model, the Lucas model, the Romer model, the Grossman and Helpman model, and the model posited by Aghion and Howitt.

The first half of the book describes the Harrod-Domar consistency condition as a constraint that can be used to describe models for steady-state growth. What the Harrod-Domar consistency condition states is that the savings rate must just equal the required ratio of investment to output for a steady state to be possible ($s = vn$, where s is savings rate, v is capital requirements per unit output, n is the growth rate of the work force). The permutations that are discussed that use the Harrod-Domar consistency criteria include one with a variable capita/output ratio, one without direct substitution, and one with two assets. Critical differences between the models presented include not only the model formulation, but also the solution to the steady-state conditions described, which are typically manifold encompassed steady states. Additionally, some of the models postulated provide that if the proper path to a steady state is not chosen, that is possible to fall to an increasingly sub-optimal state.

The next topic discussed is a standard model to describe economic growth. The model proposed is one where growth is exogenously determined. There are six important conclusions to note about this model. First, the rate of growth of per-capita consumption, per-capita output, and per-capita capital are equal to the exogenously defined rate of labor-augmenting technological progress, so the steady-state rates of growth are exogenously defined. Second, that steady state is approached asymptotically through any optimal path from any initial condition. Third, at the steady state the investment-output ratio is a constant depending on technology, demography, and tastes. Forth, that it is all right to assume the behaviorist assumption of a constant investment-output ratio, so that there exists some combination of preferences that make a savings level optimal. Fifth, the optimal savings level is less than the elasticity of output with respect to capital. And finally, as long as the savings rate is less than the optimal level a one-time increase in it does not change the growth rate but does move the economy to a higher output path.

The Lucas model that is described emphasizes the endogenous accumulation of human capital, and the effect of this on the growth rate in output. Specific assumptions about the model include that the accumulation of human capital is economically motivated, and the constraint that there are diminishing returns to capital does not hold. The Lucas model proposed consists of three different equations pertaining to consumption, physical capital, and human capital. These equations describe the path of the economy as being obtained by the maximizing of a utility integral similar to the exogenous growth models. The important difference is that there is provision made to allocate time to work or leisure, which has significant impact in the rate of human capital formation and the rate of growth in the economy.

The Romer model that is described provides for endogenous growth through complexity of output produced as a result in investment in human capital. Specifically the model provides that for a set level of resources that a level of complexity of goods can be produced, $R = N\eta\bar{x}$ where R is the resource, N is the number of variety of goods, η is a type of human capital, and ($\bar{x} = x_1 = x_2 = x_3 = x_4 = \ldots = x_N$) is the average output for the good x_i. The important point in the Romer model is the significance of human capital investment in the research and development of new lines of capital goods, succinctly put the relationship is discontinuous with a certain level of production having to be maintained before investment into research and development should occur. With Romer there is no limit on the number of capital goods that can be produced, and hence there is no limit on growth.

Grossman and Helpman introduce a model where growth originates from two different sources. The first source is similar to the Romer model where output increases can be traced to increases in the variety of capital outputs produced. The second source that contributes to the growth in output is the increase in ability to produce a complex variety of output through knowledge capital accumulation. The model as posited is formulated through the development of a demand side function, and a supply side function. And it is through adjustments in the complexity of output, as well as knowledge capital that growth is achieved.

The model introduced by Aghion and Howitt is actually a fallback in perspectives on innovativeness similar to those posited by Schumpeter. Specifically their model provides for several different novelties. First, they introduce chance into the research and development process. Second, they allow for the idea of "creative destruction" from

Schumpeter: That successful research and development efforts can make previous generations of research and development unprofitable, thus the rents from previous innovations are only temporary. Third, which the results of regression analysis provide for the possibility of endogenous cycles brought on by the innovation mechanism.

8. Solow, Robert M. Learning from 'Learning by Doing': Lessons for Economic Growth. Stanford, CA: Stanford University Press, 1997.

This work is an examination by the author on the significance of learning on economic growth. The author reviews Arrow's 1962 paper "The Economic Implications of Learning by Doing", and reexamines and extends some of the notions developed there. The topics that are discussed include learning by doing in the context of growth theory, the significance of innovation and continuous improvement, a set of variations and simulations evaluated, and a set of economic policy suggestions to foster growth.

On the topic of learning by doing in the context of growth theory, Solow elaborates on the 1962 Arrow paper. One point made is that the classical growth models fail to take into account the significance of education, and that education enhances the formation of knowledge capital. The remainder of the discussion elaborates on the development of Arrow's growth model, and that certain deficiencies lie therein. The first area of concern is that the production function developed by Arrow is not truly a production function as all components of capital investment are treated the same. Additionally, Solow notes that the marginal returns to capital invested equation developed allows for certain incongruencies that appear to provide for increasing returns to scale that are simply the consequence of having a discontinuity in the model formulation.

Regarding the significance of innovation and continuous improvement, Solow makes several points. The first is that the significance of continuous improvements on growth increases. Additionally, although investment may not create technology directly, it does create "know-how" whereby the technology can be created. Following these revelations Solow extends the Arrow model to allow for endogenous growth sources, in particular the impact of learning by doing.

Solow examines several simulations of the models that he developed previously. Initially the models are tested with a fixed investment rate, learning by doing multipliers, and innovation efficiency. Each of these is then allowed to be variable and the effects of this are evaluated. Results of the simulation show that frequent small improvements in technology appear more essential for sustained growth than infrequent significant innovation.

Solow suggests several policies for sustained economic growth. First, he notes that endogenous growth is good, but that growth from other factor endowments are equally important and must not be ignored. Second, he emphasizes that sound macroeconomic policies can't be underestimated, and must comprise the bulwark of policy formulation. He notes that even with an environment favoring technological innovation that if other systemic problems exist such as rampant inflation, that innovation will not necessarily overcome this.

[1] Goncalo L. Fonseca and Leanne J. Ussher, The History of Economic Thought: Classical Growth Theory From Smith to Marx. <http://homepage.newschool.edu/het/>.
[2] Ibid.
[3] Ibid.
[4] Adam Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations;* Modern Library Edition, New York, 1937; p. 10.
[5] Goncalo L. Fonseca and Leanne J. Ussher, The History of Economic Thought: Classical Growth Theory From Smith to Marx. <http://homepage.newschool.edu/het/>.
[6] Ibid.
[7] Lewis-Guodo Liu and Robert Premus, *Global Economic Growth: Theories, Research, Studies, and Annotated Bibliography, 1950-1997* (Greenwood Press, Westport, CT, 2000), 4.
[8] Robert M. Solow, *Learning from 'Learning by Doing': Lessons for Economic Growth* (Stanford University Press, Stanford, CA, 1997), 4.
[9] Albelo Alvarez and D. Carmen, "Complementarity Between Physical and Human Capital, and Speed of Convergence." *Economic Letters* 64 (1999): 357.
[10] James D. Hamilton and Josefina Monteagudo, "The Augmented Solow Model and the Productivity Slowdown." *Journal of Monetary Economics* 42 (1998): 414.
[11] Ibid., 420.
[12] D. Asteriou and G. M. Agiomirgianakis, "Human Capital and Economic Growth Time Series Evidence from Greece." *Journal of Policy Modeling* 23 (2001): 486.
[13] Ibid., 487.
[14] Robert J. Barro, *Determinants of Economic Growth: A Cross-Country Empirical Study* (The MIT Press, Cambridge, MA 1997) 13.
[15] This is actually the geometric mean of growth of real per capita GDP for the time period under consideration.
[16] Several trend lines were tested with the quadratic form having the highest adjusted R-squared value.
[17] Only 25 of the 30 OECD nations were included because of insufficient information on the Czech Republic, Slovakia, Germany, Hungary, and Poland.
[18] The convergence of the African subset is shown between the two bold red dashed lines.
[19] N. Gregory Mankiw, David Romer, and David N. Weil, "A Contribution to the Empirics of Economic Growth." *The Quarterly Journal of Economics* 102.2 (May 1992): 419.
[20] Paula K. Lorgelly and P. Dorian Owen, "The Effect of Female and Male Schooling on Economic Growth in the Barro-Lee Model." *Empirical Economics* 24 (1999): 542.
[21] D. Asteriou and G. M. Agiomirgianakis, "Human Capital and Economic Growth Time Series Evidence from Greece." *Journal of Policy Modeling* 23 (2001): 487.
[22] N. Gregory Mankiw, David Romer, and David N. Weil, "A Contribution to the Empirics of Economic Growth." *The Quarterly Journal of Economics* 102.2 (May 1992): 417-418.
[23] Ibid., 417.
[24] Robert J. Barro, *Determinants of Economic Growth: A Cross-Country Empirical Study* (The MIT Press, Cambridge, MA 1997) 13.
[25] The interaction of GDP variable with human capital was highly collinear. The rule of law index variable was not available for the time periods being investigated. The terms of trade variable is unnecessary as the GDP variable being evaluated is the terms of trade corrected GDP.
[26] Seemingly unrelated regression (SUR), also known as joint generalized least squares (JGLS) or as the Zellner estimation, is a generalization of OLS for multi-equation systems. Like the OLS method, SUR assumes that all the regressors are independent variables, but SUR uses the correlations among the errors in different equations to improve the regression estimates. SUR requires an initial OLS regression to compute residuals. The residuals are used to estimate the cross-equation covariance matrix.
[27] Robert J. Barro, *Determinants of Economic Growth: A Cross-Country Empirical Study* (The MIT Press, Cambridge, MA 1997) 13-15.

[28] Paula K. Lorgelly and P. Dorian Owen, "The Effect of Female and Male Schooling on Economic Growth in the Barro-Lee Model." *Empirical Economics* 24 (1999): 552.