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EMPIRICAL TESTS OF EXOGENOUS
AND ENDOGENOUS GROWTH MODELS

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy
in the Graduate School of The Ohio State University

by
Ji Uk Kim, B.A., M.A.

*****
The Ohio State University
1995

Dissertation Committee: Approved by
Paul Evans
Pok-Sang Lam
Amy Glass

Adviser
Department of Economics
ACKNOWLEDGMENTS

"Commit your way to the Lord; trust in him and he will do this"

(PSALMS 37:5)

Professor Paul Evans will be in my prayers for his health and his study because I am asking God to bless all the wonderful people in my life. He has shown me his patience, kindness, and confidence through this research and the way to be a researcher. I would like to express to sincere appreciation to him. Thanks go also to my committee members, professor Pok-Sang Lam, and professor Amy Glass for their suggestions and advice.

I acknowledge the financial support of the Department of Economics in the Ohio State University through my study.

Church members and my family, especially my wife and my son have prayed for me. Thank you all. This dissertation is dedicated to my mother and late father.
VITA

Aug. 10, 1957  Born - Pusan, Korea

Feb. 26, 1981  Bachelor of Arts in Economics
               Chung-Ang University
               Seoul, Korea

Jun. 26, 1985  Master of Arts in Economics
               Chung-Ang University
               Seoul, Korea

1992 - 1995  Graduate Teaching/Research Associate
              The Ohio State University
              Columbus, Ohio

FIELDS OF STUDY

Major Field: Economics

Studies in Money and Macroeconomics

Studies in Public Finance and Urban Economics
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CHAPTER I.

INTRODUCTION

Recently, Paul Romer (1986), Robert Lucas (1988), and Sergio Rebelo (1991) have introduced a new class of growth theories characterized by endogenous growth. These endogenous growth models relax some of the assumptions of neoclassical growth models. The neoclassical growth model developed by Robert Solow (1956) assumes diminishing social returns to reproducible factors and constant return to scale to all factors. Under these assumptions, poor countries with low capital-labor ratios would have high marginal products of capital ceteris paribus. As a result, they would grow faster ceteris paribus than rich countries and tend to catch up. Thus, per capita incomes would converge across economies differing only in initial per capita income. However, this hypothesis must explain the massive cross-country difference in per capita income in terms of innate differences in technology, preference, market structure, government policy, and barriers to technological transfer among others.
Moreover, it provides no explanation for cross-country differences in trend growth rates.

Endogenous growth models assume constant social returns to reproducible factors including physical and human capital and knowledge. Often, externalities to the production of new ideas and knowledge more generally play a key role in generating more economic growth. In the steady-state, the growth rate of per capita income depends on the rate of investment in these reproducible factors. So, Rebelo(1991), Barro(1990), Lucas(1988), and King and Rebelo(1990) emphasized the role of taxes and subsidies as important factors that influence the growth rate through their effects on investment rates.

In this dissertation, we develop models nesting both exogenous and endogenous growth models in which we test the assumptions of diminishing or constant returns to reproducible production factors. We also examine the relationship between long run growth and public policy.

In Chapter II, we investigate whether growth regressions are robust. Much of the growth literature has reported growth regressions to evaluate growth theories. Cross-sectional ordinary least squares regressions relate the average growth rate of per capita income over some period to initial per capita income and country characteristics. These papers apply standard methods of inference to the
estimated coefficients. But results vary considerably. For example, Barro (1991) finds that the ratio of government consumption to GDP has significantly negative effects on growth while Kormendi and Meguire (1985) and Easterly and Rebelo (1993) do not. In regards to the growth rate of population or labor force, Barro find it to be significantly negative, Grier and Tullock positive, and De Long and Summers and Easterly (1994) insignificant. Many other such examples can be cited. Therefore, many results in the literature appear not to be robust to the variables. Following Levine and Renelt (1992), we test the robustness of coefficient estimates to alterations in the conditioning set of information. We also examine the robustness to the countries included in the sample. We find that most are not robust.

The endogenous growth models developed by Lucas (1988) and Rebelo (1991) assume constant returns to scale in reproducible factors of production function in contrast to the neoclassical growth model, which assumes diminishing returns. Therefore, they imply that the rate of return should not vary with the level of per capita income, keeping the composition of the stock of reproducible factors constant. If reproducible factors of production can be produced with constant returns in each country, countries face different trend growth paths. Level effects can be explained by the same factors that explain differences in trend growth rates
in endogenous growth models. Chapter III develops a regression equation nesting a variant of Rebelo's (1991) AK model with Robert Solow's (1956) neoclassical model and tests whether three samples of countries support endogenous or exogenous growth models. The test exploits both time-series and cross-sectional features of the data analyzed. The empirical results provide no evidence that individual countries face diminishing returns to the accumulation of reproducible capital and therefore support endogenous growth models.

Chapter IV formulate a model that nests both the exogenous growth, or neoclassical, model of David Cass (1965) and the AK model of Rebelo. It then tests the null hypothesis implied by exogenous growth that the share of government consumption in output affects the level of output but not its growth rate against the alternative hypothesis implied by endogenous growth that the growth rate is also affected. In simple regression of Chapter II, the ratio of government consumption affected the level of per capita output negatively but did not affect the trend growth rate. This result, however, is less than robust. In Chapter IV, our empirical results provide no evidence for the endogenous growth theories in which variation of government consumption financed by a proportional tax on income changes the steady-state growth rate.
Chapter III and IV, provide opposite results: the former supports endogenous growth resulting from constant returns to scale to reproducible factors of production and the latter is consistent with exogenous growth and diminishing returns. These conflicting results provide evidence in addition to that provided by Chapter II that robustness of results is hard to come by in tests of growth theories.

Chapter V concludes the dissertation. It summarizes the Chapter II - IV and offers some tentative conclusions.
CHAPTER II

ARE GROWTH REGRESSIONS ROBUST?

II-A. Literature Review

In the empirical growth literature, many papers have reported growth regressions to evaluate growth theories. Some examples are Kormendi and Meguire (1985); Baumol (1986); De Long (1988); Romer (1989, 1993); Grier and Tullock (1989); Danny Quah (1990), Barro (1991); De long and Summers (1991); Barro and Sala-i-Martin (1992); Barro, Mankiw, and Sala-i-Martin (1992); Mankiw, Romer, and Weil (1992); Levine and Renelt (1992); Auerbach, Hassett, and Oliner (1993); King and Levine (1993); Easterly (1993, 1994); Easterly and Rebelo (1993); Easterly, Kremer, Pritchett, and Summers (1993); Fischer (1993); Kremer (1993); Blomstrom, Lipsey, and Zejan (1993); Persson and Tabellini (1994); and Alesina and Rodrik (1994). These papers estimate cross-sectional ordinary least squares regressions relating the average growth rate of per capita
income over some period to initial per capita income and country characteristics. They then apply standard methods of inference to the estimated coefficients. Results vary considerably, however.

For example, Kormendi and Meguire find evidence that civil liberties have significant positive effects on growth, but Grier and Tullock find different results. Baumol finds evidence that initially poor countries grow faster while De Long and Romer do not. Barro finds that the ratio of government consumption to GDP has significantly negative effects on growth while Kormendi and Meguire and Easterly and Rebelo do not. Levine and Renelt, Fischer, and Easterly (1993) found the black-market exchange rate premium to be insignificant in cross-section regressions. By contrast, Barro (the absolute value of deviations of the relative price of investment goods), De Long and Summer (a high relative price of equipment investment goods), and Easterly (1994, the black market premium) find these variables to have a negative and significant effects on growth. With regard to the growth rate of population or labor force, Barro find it to be significantly negative; Grier and Tullock, positive; and De Long and Summers and Easterly (1994), insignificant. De Long and Summers have argued for the existence of externalities to equipment investment. However, Auerbach, Hassett, and Oliner use De Long and Summers’ own data excluding just one country (Botswana) to
refute De Long and Summers' claim to have uncovered robust evidence of high social returns to equipment investment. Therefore, we find that few results are robust to the variables or to the sample included in the regression.

A list of the explanatory variables considered as country characteristics includes human capital (Barro), investment in physical capital (Mankiw, Romer, and Weil), government spending (Kormendi and Meguire and Easterly and Rebelo), inflation (Easterly 1994), quantity of equipment investment (De Long and Summers, Auerbach, Hassett, and Oliner), economic policy (Easterly; Easterly, Kremer, Pritchett, and Summers; Fischer), population growth (Kremer), income distribution (Persson and Tabellini, Alesina and Rodrik), development policy (Romer 1993), distortionary policy (Easterly), political stability (Barro), financial system (King and Levine), international finance and trade (Kormendi and Meguire, Barro, Mankiw, and Sala-i-Martin).

Levine and Renelt (1992) used equations of the form

\[ y = \beta'_1 I + \beta'_m M + \beta'_z Z + u \]

where \( y \) is per capita GDP growth, \( I \) is the vector of variables always included in the regression, \( M \) is the variable of interest, and \( Z \) is a vector of variables chosen
from a pool of variables identified by past studies as potentially important explanatory variables. I variables are \( \text{INVT} \) (investment share of GDP), \( \text{RGDP60} \) (real GDP per capita in 1960), \( \text{GPO} \) (growth rate of population), and \( \text{SEC} \) (the secondary-school enrollment rate in 1960). They used a variant of Edward Leamer’s (1983) extreme-bounds analysis to test the robustness of coefficient estimates to alterations in the conditioning set of information. They find that almost all results are fragile and show that many previous inferences are not robust. They found, however, a positive and robust correlation between average growth rates and \( \text{RGDP60} \) and \( \text{INVT} \). Blomstrom, Lipsey, and Zejan (1993) find some results of multiple regression and simple causality tests that growth induces subsequent capital formation to a much greater extent than that capital formation induces subsequent growth. Thus, they find no robust result that fixed investment is the key to economic growth. From all above results, estimates of coefficients appear not to be robust to the variables included in the regression.

This chapter further investigates how robust results are to the variables and sample included in the regression. The structure of the paper is as follows: Section II.B. introduces the basic framework of analysis and describes data. Section II.C. discusses several empirical issues and gives the main results. Section II.D. concludes.
II.B. The Model and Data

II.B.1. The Model

We start with a basic model similar to one formulated and fitted by Mankiw, Romer, and Weil (MRW):

\[
GRW_i = \alpha + \beta_1 GDP60_i + \beta_2 \ln(INVT_i) + \beta_3 \ln(GPOP_i) + \beta_4 \ln(SCHOOL_i) + \varepsilon_i
\]

II.B.2. Data

Our sample consists of 108 countries for 1960-1985. Each observation corresponds to a country. We consider the following variables:

(i) GRW, the annual average growth rate of real GDP per capita. Its mean value is 0.021, and it ranges from -0.017 to 0.075.

(ii) GDP60, the log of initial per capita real GDP. It allows for differences in the stage of development and permits testing of endogenous growth against exogenous growth.
(iii) INVT, the annual average ratio of real gross domestic investment in physical capital to real GDP.

(iv) GPOP, the average annual rate of population growth.

(v) SCHOOL, a measure or measures of schooling.

   We consider three such measures:

(vi) SEC60, secondary school enrollment rates of the population aged 12-17 in 1960.

(vii) AVSEC, the average of secondary school enrollment rates in 1960 and 1985.

(viii) GEETO, the annual average ratio of government expenditure on education to GDP.

   Finally, we consider whether the regression equation (1) can be improved on by including

(vi) GOVC, the average ratio of real government consumption expenditures to real GDP.

All of the data come from Barro and Wolf (1989).
II.C. Empirical Results

II.C.1 Conditioning information set

The first column of Table 1 reports the results of fitting equation (1) using SEC60 as our measure of schooling. All three estimated coefficients except ln(GPOP) are highly significant. In MRW's results, the estimated coefficient on ln(.05 + GPOP) was statistically significant. Column (ii) in Table 1 uses average school enrollment rates (AVSEC) in place of SEC60 with much less satisfactory results. The three estimates on ln(INVT), ln(GPOP), and ln(AVSEC) are not significant. Column (iii) in Table 1 uses the annual average ratio of government expenditure on education to GDP (GEETO) in place of SEC60. Coefficients of all variables are significant, but GEETO has an implausible negative effect. We add two variables, ln(SEC60) and ln(AVSEC) to column (iv). The growth regression (iv) shows that the adding two variables make the results worse. When ln(GOVC) adds up column (i), ln(GPOP) is still insignificant at column (v).
ln(GOVC) replaces ln(GPOP) as government policy factor from column (i). The below equation reports the results.

\[
GRW_i = 0.589 - 0.0135 \ln(GDP60_i) + 0.0248 \ln(INVT_i) + 0.0073 \ln(SEC60_i) \\
\text{SEE} = 0.0133, \quad R^2 = 0.5, \quad \text{Numbers in parentheses are t-ratios.}
\]

All variables have their expected sign and are highly significant. Equation (3) has robust coefficients and has considerable explanatory power (adjusted R-square is 0.496). We, therefore, choose these variables to form the basic of conditioning information set.

III.C.2. Econometric Issues

_Ridge Regression_

Very often the explanatory variables are highly intercorrelated, producing multicollinearity. SEC60 is relatively strongly correlated with GDP60, GPOP, and
Multicollinearity is only a problem where estimates on some of the coefficients have large standard errors and low $t$-ratios because correlation among the variables is large. From the Table 1, estimates on $\ln(GPOP)$ and $\ln(GEETO)$ have large standard errors and low $t$-ratios. One measure of multicollinearity is the condition number discussed by and Belsley et al. (1980). The condition number is defined as the square root of the ratio of the largest to the smallest eigenvalue of the matrix $X'X$ of the explanatory variables.

In Table 1, we present the condition number (CN) for each model. The greater the intercorrelation among the variables, the higher will be the CN. The model (Table 2, (i)) with variables, $\ln(GPOP)$ and $\ln(GEETO))$ has CN, 17.632. Multicollinearity does not appear to be serious from the results.

One of the solutions for multicollinearity is to use ridge regression, a technique introduced by Hoerl and Kennard (1977). The ridge regression estimates of $b$ in $y = Xb + u$ is given by

$$\begin{equation}
(4) \quad b(k) = (X'X + kI)^{-1}X'y
\end{equation}$$

where $k>0$ is constant, often called the shrinkage parameter. Least squares is the special case of $k=0$. The estimate $b(k)$ is biased, but has a smaller standard error than the LS estimator. Choosing $k$ is real problem with ridge regression, but we calculated some value of $k$ following the method suggested by Hoerl et al. (1975).
Table 2 compares the LS estimators and ridge estimators. Column (ii) in Table 2 suggests that ln(GPOP) should be retained. But, when ridge regressions without ln(GEETO) but with ln(GPOP) shows that it become less important.

Dropping Variables

We can have smaller mean square errors than the OLS estimators, by dropping some variables. We drop two variables, ln(GPOP) and ln(GEETO) and then, run ridge regression. Column (vi) of Table 2 reports the results where we have the lowest standard errors of coefficients.

Weighted Least Squares

Heteroskedasticity may be present in the error term of equation (2). If so, the t-ratios reported in Table 1 and equation (3) are inconsistent. We used two methods to handle this potential problem. First we computed weighted least squares assuming that residual standard deviations are proportional to 1/GDP60. Second, we used White(1980) method for computing covariance matrix robust to heteroskedasticity. Since these methods give similar results, we report only the White results:
\[ g_i = 0.589 - 0.0135 \ln(\text{GDP60}_i) + 0.0248 \ln(\text{INVT}_i) + 0.0073 \ln(\text{SEC60}_i) - 0.0139 \ln(\text{GOVC}_i) \]

\begin{align*}
(5) & \\
& (0.0108) \quad (0.0027) \quad (0.0039) \quad (0.0023) \\
& (0.0040)
\end{align*}

SEE = .0133, numbers in parentheses are standard errors.

Outliers

Any observation for which the residual is larger than 3 times standard errors is dropped. Removing them does not much affect the results for the whole sample attained above or for the two samples of rich and poor countries considered below.

II.C.3. Rich and Poor Countries

We divide the sample in two, producing samples of 54 countries each that have the highest and lowest values of GDP60. When we run OLS regression, we use the regressors without taking logarithms except GDP60 and also with \( \ln(\text{SEC60}), \ln(\text{INVT}), \) and \( \ln(\text{GOVC}) \). See Tables 3 and 4. Compared to the results for the whole sample of countries, the overall fit is not worse. All estimated coefficients are statistically significant in Tables 3 and 4 except for the
coefficients on lnSEC60 for the rich countries and on ln(GOVC) for the poor countries. Next, we divide the sample in two, producing two sets of two the 54 countries that have the smallest and largest values of SEC60 and INVT, respectively. Table 5 reports estimates for these four samples. For the countries with the least schooling, the coefficients of ln(GOVC) are insignificant. From column (iv) of Table 5, the coefficient on ln(INVT) is not significant. These results show that the growth regressions are not entirely robust to the samples.

The Analysis of Variance Test

Consider two independent sets of data with sample sizes $n_1$ and $n_2$, respectively. The regression equations are

\begin{align*}
y &= \beta_0 + \beta_{11}x_1 + \beta_{12}x_2 + \beta_{13}x_3 + \beta_{14}x_4 + u \\
y &= \beta_1 + \beta_{21}x_1 + \beta_{22}x_2 + \beta_{23}x_3 + \beta_{24}x_4 + u
\end{align*}

A test for stability of the parameters between the populations that generated the two data sets is a test of the hypothesis:

$$H_0: \quad \beta_0 = \beta_1, \quad \beta_{11} = \beta_{21}, \quad \beta_{12} = \beta_{22}, \quad \beta_{13} = \beta_{23}, \quad \beta_{14} = \beta_{24}$$

With $n_1 = n_2 = 54$ and the result Table 3, the calculated $F$-value is 3.807. From the $F$-tables with 5 and 98 degrees of freedom, we see that the 1% critical value is 3.17. Thus we can reject the hypothesis of stability at 1% level of significance.
From \( n1 = 54 \) and the results in Table 4, calculated F-value is 1.209. From the F-tables, we see that the 10\% critical value is 1.90. Thus even at the 10\% level of significance, we cannot reject the hypothesis of stability when INVT and SEC60 are transformed to \( \ln \) INVT and \( \ln \) SEC60. Using the samples sorted by schooling and physical investment, we find calculated F-values of 0.5148 and 0.796, respectively. Hence, we cannot reject the hypothesis of stability. We think that the growth regression should be specified in logarithms to avoid structural instability.

II.C.4. Graphic Analysis

We investigate whether growth regressions are robust or fragile to the countries included in the sample. We use an equation of the form

\[
GR_i = a + b \ln GDP60_i + c \ln INVT_i + d \ln SEC60_i + e \ln GOVC_i + v_i
\]

where \( GR_i \) is the annual average growth rate of real GDP per capita. We run this equation for \( 1,2,-n \); \( 1,2,-n+1 \); \( 1,2,-n+2; \) \( -- \); \( 1,2,-N \). The estimated coefficients and 90\% confidence intervals are plotted each of these samples.
Countries are included in ascending or descending order of the values of the variables, GDP60, SEC60, INVT, and GOVC from Figure 1 to Figure 8.

First, we use base model and then, we plot the results with n=21 and N=108. We obtain the following results:

1. Ln(SEC60) estimates appear to be increasing in ln(SEC60) and ln(INVT). See Figure 1.
2. Ln(INVT) estimates appear to be increasing in ln(SEC60), decreasing in ln(INVT), and rapidly decreasing in ln(GOVC). See Figure 2.
3. Ln(GOVC) estimates do not change systematically. See Figure 3.
4. Ln(GDP60) estimates estimates are increasing in ln(GDP60) and ln(GOVC) and decreasing in ln(SEC60). See Figure 4.

Second, we estimated models in which the levels of GDP60, SEC60, INVT, and GOVC were used as the regressors.

1. The SEC60 estimate are less stable and drift more than those of ln(SEC60). See Figures 5.
2. The INVT estimates are strongly decreasing in GDP60 and INVT and increasing in SEC60. See Figure 6.
3. The GOVC estimates show no clear pattern. See Figure 7.
4. The GDP60 estimates are strongly increasing in GDP60 and decreasing in SEC60. See Figure 8.

According to the graphic analysis of estimates, we find out the estimates of variables are somewhat sensitive to the sample when the regressors are \( \ln(\text{GDP60}) \), \( \ln(\text{INVT}) \), \( \ln(\text{SEC60}) \), and \( \ln(\text{GOVC}) \) and highly sensitive when the regressors are GDP60, SEC60, INVT, and GOVC.

II.C.5. Bootstrap Resampling Methods

For sample sizes (N) for 20, 40, 60, and 80, we want to calculate the fraction of samples from all 108 countries for which \( \ln(\text{GDP60}) \), \( \ln(\text{INVT}) \), \( \ln(\text{SEC60}) \), and \( \ln(\text{GOVC}) \) and all four are statistically significant at the 0.05 level. Monte Carlo sampling methods can be used when appropriate sampling results are not available and one wishes a nonparametric method of estimating measures of precision. One of resampling methods is the bootstrap, which uses the design of Monte Carlo experiment to approximate the distribution of the error terms. We draw of 20, 40, 60, and 80 samples countries with replacement from the given data.
sets with equal probability by generating a random number from uniform distribution.

We pick 10,000 samples for each sample size at random and estimate the base model, calculate the t-value for each variable and the F-value for all four variables, and add one to a counter if significant and zero if not. Then we calculate the fraction of the 10,000 samples with significant estimates. Table 6 shows the results. All four variables are unlikely to be found statistically significant in samples of size 20 and are often insignificant in samples of size 40. In longer samples, all variables are very likely to be significant. The degree of significance of each variable increases as sample size increases. The degree of significance of \( \ln(\text{SEC60}) \) and \( \ln(\text{GOVC}) \) is less than that of the other variables.
II.D. Summary

Some empirical growth regression literature find that estimate coefficients are not robust to the variables included in regression. Also, these results stem from the inconsistency of OLS regression because they did not hold constant a set of variables in regression model. This paper shows below results,

First, when we reestimate MRW model with added countries data we find that some estimate coefficients which was robust are insignificant.

Second, we test base model using the methods, the ridge regression, dropping variables, weighted least squares, robust covariance matrix, and outliers to adjust biased estimates and large standard errors. We find that some estimates are is not significant.

Third, the key results show that the growth regressions are not robust to the samples. we devide the sample into two sample consisting of the 54 countries with highest and lowest values of GDP60, SEC60, and INVT. From the devided sample, we find that all estimated coefficients are not robust. We conclude that the growth regression should be specified in logarithms to avoid structural instability.
Forth, from graphic analysis using simple endogenous growth model, and base growth model, and also using regressors with low data, we find that estimates of variables are not stable when we change the included countries and the ascending order of variables. We show that the estimates of variables are somewhat sensitive to the sample when regressors are in logarithms and highly sensitive when the regressors are without logarithm.

Fifth, from the data generating process (DGP), the degree of significance of each variable increases as sample size increases. Some variables are less significant than other variables.
Table 1. Simple Regression (1)

<table>
<thead>
<tr>
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<th>(i)</th>
<th>(ii)</th>
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<td>0.0688</td>
<td>0.0221</td>
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<td></td>
<td>(4.6351)</td>
<td>(4.7675)</td>
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<td>(-4.5173)</td>
<td>(-6.0241)</td>
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<td>ln INVT</td>
<td>0.0213</td>
<td>0.0146</td>
<td>0.0286</td>
<td>0.0227</td>
<td>0.0246</td>
</tr>
<tr>
<td></td>
<td>(5.8207)</td>
<td>(1.5381)</td>
<td>(7.0549)</td>
<td>(5.3506)</td>
<td>(7.0051)</td>
</tr>
<tr>
<td>ln SEC60</td>
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<td></td>
<td></td>
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<td>ln GPOP</td>
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<td>-0.0024</td>
<td>-0.0056</td>
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<td>-0.0044</td>
</tr>
<tr>
<td></td>
<td>(-1.1679)</td>
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<td>ln GOVC</td>
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<td></td>
<td>-0.0147</td>
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<td>ln GEETO</td>
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<td></td>
<td>-0.0056</td>
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</tr>
<tr>
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<td></td>
<td>(-2.1734)</td>
<td></td>
<td>(-1.3809)</td>
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</tr>
<tr>
<td>ln AVSEC</td>
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<td></td>
<td></td>
<td>0.0032</td>
<td></td>
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<td>(\bar{R}^2)</td>
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<td>0.0056</td>
<td>0.0149</td>
<td>0.0142</td>
<td>0.0132</td>
</tr>
<tr>
<td>CN</td>
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<td></td>
<td></td>
<td></td>
<td>13.799</td>
</tr>
</tbody>
</table>

Notes:
1) The table reports OLS regression; independent variable (GRW) is the annual average growth rate of GDP per capita; GDP60= the log of initial per capita GDP; INVT= the annual average rate of domestic investment to GDP; SEC60= secondary education enrollment rates of the population aged 12-17 in 1960; AVSEC= the average of secondary school enrollment rates in 1960 and 1985; GEETO= the annual average ratio of government expenditures on education to GDP; GOVC= the average ratio of government consumption expenditures to GDP; GPOP= the average annual rate of population growth.
2) SEE= standard error of the estimate
3) t-values are shown in parentheses
5) CN is condition number.
Table 2. Sensitivity Analysis (1)

<table>
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<tr>
<th>Ind. Variable</th>
<th>(I)</th>
<th>(ii)</th>
<th>(iii)</th>
<th>(iv)</th>
<th>(v)</th>
<th>(vi)</th>
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<tr>
<td></td>
<td>LS</td>
<td>Ridge</td>
<td>LS</td>
<td>Ridge</td>
<td>LS</td>
<td>Ridge</td>
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<td>(0.0025)</td>
<td>(.0023)</td>
<td>(.0023)</td>
<td>(0.0024)</td>
<td>(0.0023)</td>
</tr>
<tr>
<td>ln INVT</td>
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<td>(.0034)</td>
<td>(0.0035)</td>
<td>(0.0034)</td>
</tr>
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<td>ln SEC60</td>
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<td>0.0054</td>
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<td>(0.0017)</td>
<td>(.0019)</td>
<td>(.0017)</td>
<td>(0.0017)</td>
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<td>ln GOVC</td>
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<td>-0.0147</td>
<td>-0.0154</td>
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<tr>
<td></td>
<td>(0.0042)</td>
<td>(0.0040)</td>
<td>(.0037)</td>
<td>(.0035)</td>
<td>(0.0037)</td>
<td>(0.0034)</td>
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<td>ln GPOP</td>
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<tr>
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<td>(0.0022)</td>
<td>(.0025)</td>
<td>(.0023)</td>
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<td>ln GEETO</td>
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<tr>
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<td>(0.0042)</td>
<td>(0.0039)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.50</td>
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<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.48</td>
</tr>
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<td>SEE</td>
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<td>0.0134</td>
<td>0.0132</td>
<td>0.0133</td>
<td>0.0133</td>
<td>0.0135</td>
</tr>
<tr>
<td>k</td>
<td>-</td>
<td>0.7941</td>
<td>-</td>
<td>0.3525</td>
<td>-</td>
<td>0.6866</td>
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<td>CN</td>
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<td>13.799</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>

Notes:
1) Numbers in parentheses are standard error not t-ratio;
2) Column (i), (iii) and (v) report OLS regression;
3) column (ii), (iv) and (vi) report ridge regression;
4) k is the shrinkage parameter;
5) CN indicates condition number.
<table>
<thead>
<tr>
<th>Ind. Variable Countries</th>
<th>Poor Countries(54)</th>
<th>Rich Countries(54)</th>
<th>Whole(108)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-0.0067</td>
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<td>0.0062</td>
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<td></td>
<td>(-0.7615)</td>
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<td>(1.1190)</td>
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<td>GDP60</td>
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<td>-0.0103</td>
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<td></td>
<td>(-2.3518)</td>
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<td>INVT</td>
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<td>0.1547</td>
</tr>
<tr>
<td></td>
<td>(5.1199)</td>
<td>(2.9913)</td>
<td>(6.3137)</td>
</tr>
<tr>
<td>SEC60</td>
<td>0.1085</td>
<td>0.0279</td>
<td>0.0254</td>
</tr>
<tr>
<td></td>
<td>(3.6383)</td>
<td>(2.0777)</td>
<td>(2.1720)</td>
</tr>
<tr>
<td>GOVC</td>
<td>-0.0940</td>
<td>-0.0880</td>
<td>-0.0956</td>
</tr>
<tr>
<td></td>
<td>(-2.6852)</td>
<td>(-2.6234)</td>
<td>(-3.9637)</td>
</tr>
<tr>
<td>( \bar{R}^2 )</td>
<td>0.471</td>
<td>0.348</td>
<td>0.383</td>
</tr>
<tr>
<td>SEE</td>
<td>0.0144</td>
<td>0.0133</td>
<td>0.0148</td>
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</tbody>
</table>

Notes:
1) Two samples consisting of the 54 countries with highest and lowest values of GDP60.
2) INVT, SEC60, and GOVC are not taken logarithm;
3) Numbers in parentheses are \( t \) values.
Table 4. Sensitivity Analysis (3)

<table>
<thead>
<tr>
<th>Ind. Variable Countries</th>
<th>Poor Countries(54)</th>
<th>Rich Countries(54)</th>
<th>Whole(108)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.0683</td>
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<td></td>
<td>(4.7075)</td>
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<td>(6.8266)</td>
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</tr>
<tr>
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<td>(-2.5142)</td>
<td>(-3.6175)</td>
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</tr>
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<td>ln INVT</td>
<td>0.0246</td>
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<td>0.0248</td>
</tr>
<tr>
<td></td>
<td>(5.1933)</td>
<td>(3.3463)</td>
<td>(6.9867)</td>
</tr>
<tr>
<td>ln SEC60</td>
<td>0.0085</td>
<td>0.0056</td>
<td>0.0073</td>
</tr>
<tr>
<td></td>
<td>(3.5504)</td>
<td>(1.6001)</td>
<td>(4.2721)</td>
</tr>
<tr>
<td>ln GOVC</td>
<td>-0.0103</td>
<td>-0.0143</td>
<td>-0.0139</td>
</tr>
<tr>
<td></td>
<td>(-1.4960)</td>
<td>(-2.9433)</td>
<td>(-3.7673)</td>
</tr>
</tbody>
</table>

R² | 0.472 | 0.345 | 0.496 |
SEE | 0.0144 | 0.0133 | 0.0134 |

Notes:
1) Two samples consisting of the 54 countries with highest and lowest values of GDP60.
2) Take log on explanatory variables;
3) Numbers in parentheses are t values.
### Table 5. Sensitivity Analysis (4)

<table>
<thead>
<tr>
<th>ind vals.</th>
<th>Schooling (i)</th>
<th>Schooling (ii)</th>
<th>Physical Investment (iii)</th>
<th>Physical Investment (iv)</th>
</tr>
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<tr>
<td></td>
<td>Smallest(54)</td>
<td>Largest(54)</td>
<td>Smallest(54)</td>
<td>Largest(54)</td>
</tr>
<tr>
<td>Constant</td>
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<td>0.0475</td>
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<td></td>
<td>(3.0596)</td>
<td>(4.4710)</td>
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<td>(2.6368)</td>
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<td>GDP60</td>
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<td>-0.0186</td>
</tr>
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<td>(-2.3882)</td>
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<td>(-3.6499)</td>
<td>(-4.7004)</td>
</tr>
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<td>ln INVT</td>
<td>0.0226</td>
<td>0.0257</td>
<td>0.0252</td>
<td>0.0133</td>
</tr>
<tr>
<td></td>
<td>(5.0409)</td>
<td>(3.3535)</td>
<td>(4.7573)</td>
<td>(1.2275)</td>
</tr>
<tr>
<td>ln SEC60</td>
<td>0.0064</td>
<td>0.0105</td>
<td>0.0049</td>
<td>0.0113</td>
</tr>
<tr>
<td></td>
<td>(2.1240)</td>
<td>(1.9382)</td>
<td>(2.3372)</td>
<td>(3.8956)</td>
</tr>
<tr>
<td>ln GOVC</td>
<td>-0.0120</td>
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<td>-0.0111</td>
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<td>(-1.6870)</td>
<td>(-3.0741)</td>
<td>(-1.9974)</td>
<td>(-3.3139)</td>
</tr>
</tbody>
</table>

| 2        | 0.401         | 0.409         | 0.417                     | 0.322                    |
| SEE      | 0.0136        | 0.0134        | 0.0123                    | 0.0142                   |

**Notes:**
1) Reestimated base model with dividing two groups, poor(54) and rich(54) countries;
2) Numbers in parentheses are t value;
3) Results (i) and (ii) are estimated using data in ascending order of SEC60;
4) Results (iii) and (iv) are estimated using data in ascending order of INVT.
Table 6. Fraction of Samples with Significant Estimates

<table>
<thead>
<tr>
<th>Sample Size (N)</th>
<th>ln(GDP60)</th>
<th>ln(INVT)</th>
<th>ln(SEC60)</th>
<th>ln(GOVC)</th>
<th>All 4 vars.</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.6478</td>
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<td>0.4657</td>
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<td>0.2941</td>
</tr>
<tr>
<td>40</td>
<td>0.9086</td>
<td>0.9677</td>
<td>0.6723</td>
<td>0.5823</td>
<td>0.6086</td>
</tr>
<tr>
<td>60</td>
<td>0.9813</td>
<td>0.9972</td>
<td>0.8227</td>
<td>0.7500</td>
<td>0.9183</td>
</tr>
<tr>
<td>80</td>
<td>0.9974</td>
<td>0.9999</td>
<td>0.9127</td>
<td>0.8689</td>
<td>0.9881</td>
</tr>
</tbody>
</table>

Notes:
1) Draw 10,000 samples for each N at random;
2) t-test for each variable and F test for all four.
3) % of Significance = number of significance / 10,000
Figure 1. Estimates $\ln(\text{SEC60})$ and 90% Confidence Intervals

Model: $GR = a + b \ln(\text{GDP60}) + c \ln(\text{INVT}) + d \ln(\text{SEC60}) + e \ln(\text{GOVC}) + \nu$
Figure 1 (continued)

(iii) ascending order of INVT

(iv) ascending order of GOVC
Figure 2. Estimates $\ln(\text{INVT})$ and 90% Confidence Intervals

Model: $\text{GR} = a + b \ln(\text{GDP60}) + c \ln(\text{INVT}) + d \ln(\text{SEC60}) + e \ln(\text{GOVC}) + \nu$
Figure 2. (continued)

(iii) ascending order of INVT

(iv) ascending order of GDP60
Figure 3. Estimates \( \ln(\text{GOVC}) \) and 90% confidence intervals
Model: \( GR = a + b \ln(\text{GDP60}) + c \ln(\text{INVT}) + d \ln(\text{SEC60}) + e \ln(\text{GOVC}) + v \)
Figure 3. (continued)

(iii) ascending order of INVT

(iv) ascending order of GOVC
Figure 4. Estimates ln(GDP60) and 90% Confidence Intervals
Model: \( GR = a + b \ln(GDP60) + c \ln(INVT) + d \ln(SEC60) + e \ln(GOVC) + v \)
Figure 4. (continued)

(iii) ascending order of INVT

(iv) ascending order of GOVC
Figure 5. Estimates(SEC60) and 90% Confidence Intervals

Model: $GR = a + b \text{GDP60} + c \text{INVT} + d \text{SEC60} + d \text{GOVC} + \nu$
Figure 5. (continued)

(iii) ascending order of INVT series

(iv) ascending order of GOVC series
Figure 6. Estimates(INVT) and 90% Confidence Intervals

Model; $GR = a + b \text{GDP60} + c \text{INVT} + d \text{SEC60} + d \text{GOVC} + \nu$
Figure 6. (continued)

(iii) ascending order of INVT series

(iv) ascending order of GOVC series
Figure 7. Estimates (GOVC) and 90% Confidence Intervals

Model; $GR = a + b \text{GDP60} + c \text{INVT} + d \text{SEC60} + d \text{GOVC} + \nu$
(iii) ascending order of INVT series

(iv) ascending order of GOVC series
Figure 8. Estimates(GDP60) and 90% Confidence Intervals

Model: \( GR = a + b \text{GDP60} + c \text{INVT} + d \text{SEC60} + d \text{GOVC} + \nu \)
Figure 8. (continued)

(iii) ascending order of INVT series

(iv) ascending order of GOVC series
CHAPTER III

DIMINISHING OR CONSTANT RETURNS

III.A. Introduction

The main idea of the neoclassical growth model is diminishing return to reproducible factors in the production function. The lower is the capital-labor ratio in poor country, the larger the rate of return to capital is ceteris paribus. Thus, poor countries should grow faster than the rich country ceteris paribus and should tend to converge to a steady-state growth path along which income per capita grows at the exogenous rate of technological improvement. If countries have access to all useful technical knowledge, per capita output produced with diminishing returns in production of reproducible factors should revert in all countries toward balanced growth paths that are parallel.

Some of the empirical growth literature has attempted to support exogenous growth models. Mankiw, Romer and Weil (1992) estimated a share for physical and human capital of 0.67 in an augmented Solow model. This share
exceeds 0.33 the share for physical capital alone, but is significantly below unity. Barro and Sala-i-Martin (1992) estimate a share of 0.8 for a broad concept of capital including human capital which is also significantly below unity. These implied models are less influenced by the diminishing returns of the simplest version of the neoclassical growth model. However, the neoclassical model does not by itself explain sustained economic growth and rule out differences in trend growth rates across countries.

The endogenous growth models developed by Lucas (1988) and Rebelo (1991) assume constant returns to scale in reproducible factors of production. Therefore, they imply that the rate of return should not vary with the level of per capita income keeping the composition of reproducible factors constant. If reproducible factors of production can be produced with constant returns in each country and the incentives to invest in these factors vary across countries, they have different trend growth paths. The same factors that explain level differences in exogenous growth models explain differences in trend growth rates in endogenous growth models.

In this chapter, we develop a regression equation that nests an AK model and Solow's exogenous growth model. Using panel data for three samples of countries, we then test endogenous growth models against exogenous growth models. These empirical results provide no evidence that individual countries face
diminishing social returns to the accumulation of reproducible factors and therefore supports constant social returns to scale.

The organization of this paper is as follows. Section III.B describes the model, and derives the implications of the model. Section III.C presents the estimation strategy and empirical results. Section III.D concludes.

III.B. Discussion of the Model

The simplest endogenous growth model is the AK model used by Sergio Rebelo (1991). The production function in this model exhibits social constant returns to reproducible factors. The neoclassical growth model of Solow has diminishing returns to scale in reproducible capital. The following model nests both models:

(1) \[ Y_{nt} = AK_{nt-1}^\alpha H_{nt-1}^\beta e^{(1-\alpha-\beta)t}, \quad \alpha > 0, \quad \beta > 0, \quad \alpha + \beta \leq 1 \]

(2) \[ \Delta(K_{nt} + H_{nt}) = s_{nt} Y_{nt} - \delta_{nt} (K_{nt-1} + H_{nt-1}) \]

(3) \[ \alpha AK_{nt-1}^{\alpha-1} H_{nt-1}^{\beta} e^{(1-\alpha-\beta)t} - \delta_{nt} = \beta AK_{nt-1}^\alpha H_{nt-1}^{\beta-1} e^{(1-\alpha-\beta)t} - \delta_{nt} \]
where $Y_{nt}$ is per capita output in country $n$ during period $t$; $K_{nt}$ and $H_{nt}$ are the per capita physical and human capital in country $n$ during period $t$; $A$ and $\gamma$ are the level of technology and the exogenous rate of technological progress which are assumed to be constant across countries and over time; $\alpha$ and $\beta$ are physical and human capital's shares in production; $\delta_{nt}$ is the common replacement rate for physical and human capital in country $n$ during period $t$; and $s_{nt}$ is the accumulation rate for country $n$ in period $t$.

Equation (1) implies a common production technology for all countries, diminishing social returns to scale in reproducible factors if $\alpha + \beta < 1$ and constant social returns if $\alpha + \beta = 1$. According to equation (2), physical and human capital are immediately fungible into each other, and physical and human capital depreciate at the same rate $\delta_{nt}$.

Equation (3) equates their net marginal products.

We point out that if $\alpha + \beta < 1$, the model is variant of Solow's (1956) model and if $\alpha + \beta = 1$, it is a variant of Rebelo’s AK model. From equation (3), we get

$$ (\beta / \alpha)K_{nt-1} = H_{nt-1} $$

We can show equations (5) holds all the times.
Next, we use equations (5) plus equation (2) to derive equation (6);

$$\Delta K_{nt} = i_{nt} Y_{nt} - \delta_{nt} K_{nt-1}.$$  

where \( i_{nt} \) is the gross investment rate in physical capital for country \( n \) in period \( t \). Divide equation (6) by \( K_{nt-1} \)

$$\frac{\Delta K_{nt}}{K_{nt-1}} = \frac{i_{nt} Y_{nt}}{K_{nt-1}} - \delta_{nt}$$

Differentiation of equation (1) gives us the equation for proportional growth rate of output:

$$\frac{\Delta Y_{nt+1}}{Y_{nt}} = \alpha \frac{\Delta K_{nt}}{K_{nt-1}} + \beta \frac{\Delta H_{nt}}{H_{nt-1}} + (1 - \alpha - \beta)\gamma$$

From (5) and (6'), we can rewrite equation (7) as

$$\Delta \ln Y_{nt+1} = (\alpha + \beta)i_{nt}(Y_{nt} / K_{nt-1}) - \delta_{nt} + (1 - \alpha - \beta)\gamma$$

$$= (1 - \alpha - \beta)\gamma - (\alpha + \beta)\delta_{nt} + (\alpha + \beta)i_{nt}(Y_{nt} / K_{nt-1})$$

since \( \Delta H_{nt} / H_{nt-1} = \Delta K_{nt} / K_{nt-1} \) at all times.
Substituting equation (4) into equation (1) gives us

\[ Y_{nt} = BK_{nt-1}^{\alpha+\beta}e^{(1-\alpha-\beta)\gamma t} \]

where \( B = A(\beta / \alpha)^\beta \). Solving equation (9) for \( K_{nt-1} \), we obtain

\[ K_{nt-1} = Y_{nt}^{1/(\alpha+\beta)}B^{-1/(\alpha+\beta)}e^{-(1-\alpha-\beta)\gamma t/(\alpha+\beta)} \]

From equations (9) and (10), we get

\[ Y_{nt} / K_{nt-1} = (e^{-\gamma t}Y_{nt})^{1/[1/(\alpha+\beta)]}B^{1/(\alpha+\beta)} \]

Substituting equation (11) into equation (8) gives us

\[ \Delta \ln Y_{nt+1} = (1 - \alpha - \beta)\gamma - (\alpha + \beta)\delta_{nt} \]

\[ + (\alpha + \beta)\int_{nt} \left( e^{-\gamma t}Y_{nt} / B \right)^{1-[1/(\alpha+\beta)]} \]

The tested model is given by

\[ \Delta \ln Y_{nt+1} = a + di_{nt} \left( e^{-\gamma t}Y_{nt} \right)^m + \nu_{nt} \]

where \( d = (\alpha + \beta)B^{1/(\alpha+\beta)} \), \( m = 1 - 1 / (\alpha + \beta) \), \( \nu_{nt} \) is the deviation of \(-(\alpha + \beta)\delta_{nt}\) from its mean, and \( a \) is \((1 - \alpha - \beta)\gamma \) less the mean of \((\alpha + \beta)\delta_{nt}\).

Constant returns to scale for \( K \) and \( H \) implies that \( m = 0 \), and diminishing returns
imply $m < 0$. For that reason, the AKSolow model can be tested against the neoclassical Solow model by testing

$$(14) \quad H_0 : m = 0 \quad \text{vs} \quad H_1 : m < 0$$

III.C. Empirical Analysis

III.C.1 Data

We obtain data on per capita income and the ratio of real gross domestic investment in physical capital to GDP from the Penn World Tables 5.5 of Summers and Heston. The panel data consists of data for the years 1960-1985 for three samples of countries; the 98 Non-oil, the 75 Intermediate, and the 22 OECD countries considered by Mankiw, Romer and Weil.
III.C.2 Empirical Results

In the empirical part of Mankiw, Romer, and Weil (1992) used cross-sectional data for various groups of countries, their reduced form equation for steady-state income per capita is

\[
\ln Y(T) = \ln A + gT - \left[\frac{(\alpha + \beta)}{(1 - \alpha - \beta)}\right] \ln(n + g + d) + \left[\frac{\alpha}{(1 - \alpha - \beta)}\right] \ln(i_k) + \left[\frac{\beta}{(1 - \alpha - \beta)}\right] \ln(i_h)
\]

where \( Y(T) \) is output per worker in 1985, \( A \) is the level of productivity, \( g \) is the constant exogenous rate of labor augmenting productivity growth, \( n \) is the average growth rate of the labor force between 1960 and 1985, \( d \) is the constant depreciation rate of physical capital, \( i_k \) is average gross investment rate in physical capital between 1960 and 1985, and \( i_h \) is a proxy for the average gross investment rate in human capital between 1960 and 1985. They estimated \( \alpha \) and \( \beta \) are about 1/3.

Our approach makes use of all of the time variation in the data and allows for the possibility that the error term \( u_{nt} \) has country-specific and individual-specific effects. In terms of the theory, we are assuming that physical and human capital depreciates at a rate \( \delta_{nt} \) that differs across and over time. Specifically, we fit the model.
(16) \[ \Delta \ln Y_{nt+1} = d_{nt} (Y_{nt} e^{-\gamma t})^m + \eta_n + \mu_t + \varepsilon_{nt} \]

where \( \eta_n \) and \( \mu_t \) are treated as country-specific and time-specific fixed effects and \( \varepsilon_{nt} \) is assumed to be orthogonal to the \( i_{nt} (Y_{nt} e^{-\gamma t})^m \) and to be independently and identically distributed with a zero mean and finite variance.

In practice, because we do not have exact estimates of the exogenous rate of technological progress(\( \gamma \)), we do not estimate this parameter. The regression model (16) is estimated by imposing the values.

(17) \[ \tilde{\gamma} = \sum_{n=1}^{N} \sum_{t=1}^{T} \Delta \ln Y_{nt} / (NT), \]

for \( N = 98, 75, \) and 22, and \( T = 25. \)

Table 7 reports our estimates of \( d \) and \( m \) for equation (16) with \( \gamma = \tilde{\gamma} \). We see that \( d \) and \( m \) are estimated to be significantly positive. Consequently, the null hypothesis \( m = 0 (\alpha + \beta = 1) \) cannot be rejected in favor of \( m < 0 (\alpha + \beta < 1). \) This result holds for all three samples of countries (the 98 Non-oil, the 75 intermediate, and the 22 OECD countries). These empirical results are more consistent with endogenous growth model than they are with Solow’s neoclassical growth model. In Table 8, the estimated coefficients on \( m \) are negative but not

---

1. When we estimated \( \gamma \) using nonlinear least squares, we obtained negative estimates.
statistically significant. Consequently, the null hypothesis $m = 0(\alpha + \beta = 1)$ cannot be rejected. This result holds for both samples of countries. The estimated coefficient on $d$ in the 76 Non-oil and Non-OECD country group is significant and smaller than that on $d$ in Table 7. This finding indicates that it is inappropriate to pool the OECD countries with the other countries.

On the assumption that $m = 0(\alpha + \beta = 1)$, equation (16) reduces to

\begin{equation}
\Delta \ln Y_{nt+1} = B_{nt} + \eta_n + \mu_t + \varepsilon_{nt}
\end{equation}

Estimating equation (18) yielded that $B$ are $0.1439(0.014)$, $0.1385(0.012)$, and $0.1870(0.024)$ for the 98 Non-oil countries, the 75 intermediate countries, and the 22 OECD countries, respectively. The figures in parentheses are standard errors. Because $B = A\left(\frac{1 - \alpha}{\alpha}\right)^{1-\alpha}$, these values for $B$ imply that $A$ is $0.091$, $0.087$, and $0.118$ for these three groups of countries if physical capital is paid its marginal product and is paid a third of output. These estimates are reasonable values for the rate of return on accumulated physical and human capital and suggest that rich countries have higher productivity and higher trend growth rates than poor countries.
III.D. Summary

We have developed a regression equation that nests an AK model and Solow’s neoclassical model. Using panel data for the samples considered by Mankiw, Romer, and Weil (1992), the 76 Non-oil and Non-OECD, the 53 intermediate and Non-OECD for the years 1960-1985, we tested these two models against each other.

Although the results are not entirely consistent with endogenous growth, they are more consistent with endogenous growth than exogenous growth.
### Table 7. Parameter Estimates (1)

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<th></th>
<th>d</th>
<th>m</th>
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</thead>
<tbody>
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<td><strong>Non-oil</strong></td>
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<td></td>
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<td>(Stand.error)</td>
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<td>(.175)</td>
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<td>Significance</td>
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<td>Estimates</td>
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<td>0.644</td>
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<tr>
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<tr>
<td>Estimates</td>
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<tr>
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**Note:**

1. Test regression equation: $\Delta \ln Y_{nt+1} = d_{nt} (e^{-\gamma t} Y_{nt})^m + \eta_n + \mu_t + \epsilon_{nt}$
2. $\gamma$ of the Non-oil 98 countries, the intermediate 75 countries, and the 22 OECD countries are 0.0183, 0.0231, and 0.0295, respectively.
Table 8. Parameter Estimates (2)

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<td>0.7400</td>
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<td>Non-OECD</td>
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<td>Significance</td>
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<td>0.2384</td>
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<td>(53)</td>
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</tr>
</tbody>
</table>

Note:

1. test regression equation: \( \Delta \ln Y_{nt+1} = d_{nt}(e^{-\gamma Y_{nt}})^m + \eta_n + \mu_t + \epsilon_{nt} \)
2. \( \bar{\gamma} \) of the 76 Non-oil and Non-OECD countries and the 53 intermediate and Non-OECD countries are 0.0169, 0.0214 respectively.
CHAPTER IV

LONG RUN GROWTH AND PUBLIC POLICY

IV.A. Introduction

Recent papers have examined the relationship between public policy and long-run growth. Lucas(1988), Rebelo(1991), Barro(1990), and King and Rebelo(1990) have emphasized the role of taxes and subsidies as important factors influencing the investment decisions and thus growth. Jones, Manuelli and Rossi(1993) find that divergent paths of development result from different government policies. Using a simple endogenous growth model, Ireland(1994) finds that a permanent and substantial reduction in marginal rates of income taxation can provide for both vigorous economic growth and long-run government balance.

Using a model that nests both the exogenous growth, or neoclassical, model of David Cass(1965) and the endogenous growth model of Sergio Rebelo(1991), we evaluate the hypothesis that cross-country differences in income
per capita and rates of growth result from differences in their public policies. To be specific, our empirical analysis tests the null hypothesis implied by exogenous growth that the share of government consumption in output affects the level of output but not its growth rate against the alternative hypothesis implied by endogenous growth that the growth rate is also affected. In this paper, our empirical results provide no evidence for the endogenous growth theories.

This chapter is organized as follows. Section IV.B provides an overview of the basic neoclassical model and of a simple endogenous growth model, analyzes the effect of the share of government consumption in output, and then expands the model in encompassing both growth theories. Section IV.C is devoted to empirical results. Section IV.D summarizes.

IV.B. A basic exogenous and endogenous model

The economy is inhabited by a large number of infinitely-lived consumers. We normalize the population of the economy to be unity, so the aggregate and
per-capita quantities coincide. The representative consumer maximizes the additively time separable utility function,

\[
\text{Max } U(c_{t+i})_{i=0}^{\infty} = \sum_{i=0}^{\infty} \beta^i \left[ \frac{c_{t+i}^{1-\theta} - 1}{1 - \theta} \right], \quad 0 < \beta < 1, \quad \theta > 0.
\]

where \(\beta\) is discount factor and \(1 / \theta\) is the intertemporal elasticity of substitution.

IV.B.1 Neoclassical model of economic growth

In this economy, gross output \(y_t\) is a single good that is produced using capital \(k_t\), which is a composite of both physical and human capital. Output is produced according to a neoclassical production function with diminishing returns to scale:

\[
y_t = A k_t^{\eta} \exp[(1 - \eta)yt], \quad 0 < \eta < 1.
\]

where \(\gamma\) is exogenous technological progress. The capital stock depreciates at the constant rate \(\delta\), which is assumed to be between zero and one. The sole activity of the government is assumed to be consuming a fraction \(g\) of gross output, financed by a proportional tax on income.
The budget constraint of the representative consumer at time $t$ is therefore

$$c_t + k_{t+1} = (1 - \delta)k_t + (1 - g_t)Ak_t^\gamma \exp[(1 - \eta)\gamma t].$$

When he maximizes equation (1) subject to equation (3), the first order conditions are well known to be (3) and

$$
\left(\frac{c_{t+1}}{c_t}\right)^\theta = \beta \{ (1 - \delta) + (1 - g_{t+1})\eta A k_{t+1}^{\eta-1} \exp[(1 - \eta)\gamma(t + 1)] \}.
$$

Rewriting these first-order conditions in terms of the detrended variables $\tilde{c}_t = c_t \exp(-\gamma t)$ and $\tilde{k}_t = k_t \exp(-\gamma t)$ yields

$$
\Delta \ln \tilde{c}_{t+1} = -\gamma + \frac{1}{\theta} \ln \left\{ \beta [(1 - \delta) + (1 - g_{t+1})\eta A k_{t+1}^{\eta-1}] \right\}
$$

$$
\Delta \ln \tilde{k}_{t+1} = -\gamma + \ln [(1 - \delta) + (1 - g_t)Ak_t^{\eta-1} - (\tilde{c}_t / \tilde{k}_t)]
$$

In the steady state, $\Delta \ln \tilde{c}_{t+1} = \Delta \ln \tilde{k}_{t+1} = 0$ and $g_{t+1} = g_t = g^*$ for all $t$. Equations (5) and (6) imply that $\ln (\tilde{c}_t / \tilde{k}_t)$ and $\ln \tilde{k}_t$ have the unique values $\ln (c^* / k^*)$ and $\ln k^*$ given by

$$
\ln k^* = \left( \frac{1}{1 - \eta} \right) \ln \left[ \frac{\eta A (1 - g^*)}{e^{\gamma \theta} / \beta - (1 - \delta)} \right]
$$
Linearizing equations (5) and (6) around $\ln \tilde{k}^*$ and $\ln(\tilde{c}^* / \tilde{k}^*)$ then yields

\[
\begin{bmatrix}
\Delta \ln \tilde{c}_{t+1} \\
\Delta \ln \tilde{k}_{t+1}
\end{bmatrix} = 
\begin{bmatrix}
0 & \mu \\
-\chi & \kappa
\end{bmatrix}
\begin{bmatrix}
\tilde{c}_t - \tilde{c}^* \\
\tilde{k}_t - \tilde{k}^*
\end{bmatrix}
\]

where $\mu = \frac{1}{\theta} \{\beta(1 - \delta)e^{-\gamma\theta} - 1\}(1 - \eta), \ \chi = (1 - \delta)e^{-\gamma} - 1 + \frac{e^{\theta} - (1 - \delta)\beta e^{-\gamma}}{\beta \eta}$, and $\kappa = \frac{e^{\theta}}{\beta} - 1$. The characteristic polynomial for this system is $\lambda^2 - \kappa \lambda + \mu \chi$.

whose roots are $\lambda_1, \lambda_2 = \frac{\kappa \pm \sqrt{\kappa^2 - 4\mu \chi}}{2}$. We assume that the system is saddlepoint stable so that $0 < \lambda_1 < 1 < \lambda_2$. As a result, the solution for $\ln \tilde{k}_t$ takes the form

\[
\ln \tilde{k}_t - \ln \tilde{k}^* = \phi_1 \lambda_1^t
\]

To find $\phi_1$, we use the initial condition. The solution for $\ln \tilde{k}_t$ is thus

\[
\ln \tilde{k}_t - \ln \tilde{k}^* = \lambda_1 (\ln \tilde{k}_{t-1} - \ln \tilde{k}^*)
\]
From the production function (2) and equation (11), we obtain

\[ \ln \tilde{y}_t - \ln \tilde{y}^* = \lambda_1 (\ln \tilde{y}_{t-1} - \ln \tilde{y}^*) \]

The solution for \( \ln y_t \) implies

\[ \ln y_t = \lambda_1 \gamma + \gamma (1 - \lambda_1) t + (1 - \lambda_1) \ln \tilde{y}^* + \lambda_1 \ln y_{t-1}. \]

Differencing equation (13) then produces

\[ (\Delta \ln y_t - \gamma) = \lambda_1 (\Delta \ln y_{nt-1} - \gamma) \]

The production function implies that

\[ \ln \tilde{y}^* = \ln A + \left( \frac{1}{1 - \eta} \right) \ln \left[ \frac{\eta A (1 - g^*)}{e^{\gamma \theta} / \beta - (1 - \delta)} \right] \]

According to equations (15) and (13), increasing \( g^* \) lowers \( \tilde{y}^* \) and leads to an adjustment of that path for \( \ln y_t \) downward. Growth is slower than \( \gamma \) along the transition path but ultimately returns to \( \gamma \); see equation (14). Consequently, the level of the path for \( y_t \) is lowered by an increase in \( g^* \), but its trend growth rate is unaffected.
IV.B.2. The simple endogenous model

When $\eta = 1$, the production technology (2) reduces to

\[(2') \quad y_t = A k_t.\]

The budget constraint of the representative consumer is then given by

\[(3') \quad c_t + k_{t+1} = (1 - \delta)k_t + (1 - g_t)A k_t = [(1 - g_t)A + 1 - \delta]k_t.\]

It is assumed that $(1 - g_t)A > \delta$ so that gross investment can be positive.

When we maximize equation (1) subject to equation (3'), the first order conditions are well known to be (3') and

\[(4') \quad \frac{c_{t+1}}{c_t} = \beta[(1 - g_{t+1})A + 1 - \delta] \]

Equation (3') and (4') in turn imply that

\[(5') \quad \Delta \ln c_{t+1} = \frac{1}{\theta} \left[ \ln \left(1 - g_{t+1}\right) A + 1 - \delta \right] + \ln \beta \]

\[(6') \quad \Delta \ln k_{t+1} = \ln \left(1 - g_t A + 1 - \delta - \frac{c_t}{k_t} \right) \]
In the steady state, \( g_{t+1} = g_t = g^* \) and \( c_t \) and \( k_t \) grow a constant and common rate so that \( c_t / k_t \) is constant. Hence,

\[
(7') \quad \Delta \ln k_{t+1} = \left( \frac{1}{\theta} \right) \ln[\beta \{(1 - g^*)A + 1 - \delta\}]
\]

\[
(8') \quad \left( \frac{c_t}{k_t} \right)^* = -\beta^\theta \{(1 - g^*)A + 1 - \delta\}^\theta + (1 - g^*)A + 1 - \delta
\]

From equations (2') and (7'), it follows that

\[
(16) \quad \Delta \ln y_t = \left( \frac{1}{\theta} \right) \ln[\beta \{(1 - g^*)A + 1 - \delta\}]
\]

According to equation (16), increasing \( g^* \) permanently reduces the growth rate of \( y_t \) as well as its level in periods after the change.

IV.B.3 Tested model

The results obtained in the previous two sections are nonstochastic of necessity. Here we nest these two results in a stochastic model suitable for estimation. The empirical model should have the following properties:
(i) a permanent increase in $g_t$ lowers the long-run level of $y_t$ but not its trend growth rate if growth is exogenous and should lower both if growth is endogenous;

(ii) its lag structure should be flexible;

(iii) $\ln y_t$ should be integrated of order one if growth is exogenous;

(iv) $\ln y_t$ should be integrated of order two if growth is endogenous and $g_t$ is nonstationary; and

(v) $g_t$ should be nonstationary even though it is constrained to lie between zero and one.

An empirical model with these properties is

\begin{equation}
\Delta y_{nt} = \alpha_n + \beta_t + \sum_{i=1}^{\infty} \zeta_i \Delta y_{nt-i} + \sum_{i=0}^{\infty} \lambda_i z_{nt-i} + u_{nt}
\end{equation}

where $z_t = \ln \left( \frac{g_t}{1 - g_t} \right)$. Note that $z_t$ is free to wonder between $-\infty$ and $+\infty$ and can reasonably be presumed to be integrated of order one. This presumption is tested in the next section. In equation (17),

$H_0 : \sum \lambda_i = 0$
must hold under exogenous growth with $\lambda_i$'s tending to be negative for small $i$'s and positive for large $i$'s. If growth is endogenous by contrast,

$$H_1 : \sum \lambda_i < 0$$

should hold.

Under $H_0$, $\Delta$ is a factor of $\sum \lambda_i L^i$, where $L$ is the lag operator. As a result, $\sum \lambda_i z_{nt-i}$ is integrated of order zero even though $z_{nt}$ is integrated of order one. Hence, so long as $1 - \sum \zeta_i L^i$ has all of its roots outside the unit circle and $\beta_t$ is stationary as is assumed, $y_t$ is integrated of order one. Under $H_1$, $L = 1$ is not a root of the polynomial $1 - \sum \lambda_i L^i$.

In equation (17), $\alpha_n$ and $\beta_t$ are treated as country-specific and time-specific effects and $\nu_{nt}$ is assumed to be independently and identically distributed with a zero mean and finite variance.

To get rid of $\alpha_n$, which seriously biases panel estimates if $T$ is not large, and to overcome problems with the $z_{nt}$'s being I(1), we overdifference equation (17). The tested model is given by

$$\Delta^2 y_{nt} = \sum_{i=1}^{\infty} \zeta_i \Delta^2 y_{nt-i} + \sum_{i=0}^{\infty} \lambda_i \Delta z_{nt-i} + \phi_t + \omega_{nt}$$
where $\omega_{nt} = \Delta y_{nt}$ and $\phi_t = \Delta \beta_t$. When we run the regression equation (18), instrument variables are necessary since $\omega_{nt}$ and $\Delta^2 y_{nt-1}$ are necessarily correlated. The exogenous model can be tested against the endogenous model by testing

(19) $H_0 : \sum \lambda_i = 0$

against

(20) $H_1 : \sum \lambda_i < 0$

IV.C. Empirical Results

IV.C.1 Data

The data are from the Penn World Tables 5.5 constructed by Summers and Heston. The data set includes per capita real gross domestic product and real government consumption as a fraction of real gross domestic product. The panel data consists of the 98 countries used by Mankiw, Romer and Weil for the time period 1960-1985.
IV.C.2 Empirical Results

First of all, we need to determine whether $z_{nt}$ can be reasonably treated as an I(1) variable as posited in the previous section. The results of augmented Dickey-Fuller tests with zero to three lags on $z_{nt}$ are shown at Table 1. The calculated values are from -7.1121 to -5.4854 comparing to tabulated value -14.06 (n =100 and t =25, 5% significance level) from the table constructed by Levin and Lin (1992). We cannot reject the null that this variable $z_{nt}$ has a unit root.

We now test whether $y_{nt}$ is I(1). Growth is unlikely to be endogenous if strong evidence can be found that $y_{nt}$ is I(1) rather than I(2) and if $z_t$ is indeed I(1). The calculated values for Dickey-Fuller on $\Delta y_{nt}$ are between -41.614 to -18.608 for zero to three lags. The results strongly indicate that $\Delta y_{nt}$ is stationary.

Even though exogenous growth is consistent with the univariate properties of $y_{nt}$, the bivariate test based on estimates of equation (18) should be more powerful and are thus worth performing.

Now, we test the null hypothesis that the share of government consumption in output does not affect the growth rate of output against the alternative
hypothesis that the effect is negative. When we run the regression equation (18),
the time fixed effects were removed by deviating the variables from their cross-
country averages. The instrumental variables consisted of $\Delta^2 \ln y_{nt-2}$,
$\Delta^2 \ln y_{nt-3}$, ..., $\Delta^2 \ln y_{nt-q-1}$ and $\Delta z_{nt}$, $\Delta z_{nt-1}$, ..., $\Delta z_{nt-q}$ deviated from
their cross-country averages.

Estimating the regression model (18) yielded the coefficients in sums
($\sum \lambda_i$) reported in table 2. The coefficient sum becomes insignificantly different
from zero for appreciable lag lengths. This result does not reject the null
hypothesis that the share of government consumption in output affects the level of
output but not its growth rate. Therefore, exogenous growth cannot be rejected in
favor of endogenous growths. This result agrees with those indicated by the
univariate tests discussed above.

IV.D. Summary

Using a model that nests both the exogenous growth, or neoclassical,
model of David Cass(1965) and the endogenous growth model of Sergio
Rebelo (1991), we evaluated the hypothesis that cross-country differences in income per capita and trend rates of growth result from differences in their public policies. The sole activity of the government was assumed to be consuming a fraction $g$ of gross output, financed by a proportional tax on income.

We test the null hypothesis that the share of government consumption in output does not affect the growth rate of output against the alternative hypothesis that the effect is negative. First of all, we found that the variable $z_{nt}$ has a unit root and $\Delta y_{nt}$ should be treated as stationary. Next, the time fixed effects were removed by deviating the variables from their cross-country averages, country fixed effects were removed by overdifferencing, and the instrumental variables were used for estimation.

The coefficient sum resulting from estimating the regression model become insignificantly different from zero for appreciable lag lengths. This result is consistent with the null hypothesis of exogenous growth that the share of government consumption in output does not affect the growth rate of output. We have thus provided evidence that cross-country differences in income per capita result from differences in their public policies, but no evidence that differences in trend growth rates result.
### Table 9. ADF Test for $z_{nt}$ and $\Delta y_{nt}$

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<th>Test Statistic for $\Delta y_{nt}$</th>
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### Table 10. Results from Fitting Equation (18) using Instrumental Variables

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<thead>
<tr>
<th>Lag Length (q)</th>
<th>Coefficient Sum</th>
<th>Standard Error</th>
<th>Significance Level</th>
</tr>
</thead>
<tbody>
<tr>
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<td>-0.0782</td>
<td>0.013</td>
<td>0.000</td>
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<tr>
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<td>0.017</td>
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<td>3</td>
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<td>0.023</td>
<td>0.094</td>
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<td>4</td>
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<td>0.027</td>
<td>0.310</td>
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<tr>
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<td>0.030</td>
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<tr>
<td>6</td>
<td>0.0042</td>
<td>0.033</td>
<td>0.899</td>
</tr>
</tbody>
</table>

Notes:
1) Estimated coefficient = \( \sum \lambda_i \)
2) \( N = 98 \) and \( T = 26 \)
3) The instrumental variables: \( \Delta^2 \ln y_{nt-2}, \Delta^2 \ln y_{nt-3}, \ldots, \Delta^2 \ln y_{nt-q-1} \) and \( \Delta z_{nt}, \Delta z_{nt-1}, \ldots, \Delta z_{nt-q} \) deviated from their cross-country averages.
CHAPTER V.

SUMMARY AND CONCLUSION

Paul Romer (1986) introduced endogenous growth into growth theories. The main idea is that growth rate is determined endogenously by stock of knowledge, human capital, and externalities of new ideas, so that growth rate is related to government policies and the economic environment.

In this dissertation, we developed models nesting both exogenous and endogenous growth and tested the assumptions of diminishing and constant returns to reproducible production factors and the relationship between long run growth and public policy using panel data.

The empirical growth regression literature is replete with conflicting results, suggesting that they lack robustness. In Chapter II, we tested the robustness of a base model using many econometric methods. First, we employed ridge regression and calculated covariance matrices consistent to heteroskedasticity and weighted least squares. We then divided the sample into

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two sample consisting of the 54 countries with highest and lowest values of a set of variables. Next, we used graphic analysis to consider many possible samples. Finally, we used bootstrap resampling methods to evaluate the robustness of statistical significance to sample size and composition. We find that some of the estimated coefficients are not robust and the degree of significance of each variable tends to increase as sample size increases. Some variables, ln(SEC60) and ln(GOVC) are less significant than other variables, ln(GDP60) and ln(INVT).

In Chapter III, we developed a regression equation that nests an AK model with a neoclassical Solow model. Using panel data for the samples considered by Mankiw, Romer, and Weil for the years 1960-1985, we tested these two models against each other. We found no evidence in favor of neoclassical Solow model and no evidence that countries face diminishing returns to the accumulation of reproducible capital. These results support endogenous growth.

Chapter IV used a model that nests both the exogenous growth, or neoclassical, model of David Cass (1965) and the endogenous growth model of Sergio Rebelo (1991). We evaluated the hypothesis that cross-country difference in per capita income and rates of growth result from differences in the share g of government consumption in output. The coefficient sum on g that results from
estimating the regression model becomes insignificantly different from zero for lag length longer than 4 years. This result is consistent with the null hypothesis of exogenous growth. We have thus provided evidence that cross-country differences in income per capita result from differences in their public policies, but no evidence that differences in trend growth rates result.

The conflicting findings of Chapters III and IV do not enable us to reach any definitive conclusion about whether exogenous or endogenous growth theories better characterize the growth experiences of our sample of countries. Further tests of these two competing theories are necessary before we can offer such any conclusions. We hope to perform these in future research.
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