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**ECONOMIC GROWTH AND THE ROLE OF TAXATION: AGGREGATE DATA**

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## ABSTRACT/RESUMÉ

### **Economic growth and the role of taxation – Aggregate data**

Economic growth is the basis of increased prosperity. This makes the attainment of growth a key objective for governments across the world. The rate of growth can be affected by policy choices through the effect that taxation has upon economic decisions and through productive public expenditures. This paper surveys research that has undertaken empirical analysis of aggregate data. The focus of the survey is the identification of the factors that determine the rate of growth.

*JEL Classification: O4; H2; H3; C01.*

*Keywords: Economic growth; taxation; public policy; aggregate data.*

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### **La croissance économique et le rôle de la fiscalité – Données Agrégées**

La croissance économique est au fondement du progrès de la prospérité. Ceci fait de la croissance un objectif majeur pour les gouvernements du monde entier. Le taux de croissance peut être influencé par des choix de politique économique relatifs à la fiscalité, laquelle a un effet sur les décisions économiques des agents et est liée aux dépenses publiques productives. Cette étude résume les recherches qui ont porté sur l'analyse empirique des données agrégées. Le but de cette étude est d'identifier les facteurs qui ont une influence sur le taux de croissance.

*Classification JEL : O4 ; H2 ; H ; C01.*

*Mots clef : Croissance économique ; fiscalité ; politique publique ; données agrégées.*

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## TABLE OF CONTENTS

ABSTRACT/RESUMÉ.....	2
ECONOMIC GROWTH AND THE ROLE OF TAXATION: AGGREGATE DATA.....	5
1. Introduction .....	5
2. Growth Regressions .....	6
2.1 Barro Growth Regressions.....	6
2.2 Robustness of Coefficients .....	9
2.3 Further Work .....	11
2.4 Observations .....	15
2.5 Conclusions.....	16
3. Tax Regressions .....	16
3.1 Basic Evidence.....	16
3.2 Empirical Results.....	19
3.3 Limitations .....	32
3.4 Observations .....	34
4. Growth Accounting .....	35
4.1 East Asian Growth.....	36
4.2 Extensions.....	38
4.3 Testing for Endogeneity .....	47
4.4 Education and TFP .....	50
4.5 Observations .....	51
5. Conclusions .....	52
APPENDIX 1. EXTREME BOUNDS ANALYSIS.....	53
APPENDIX 2. GROWTH ACCOUNTING.....	54
REFERENCES .....	57

### Tables

1. Growth characteristics 1960 - 1989.....	7
2. Mean coefficients .....	12
3. Significance of variables .....	14
4. Results from regression of GDP growth rate .....	15
5. Regression on marginal and average rates .....	21
6. Significance of marginal tax rates .....	23
7. Regression results.....	24
8. Regression on average and marginal taxes.....	26
9. Regression results.....	28
10. Yearly estimation with eight lags .....	29
11. Results of extreme bounds analysis.....	30

12. Corporate and personal taxes .....	32
13. Key indicators for Peru and Sweden .....	34
14. Real GDP growth and productivity .....	36
15. Sources of growth.....	38
16. Estimate of Cobb-Douglas Production Function.....	39
17. Decomposition of Growth 1960-1994.....	40
18. Explanation of relative TFP .....	42
19. Proximity to frontier and value of education.....	43
20. Nonparametric and conventional estimates of TFP growth .....	44
21. Nonparametric estimates of elasticities and shares .....	45
22. Growth accounting US 1950-1993.....	46
23. Testing the Solow model.....	48
24. Regression for TFP.....	49
23. Fixed effects estimate.....	50

**Figures**

1. US tax and growth rates .....	17
2. US tax and growth rates .....	18
3. Average and marginal tax rates .....	19
4. Real income growth and tax rates in OECD countries, 1960-2004.....	20
5. Growth and government expenditure 2004 .....	32

## ECONOMIC GROWTH AND THE ROLE OF TAXATION: AGGREGATE DATA<sup>1</sup>

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This discussion paper is the second in a series of three that review the economic literature on the links between taxation and economic growth. These papers are extracted from the report *Economic Growth and the Role of Taxation* prepared for the OECD under contract CTPA/CFA/WP2(2006)31. The first and third papers discuss theoretical analysis and the analysis of disaggregate data respectively.

### 1. Introduction

1. The development of endogenous growth theory has provided many new insights into the sources of economic growth. The essence of the new theory is that growth is a consequence of rational economic decisions. Firms expend resources on research and development to secure profitable innovations. Consumers invest in education to develop human capital and increase lifetime earnings. Governments increase growth by providing public inputs, encouraging foreign direct investment, and enhancing educational opportunities. Through the aggregation of these individual decisions the rate of growth becomes a variable of choice, and hence a variable that can be affected by the economic policies of governments.

2. Viewed from an endogenous growth perspective the link between taxation and growth seems self-evident. Corporate taxation affects the return to innovation and hence must affect the optimal amount of research and development. Personal income taxation reduces the returns to education so must reduce the accumulation of human capital. In simulations of economic growth models the effect of taxation on growth has frequently been demonstrated to be considerable. A clear presumption exists that data on economic activity must reveal a strong correlation between taxation and growth.

3. It is therefore surprising to discover that aggregate data provides no convincing explanation of this correlation. There are numerous explanations for this finding, including the difficulty of disentangling the positive effect of government expenditure from the negative effect of the taxes used for financing. Whatever the explanation may be, the implication is that the tax effect must be sought in the micro data on individual decisions. This is the subject of the third paper in the series.

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<sup>1</sup> Thanks are due to Christopher Heady for initiating and supporting the project, Nigar Hashimzade, Joel Slemrod, Stephen Bond, and participants at OECD presentations as well as Irene Sinha for excellent editorial support. Correspondance: Department of Economics, University of Exeter, Exeter, EX4 4PU, UK, [gdmyles@ex.ac.uk](mailto:gdmyles@ex.ac.uk)

4. There are three main sections in this paper. Section 2 surveys the extensive literature on growth regressions that began with the work of Barro (1991). Section 3 focuses on regressions that have a more detailed analysis of taxation. Section 4 studies growth accounting focussing, in particular, on the insight it gives into the source of growth in South East Asia. Appendix 1 describes the application of extreme bounds analysis. Appendix 2 describes the method of growth accounting and the interpretation of the Solow residual.

## 2. Growth Regressions

5. There is a substantial body of literature that seeks to identify from data the factors that determine the rate of growth. This line of research was pioneered by Barro (1991) and the general methodology now goes under the name of *Barro growth regressions*. The methodology has developed as the research has been undertaken, but the conclusions (and even the methodology) remain contentious. This section describes the major findings of the growth regression literature and the conceptual issues that arise.

6. The general form of a Barro growth regression uses the growth rate of GDP as the left-hand side variable. The variables on the right-hand side are selected from a very wide range of potential regressors. This range includes economic variables, such as ratio of investment to GDP, and non-economic variables such as political rights and violent wars. The non-economic variables are included to capture the stability of the political environment of each country. The data are typically taken from the Summers and Heston (1988) data set and its later developments. This data set covers a large cross-section of countries and attempts to ensure consistency of definition and measurement across countries and across time.

7. Plosser (1992) provides a very useful table that illustrates the key issues involved. The table summarises the basic data from a sample of 97 countries, and the correlation between the variables and the growth rate of GDP. This is reproduced as Table 1 below. The statistics are presented for the entire sample, and for a partition of the total sample into fast-growth and slow-growth countries. The table shows that fast-growth countries have a higher investment to GDP ratio, lower inflation, engage in more trade, and have greater school enrolment rates. Slow-growth countries have faster population growth and more political instability. Initial per capita GDP in 1960 is positively correlated with growth. This observation runs counter to the convergence argument developed from analysis of the Solow growth model. The essence of the growth regressions is to test whether these correlations can be supported by formal statistical significance tests of explanatory power.

### 2.1 Barro Growth Regressions

8. Barro (1991) analyzed a cross-section of 98 countries using data for the period 1960-1985. This analysis is worth describing in detail since it marked the start of a considerable body of literature. Several different specifications of the basic regression were run. Overall, the results showed that the growth of per capita GDP was positively related to the initial level of human capital and negatively related to the initial level of per capita GDP. This second observation is usually taken as evidence of convergence: countries with lower initial GDP grow faster than those with higher initial GDP, so there must be convergence. This finding demonstrates how the sign of the simple correlation reported by Plosser (1992) can be reversed in a regression with multiple variables. Growth was also shown to be inversely related to the share of government consumption in GDP and positively related to the variables measuring political stability.

**Table 1: Growth characteristics 1960 - 1989**

	Overall average <i>n</i> = 97	Slow growth < 0.5% <i>n</i> = 23	Fast growth > 3.5% <i>n</i> = 14	Correlation with GDP growth rate
Real per capita GDP growth 1960-89	2.03%	-0.26%	4.88%	1.00
Investment share of GDP	.21	.17	.26	.61
Share of government consumption in GDP	.15	.15	.14	.10
Inflation rate	23.00%	42.11%	7.90%	-.17
Standard deviation of inflation rate	52.38	137.19	5.68	-.16
Exports as a share of GDP	.28	.24	.35	.30
Imports as a share of GDP	.33	.30	.40	.31
Secondary school enrolment rate 1960	.21	.06	.34	.41
Primary school enrolment rate 1960	.74	.44	.98	.54
Population growth	2.06%	2.55%	1.26%	-.36
Revolutions and coups per year	.20	.35	.12	-.37
Real per capita GDP in 1960	\$1840	\$889	\$1968	.20

9. A flavour of these results can be obtained by reporting Barro's regression No.1. The fitted regression equation is

$$\gamma_{y6085} = \frac{0.0302}{(0.0066)} - \frac{0.0075}{(0.0012)} GDP60 + \frac{0.0305}{(0.0079)} SEC60 + \frac{0.0250}{(0.0056)} PRIM60 \\ - \frac{0.119}{(0.028)} g^c / y - \frac{0.0195}{(0.0063)} REV - \frac{0.0333}{(0.0155)} ASSASS - \frac{0.0143}{(0.0053)} PPI60DEV, \quad (1)$$

where the standard errors are given in parentheses. The variable  $\gamma_{y6085}$  is the annual average growth rate from 1960 to 1985.  $GDP60$  is the level of per capita GDP in 1960,  $SEC60$  the 1960 secondary school enrolment rate,  $PRIM60$  the 1960 primary school enrolment rate,  $g^c / y$  is government consumption spending,  $REV$  is the number of revolutions and coups per year,  $ASSASS$  is the number of assassination per million population per year and  $PPI60DEV$  is the deviation of the 1960 purchasing power parity value for the investment deflator from the sample mean.

10. There is clear motivation for the inclusion of each of the right-hand side variables in the regression.  $GDP60$  is included to capture the convergence hypothesis that low income countries will grow more rapidly than higher income countries. The basis of this claim is the Solow model of exogenous growth. If all countries have the same production technology those with a lower capital labour ratio will observe a higher marginal product of capital and hence higher gains from additional investment. The variables  $SEC60$  and  $PRIM60$  are included to capture the role of human capital. A central result of endogenous growth theory is that the accumulation of human capital can overcome the decreasing returns to capital in the Solow model and ensure continuous growth. The estimated coefficients show that increased human capital implies faster growth and that higher GDP in 1960 implies lower growth given equal levels of human capital. The coefficients can be interpreted as supporting the concept of  $\beta$ -convergence defined in Barro and Sala-i-Martin (1995).

11. The negative coefficient on the government expenditure variable has several interpretations. It is important to observe that this is consumption expenditure by government, so the negative coefficient does not conflict with the modelling of productive government expenditure leading to growth. The negative value may demonstrate that government spending is somehow purely wasteful, but note that in many of the countries in the sample a significant fraction of the government consumption expenditure will be upon education which is already controlled for in the regression. It is also possible that government spending is just a proxy for the entire set of government non-price interventions. These include, for example, employment legislation, health and safety rules and product standards. It may be these non-price interventions, not the level of expenditure, that are responsible for reducing growth. The government budget constraint also implies that every expenditure made by government is matched by a corresponding item of taxation or borrowing to provide finance. The negative sign could be capturing the distortionary consequences of the financing. More will be said about how government size and taxation is related to economic growth in the next section.

12. The policy implications of this regression are that increased education will raise growth, subject to the caveat that this may raise government spending which has the opposite effect, and the economic stability is important for growth. The effects of educational expenditure are discussed from an alternative perspective in the third paper. At this point it is worth noting that there are significant questions to be raised about the interpretation of the human capital variable that enters these regression equations. In terms of the theory of endogenous growth human capital measures the level of skill in production activities. It is not immediately clear that the proportion of population in education is a good measure of this skill. The literature on human capital has distinguished between specific and general training. Measures of primary

and secondary education are more likely to contribute to general training rather than specific training. If it is specific training that raises the productivity in employment then the education measures will not capture what is really relevant for human capital.

13. More recent research by Loayza and Soto (2002) in a Central Bank of Chile report provides a table of growth rates for various regions and the result of a Barro growth regression. This regression confirms with the standard results reported above. Keller and Poutvaara (2005) add both human capital and R&D into the standard growth regression framework. They show that for the non-oil producing and non-OECD countries the coefficients on physical capital, human capital and R&D are significant and positive both for income and growth.

## 2.2 Robustness of Coefficients

14. The literature on growth regression has identified a wide range of variables that one or more regression has found to be correlated with the growth rate. Loayza and Soto (2002) provide a discussion of the theory behind the inclusion of some of the most common variables. However, the theory provides limited guidance on what should be included, and even less on which variables can be excluded. In addition, the greater the number of variables that are included as explanatory variables the greater is the likelihood that some subset of variables will be highly correlated with each other thus making it difficult to disentangle the individual effects. This raises the issue of how to refine the regressions and identify the variables that need to be considered.

15. In a paper of fundamental importance Levine and Renelt (1992) demonstrated the basic deficiency of growth regressions. Their work took two existing papers (Barro (1991) and Kormendi and Meguire (1985)) and placed all the variables found to be significant in these papers into a single regression. When included together all of the variables became insignificant. This finding was used to motivate the use of extreme bounds analysis, a technique introduced by Leamer (1983). Extreme bounds analysis conducts a regression with a set of basic regressors, then the regressor of interest, then includes a further set of possible regressors. The latter variables are chosen from the set of potential regressors to obtain the maximum and minimum values of the estimated parameter on the variable of interest. The regression is termed *fragile* if the coefficient on the variable of interest switches from significant to insignificant as the set of regressors is changed or if the estimated parameter changes sign. Further details are given in the appendix to this paper.

16. Levine and Renelt use four basic variables in all regressions. These are all supported as relevant by the theoretical analysis of the Solow growth model. These variables are the investment share of GDP, the initial level of GDP per capita in 1960, the initial secondary-school enrolment rate, and the average annual rate of population growth. In implementing the extreme bounds analysis Levine and Renelt restrict attention to the inclusion of only three additional regressors but still find almost all variables are fragile. The only variable that is not fragile is the ratio of investment to GDP for the growth regression. The analysis is repeated for an investment regression and the only variable that is not fragile is the ratio of trade to GDP. There is also some weak evidence of conditional convergence. That is, the parameter on initial GDP is negative in the regression for growth. This paper was the starting point for all of the later literature since it introduced the extreme bounds analysis and the concept of a fragile coefficient.

17. The problems inherent in growth regressions are explored further in Levine and Zervos (1993). Their discussion begins with a summary of the statistical problems. First, the data may be inaccurate and inconsistent. These problems are particularly relevant for growth regressions that use data from a large number of countries with differing techniques for collecting data and defining variables. Second, the data may not be drawn as a random sample if there are fundamental differences between countries. Third, there is the problem of averaging the data across a number of countries and over a time interval in which many

factors are likely to have changed. There are also limitations in the use that can be made of the regressions. The regressions do not demonstrated causality but only correlation. Furthermore, the results cannot be interpreted in policy terms because many of the variables do not link directly with policy instruments.

18. The paper provides a simple discussion of extreme bounds analysis and the methodology for testing whether a variable has a robust relationship with growth. It is concluded that only the state of financial development and the black-market premium have a significant effect, and that other variables have a relationship that is fragile. However, it is not clear what the black-market premium is capturing. In summary this paper paints a very negative picture of the literature on growth regressions.

19. There are two conclusions that can be drawn from this discussion. The first is the obvious one that in fact only a very small number of variables are correlated with economic growth. The extreme bounds test reveals that most of the reported correlations are fragile and possibly an artefact of the choice of conditioning variables. The second argument that can be made is that the extreme bounds test is too strong. Under this second interpretation it is the test that is rejected and not the correlations or the methodology.

20. Two reasons for rejecting the extreme bounds test are provided in Sala-i-Martin (1994). The paper observes that over 50 variables have been found to be correlated with growth in the literature but before these can be taken as a guide to policy the Levine and Renelt (1992) criticism has to be addressed. The view of Sala-i-Martin is that the point estimates of the coefficient must follow a distribution as the conditioning set is changed. He then observes it is unlikely that the domain of the distribution is only positive or only negative. This suggests that the extreme bounds test may be too strong and what really matters is the distribution of the estimator and whether it is concentrated on a narrow subset of the domain. Also, it is observed that Levine and Renelt always find some set of policy variables that matter. It is proposed that the issue is the correlation of the policy variables which are all different imperfect measures of some underlying economic picture - such as high inflation distorted trade and repressed financial sectors all being present simultaneously. Hence, it is not that policy does not matter but that the data cannot precisely identify which policy.

21. Sala-i-Martin (1997a, b) implements an alternative method of determining which coefficients have a significance that survives regardless of the choice of other regressors. This alternative method is to run many regressions to obtain a distribution for the estimated coefficients and then look at how much weight in this distribution lies on either side of the origin. This can only be implemented by making an assumption about the distribution of the coefficients. Both the normal distribution across models and a non-normal distribution are considered. In the normal case the mean of the sample is constructed by calculating a weighted average using the likelihood of the regression as the weight. Then the variance is computed using the same weights. In the non-normal case for each regression the area under the density function to the right of 0 is calculated then the weighted average of all these densities is found. This is repeated for unweighted average to avoid the problem that spurious regression caused by endogenous regressors may assign too much weight to bad regressions. Then the procedure of Levine and Renelt is repeated using some of the regressor in all equations, one variable of interest and three drawn from the set. Sala-i-Martin found 63 variables in the literature that he chose to use (he claims more are available) plus average growth rate of GDP between 1960 and 1992. For the three fixed variables he chooses level of income in 1960, life expectancy in 1960 and primary school enrolment rate in 1960. The average investment rate was given a special role, as it appears in one set and not in another.

22. The results show that of the 59 variables (62 less three fixed) 58 fail the extreme bounds test in the sense that coefficient range spans zero. The one exception is the fraction of population following the Confucian religion. However, this is most likely just a dummy for East Asian countries. A larger number of variables were significant 90 or 99% of the time. In fact, 22 of the 59 variables have over 95% of their

distribution located either to the right or to the left of 0. The full list along with their average estimated coefficient is given in Table 2 in order of significance (Equipment investment being the most significant). The most important observation is that government spending (including investment) does not appear as one of these, nor do any measures of financial sophistication. The weighting process does not seem to have much impact. The fixed variables that appear in every regression were tested and found to be significant in most regressions.

### 2.3 Further Work

23. There have been several developments of the method of growth regression to take account of some of the difficulties noted above. These developments have used alternative estimation methods or restricted attention to a limited range of countries.

24. Folster and Henrekson (1999) argue that analysis of the relationship between growth and the size of government should be restricted to countries in similar wealth ranges. This argument is based on an application of Wagner's law that the demand for public sector goods depends on income and the stage of development. This argument is given support by the observation that the composition of expenditure is different between rich and poor countries. Hence, the paper focuses upon a sample of OECD countries.

25. The initial step is to regress the growth rate on the investment share in GDP, the growth rate of the labour force, the growth rate of the number of years of schooling, initial income and then two measures of government size (total taxes as a share of GDP and total expenditure as a share of GDP). This regression is undertaken for a pure cross-section of OECD countries using average growth rates and average values of variables over the period 1970-1995. In this regression the government size variables are insignificant.

26. The question is raised of why growth regressions average over the long run. One possible advantage of averaging is that it eliminates short- and medium-term effects such as business cycles. However, averaging has numerous disadvantages. First, simultaneity problems arise in that government size may be correlated with GDP for demographic reasons. Second, tax policy may be endogenous with high taxes maintained if growth is good. Third, averaging discards all information on within-country variation.

27. The paper therefore suggests the use of panel methods but with 5 year averages in order to avoid lag problems. Fixed country effects are accounted for by using dummies. Period dummies are also included to remove the spurious correlation because most countries have seen falling growth. The panel estimation reveals a highly significant negative effect for government expenditure. If the expenditure ratio increases by 10% of GDP then growth is lower by 0.7-0.8 percentage points. The estimate is subjected to an extreme bounds robustness test and expenditure is found to have a robustly negative coefficient.

28. The analysis of Folster and Henrekson (2001) is severely criticised in Agell *et al.* (2006). Three issues are raised. First, the work of Folster and Henrekson switches from actual growth to potential growth in their regressions and do not make this clear. Second, the authors of the reply cannot replicate the results, nor can Folster and Henrekson recover the data they use. Third, there are problems with the econometric specification. Folster and Henrekson use two-stage least squares but Agell *et al.* claim that they do not instrument properly.

**Table 2: Mean coefficients**

Variable	Coefficient
Equipment investment	0.2175
Number of years an open economy	0.0195
Fraction Confucian	0.0676
Rule of law	0.0190
Fraction Muslim	0.0142
Political rights	-0.0026
Latin American dummy	-0.0115
Sub-Saharan Africa dummy	-0.0121
Civil liberties	-0.0029
Revolutions and coups	-0.0118
Fraction of GDP in mining	0.0353
SD black market premium	-0.0290
Primary exports in 1970	-0.0140
Degree of capitalism	0.0018
War dummy	-0.0056
Non-equipment investment	0.0562
Absolute latitude	0.0002
Exchange-rate distortions	-0.0590
Fraction Protestant	-0.0129
Fraction Buddhist	0.0148
Fraction Catholic	-0.0089
Spanish colony	-0.0065

29. Agell *et al.* also offer some comments on a number of problems with the general methodology of growth regressions - omitted variables, measurement errors, reverse causation, non-random sample selection – and looks at reverse causation and non-random sample selection in the context of Folster and Henrekson. Reverse causation refers to public sector causing growth, and growth causing the public sector. This reverse causality should be controlled by instruments. Using this technique Agell *et al.* generally find that the effects of the tax share and the expenditure share are insignificant and unstable across specifications in the correct regressions. The non-random sample selection problem is the addition of rich countries to the sample. These are non-random so invalidating results.

30. Folster and Henrekson (2006) dispute the findings of Agell *et al.*, arguing that it is based on only one sample and uses weak instruments. It is also contended that the instruments chosen by Agell *et al.* are weak and do not solve the simultaneity issue. Folster and Henrekson continue to claim that the strongest result of their paper does show a robust negative correlation between government size and the rate of growth.

31. Sala-i-Martin *et al.* (2004) develop a further method for aggregating regression coefficients across different regressions. This uses a Bayesian approach. The Bayesian approach begins with a specification of the prior distributions of the relevant parameters conditional on each possible model. The number of variables in the growth regressions makes this impractical since this number is so large. This has the consequence that implementation of this approach begins from an arbitrary set of priors. The method in this paper (BACE) combines averaging across models with OLS estimation. The paper provides a construction for updating the prior beliefs into posterior beliefs which is developed on the basis that the data become very informative. This leaves the problem of providing priors which is solved by choosing a mean model size with the probability attached to a model declining if it becomes larger or smaller than the mean. The alternative models were then sampled using the priors initially and then the posteriors. The data employed 67 variables from the usual range.

32. For a model of size 7 this generates 18 variables with a posterior probability higher than the prior probability. These are the ones that the data are suggesting should be included. The paper also reports the fraction of regression for which the absolute value of the *t* statistic for these variables is greater than 2. Table 3 summarises the main results. The first column describes the explanatory variables. The second column gives the posterior mean coefficient on the variable from the regressions in which it was included. The final column gives the fraction of regressions for which its *t* statistic was greater than 2. The final column makes clear the fact that regression models can be found in which each variable would be judged as fragile by extreme bounds analysis.

33. The paper then proceeds to test models of different sizes. The basic conclusion from this analysis is that not much changes. The basic 18 in the table remain at the top for all sizes with the exception of 5: malaria, Spanish, years open, ethno linguistic, government consumption share. These could be a catch-all for other effects. The conclusion is that this supports previous Sala-i-Martin work and is less negative than Levine and Renelt.

34. Bhargava *et al.* (2001) look at the effect of health on growth rates. This is done by using the adult survival rate (*ASR*) as a regressor in a growth regression. The data for the analysis is taken from the Penn World Tables and the World Development Indices of the World Bank. These provide two sets of slightly different regression results. The education series are taken from Barro and Lee (1996). The estimation used panel data at 5-year intervals (1965, 1970, 1975, 1980, 1985, 1990) for 92 countries.

**Table 3: Significance of variables**

Variable	Posterior mean conditional on inclusion	Fraction of regressions with $ t \text{ stat.}  > 2$
East Asian Dummy	0.021805	0.99
Primary schooling 1960	0.026852	0.96
Investment price	-0.000084	0.99
GDP 1960 (log)	-0.008538	0.30
Fraction of tropical area	-0.014757	0.59
Population density coastal 1960s	0.000009	0.85
Malaria prevalence 9n 1960s	-0.015702	0.84
Life expectancy in 1960s	0.00088	0.79
Fraction Confucian	0.054429	0.97
African dummy	-0.014706	0.90
Latin American dummy	-0.012758	0.30
Fraction GDP in mining	0.038823	0.07
Spanish colony	-0.010720	0.24
Years open	0.012209	0.98
Fraction Muslim	0.012629	0.11
Fraction Buddhist	0.021667	0.90
Ethno linguistic fractionalisation	-0.011281	0.52
Government consumption share 1960s	-0.044171	0.77

35. What the econometric analysis reveals is that increased *ASR* is likely to raise economic growth for poor countries. Moreover, there does not seem to be a reverse causality from growth rate to *ASR*. For high-income countries an increase in *ASR* reduces the growth rate. It would seem that *ASR* is proxying the distribution of population in countries with different income. For the low-income countries an increase in *ASR* keeps the ratio of workforce to young high. In rich countries an increase in *ASR* raises the number of retired to the number working. This simple mechanism explains the growth effect of *ASR*. A sample of the results is reported in Table 4. This regression treats lagged GDP as a fully endogenous variable and appears to be their preferred specification.

**Table 4: Results from regression of GDP growth rate**

Standard errors in parentheses

Constant	0.407 (0.069)
Tropics	- 0.012 (0.0049)
Openness	0.028 (0.005)
Log of fertility rate lagged five years	- 0.028 (0.008)
Log of investment/GDP ratio lagged five years	0.014 (0.0029)
Log of adult survival rate lagged five years	0.358 (0.114)
Interaction between lagged adult survival rate and GDP	- 0.048 (0.016)
Log of GDP lagged five years	- 0.041 (0.008)
GDP at which partial derivative of GDP growth rate with respect to lagged adult survival rate is zero	1714

36. Human capital can be measured either by its stock or by its rate of accumulation. Middendorf (2006) has tested the performance of these measures in a growth regression for a subset of the OECD countries. The methodology is to use panel data methods with country-fixed effects and time-fixed effects. The results obtained using OLS regression show that average schooling (the stock variable) is significant and has a positive coefficient. The change in schooling (the accumulation variable) has a negative but insignificant coefficient. Instrumental variable estimation is then tried to account for endogeneity of regressors. Average schooling then becomes insignificant and the sign on the investment ratio is unstable. Middendorf suggests that these effects are indicative of poor instrument choice.

#### **2.4 Observations**

37. Brock and Durlauf (2001) take the criticisms even further. First they criticise the open-endedness of the theory. Observe that Durlauf and Quah (1999) count over 90 variables used, but the data sets have at most 120 countries so the chance of getting firm inferences is difficult. This also emphasises how collinearity of variables can render coefficients insignificant.

38. When many variables are included collinearity is very likely to arise which undermines the method of Sala-i-Martin (1997b) since there will be some regression for which the effect of the variable is

not robust. The regressions also rely on parameter homogeneity. However, with the number of countries being very large and the countries being very diverse it is unlikely that parameter homogeneity will hold.

39. Regressors may be endogenous rather than exogenous and the instruments used may not be good choices. This point is illustrated by showing that the Easterly and Levine (1997) result on ethnic diversity reducing growth in sub-Saharan Africa is supported even when model uncertainty is taken into account and is strengthened when parameter homogeneity is permitted. Overall the paper provides a strong criticism of existing research but gives some evidence that it is possible to move forward.

## 2.5 Conclusions

40. In terms of economics what have we learnt? From the Sala-i-Martin *et al.* (2004) we learn that the East Asian dummy performs well - but that is predictable. The same comment can be made on the ethnic diversity variable from Easterly and Levine (1997). Schooling does well too, as does the convergence hypothesis. Beyond that we have not learned much that is economically useful for conducting any policy decisions. Ultimately this line of research is a dead end if the aim is to understand what causes growth so that we can improve the situation.

41. To close this section it is worth drawing attention to the argument of Brock and Durlauf (2001) that historical studies may inform us of more than the econometric analysis of anonymous data. The discussion of growth accounting in Section 4 will show that the path to growth has differed between countries. Some have grown through capital accumulation, others through innovation. There are clearly many other distinctions between individual countries. These differences are unlikely to be apparent in aggregate data. Instead, detailed historical country study is more suitable for bringing the details to light.

## 3. Tax Regressions

42. The early literature on growth regressions presented an optimistic picture of how an explanation of growth could be obtained. This optimism was lost when the robustness of coefficient estimates was challenged. The set of robustly significant variables was eventually reduced to a very small number whose nature gave little insight into how policy might affect growth. It is notable that the regressions described in Section 2 contained very limited detail on the government sector. An aggregate measure of expenditure was considered but no measures of the tax burden. The focus of this section is placed on growth regressions that include one or more variables representing taxation. The regressions investigate the effect of the level of taxation and the structure of the tax system.

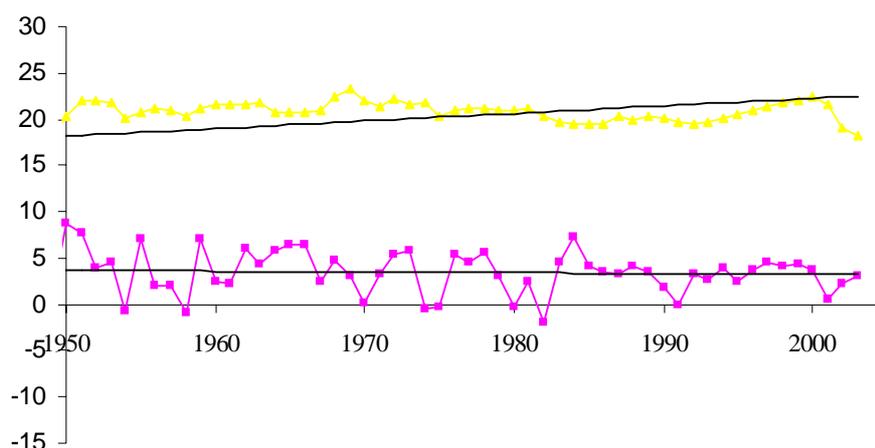
43. Taxation can have both a negative and a positive effect on growth. The negative effect arises from the distortions to choice and the disincentive effects. The positive effect arises indirectly through the expenditures financed by taxation. The endogenous growth model with a public good as an input provided a positive channel through which taxation could raise growth. The relationship was not monotonic because increases in the tax rate above the optimum would reduce the growth rate. In practice, economies could be located on either side of the optimum. Similarly, the evidence from the simulations provides a wide range of estimates for the effect of taxation upon economic growth from negligible to significant. Since the theory is so inconclusive, it is natural to turn to the empirical evidence.

### 3.1 Basic Evidence

44. At first glance, a very clear picture emerges from long-run historical evidence for individual countries: tax revenue as a proportion of gross domestic product rose significantly in all developed countries over the course of the last century, but the level of growth remained relatively stable. This suggests the immediate conclusion that, in practice, taxation does not affect the rate of growth. Data to support this claim is displayed in Figures 1 and 2. Figure 1 plots the growth rate of US gross domestic

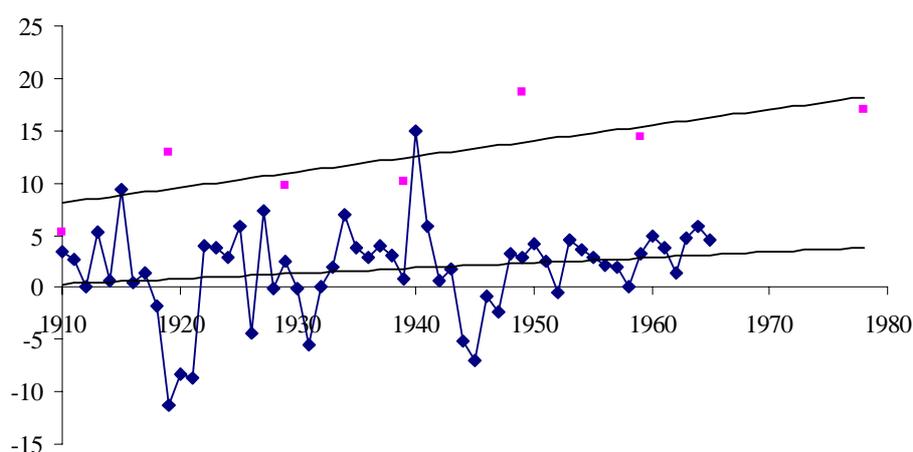
product and federal government tax revenue as a percentage of gross domestic product since 1930. Trend lines have been fitted to the data series using ordinary least squares regression. The two trend lines show a steady rise in taxation (the upper line) and a very slight decline in the growth rate (the lower line). Although the variance of the growth process reduces after 1940, statistical tests on US data have found no statistical difference between the average rate of growth prior to 1942, and after 1942. The data for the UK in Figure 2 tell a very similar story. The trend lines show an increase in taxation but, in contrast to the US, an increase in the rate of growth.

**Figure 1: US Tax and Growth Rates**



Source: US Department of Commerce: [www.bea.doc.gov/](http://www.bea.doc.gov/)

**Figure 2: UK Tax and Growth Rates**



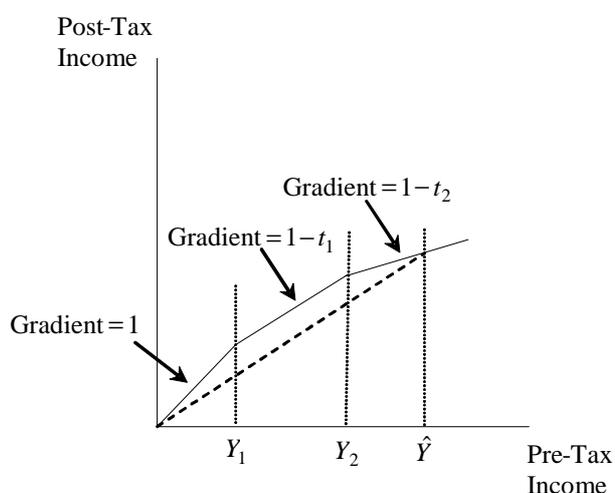
Source: Feinstein (1972), UK Revenue Statistics, Economic Trends

45. The message from these figures appears compelling but must be considered carefully. There are two reasons for caution. Firstly, a contrast between tax rates and growth across time cannot answer the question “if taxes had been lower, would growth have been higher?” To do so requires a study involving countries with different regimes. Secondly, there are substantive issues that have to be resolved about the definition of the tax rate that should be used in any such comparison.

46. To understand the problem of definition, consider Figure 3 which illustrates a typical progressive income tax. There is an initial tax exemption up to income level  $Y_1$ , then an income band at taxed at rate  $t_1$  and a final income band taxed at rate  $t_2$ ,  $t_2 > t_1$ . What is important about the figure is that it shows how the marginal rate of tax differs from the average rate of tax. For instance, at income level  $\hat{Y}$ , the marginal rate is one minus the gradient of the graph whilst the average rate is one minus the gradient of the ray to the graph (shown by the dashed line). With a progressive tax system, the marginal rate is always greater than the average rate.

47. The data displayed in Figures 1 and 2 uses tax revenue as a fraction of gross domestic product to measure the tax rate. This measure captures the average rate of tax. However, what economic theory predicts to be important for behavior is the marginal tax rate - the decision on whether or not to earn additional income depends on how much of that income can be retained. This suggests that the link between growth and taxation should focus more on how the marginal rate of tax affects growth.

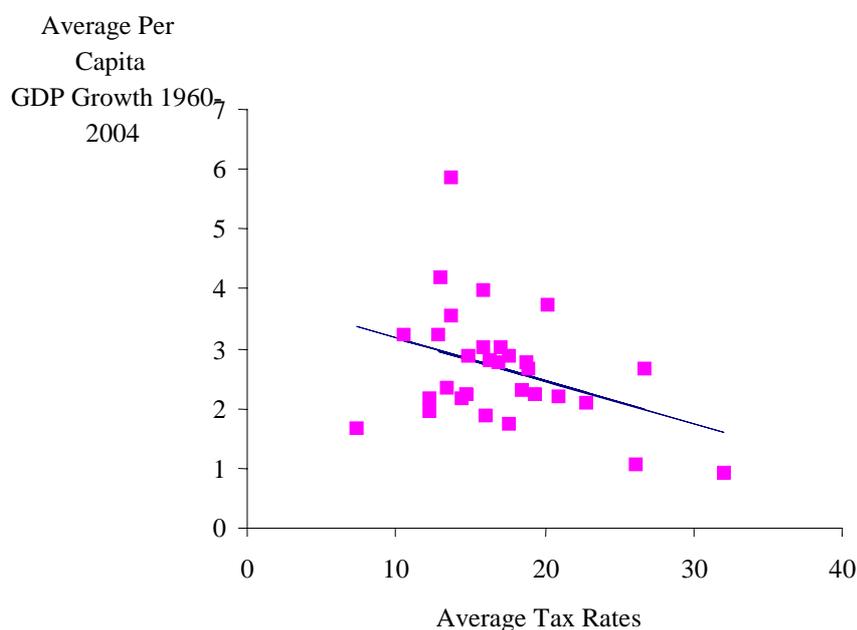
The difficulty with undertaking the analysis comes in determining what the marginal tax rate actually is. Figure 3 illustrates this problem: the marginal tax rate is either 0,  $t_1$  or  $t_2$  depending upon the income level of the consumer. In practice, income tax systems typically have several different levels of exemption (*e.g.* married and single persons allowances), several marginal tax rates, and they interact with social security taxes and with the benefit system. All of this makes it difficult to assign any unique value to the marginal rate of tax. The same comments apply equally to corporation tax, which has exemptions, credits and depreciation allowances, and Value Added Taxation which has exemptions, zero-rated goods and lower-rated goods. In brief, the rate of growth should be related to the marginal rate of tax but there are significant difficulties in finding an empirical counterpart.

**Figure 3: Average and Marginal Tax Rates**

### 3.2 Empirical Results

48. Given these preliminaries, it is now possible to review the empirical evidence. The strongest empirical link between taxation and growth was reported in Plosser (1992). Plosser calculated the correlation between the rate of growth of per capita gross domestic product and a range of variables for the OECD countries. The share of income and profit taxes in GDP was found to have a correlation of -0.52 with the growth rate of GDP. A chart plotting average tax rates in OECD countries against GDP growth over 1960 - 1989 is given to confirm this result. Even so, Plosser warns against taking the correlation as evidence of causality and presents several potential explanations for the lack of robustness in regression equations (most policies operate through investment, policies are complex and not easily represented by variables in regressions, policies are highly correlated).

49. Figure 4 displays an updated version of Chart 6 in Plosser (1992). This figure extends the sample period through to 2004. The data points are found by averaging the growth rate and the tax rate over this period for each country. A straight line fit by least squares shows the negative relationship between the growth rate and the average tax rate identified by Plosser. The obvious limitation of this finding is that the effect of taxation cannot be accepted without considering the effect of other explanatory variables. For instance, the OECD countries differ in their income levels and, as the discussion of Section 2 has shown, income is one of the most robust determinants of economic growth. Other variables may also be important. The negative relationship cannot be accepted until it has been shown to survive the inclusion of additional covariates in a regression analysis.

**Figure 4: Real income growth and tax rates in OECD countries 1960 - 2004**

Source: Penn World Table Version 6.2

50. The measure used to represent tax rates is an important issue in tax regressions. Some of the research employs the average rate of tax, while other papers attempt to construct a measure of the marginal rate of tax. This issue matters because the standard application of economic theory shows it is the marginal tax rate that matters for the degree of distortion introduced into choices. Optimal decisions are determined by trading the marginal benefit of one choice against the marginal benefit of another. The marginal rate of tax directly affects this trade-off and causes the distortion in choice. Using an average rate of tax to explain growth does not capture this important feature of taxation.

51. In an analysis of 63 countries Koester and Kormendi (1989) use IMF data to construct measures of the average tax rate and the marginal tax rate. The average tax rate variable is constructed by using revenue/GDP and the marginal tax rate variable is obtained from a regression of revenue on GDP and a constant. A series of regressions of the growth rate on tax variables and income are conducted. The regression results show little evidence of an effect of either average or marginal rate upon the growth rate, but the marginal rate is claimed to have an effect on the level of activity. The relevant growth rate regressions are presented in Table 5. The tax rates are significant when used as the sole regressor but become insignificant when the level of initial GDP is included. The inclusion of initial GDP raises the explanatory power of the regression, though it still remains small.

**Table 5: Regression on marginal and average rates**

Variable	A	B	C	D
Constant	0.060 (8.26)	0.053 (10.48)	0.058 (8.34)	0.060 (11.4)
Average tax	-0.074 -2.18		-0.005 (-0.11)	
Marginal tax		-0.25 (-1.87)		-0.011 (-0.87)
Initial GDP			-0.052 (-2.656)	-0.048 (-3.03)
$R^2$	0.072	0.05	0.17	0.18

52. The standard criticisms of this paper are as follows. First, it assumes a constant marginal rate of taxation despite significant changes in the tax systems in several of the countries over the period of the data set. Second, the inclusion of too wide a range of countries causes aggregation bias since the industrialised and non-industrialised countries may have very different responses of growth to taxation. These are criticisms that can be levelled at many of the papers in this area of the literature.

53. A comprehensive data series on personal tax rates was given in Sicat and Virmani (1988). An alternative series for the marginal tax rate was constructed and reported in Easterly and Rebelo (1993a). The method of construction involves computing the income-weighted average marginal tax rate

$$\Omega_y = \frac{\int_0^{\infty} y \tau'(y) f(y) dy}{\int_0^{\infty} y f(y) dy}, \quad (2)$$

where  $\tau'(y)$  is the marginal tax rate at income  $y$  and  $f(y)$  is the density function for income. The construction is completed by assuming that the marginal tax rate  $\tau'(y)$  is given by the logistic equation

$$\tau'(y) = \frac{a_0}{1 + a_1 \exp(a_2 y)}. \quad (3)$$

This function ensures that the marginal tax rate lies between  $a_0/(1+a_1)$  and  $a_0$ . Implementation of this formula is undertaken by setting the three parameters  $(a_0, a_1, a_2)$  to match chosen aspects of the data.

54. Easterly and Rebelo (1993b) test the tax rates of Sicat and Virmani (1988), their own method of constructing marginal tax rates, plus several other methods of defining the marginal tax rate, in tax regressions. In total 13 different measures of the tax rate are employed. The methodology adopted is to include these measures of the marginal tax rate one at a time within a basic regression equation. The basic

equation contained the standard determinants of growth found to be significant in Barro regressions; notably initial income (*PRIM60*), school enrolments (*SEC60*), assassinations (*ASSASS*), revolutions (*REV*) and war casualties (*WARCAS*). Estimation of this basic equation without the inclusion of tax rates generated the result

$$\begin{aligned} \gamma_{y7088} = & \underset{(0.51)}{0.003} - \underset{(-2.81)}{0.004} GDP60 + \underset{(1.88)}{0.025} SEC60 \\ & + \underset{(3.15)}{0.023} PRIM60 - \underset{(-1.29)}{0.01} REV \\ & - \underset{(-1.47)}{0.003} ASSASS - \underset{(-1.67)}{1.157} WARCAS, \end{aligned} \quad (4)$$

with an  $R^2$  of 0.29.

55. Table 6 reports the statistical significance level of the alternative measures of the marginal tax rate when included as an additional variable in this regression. The tax rates generally perform badly in the regressions. Only the marginal income tax rate from a regression on GDP is significant at the 5% level. In particular, the Koester and Kormendi (1989) marginal tax rate becomes insignificant when included alongside other variables in the regression equation.

56. When the significant tax rate was included the estimated regression equation became

$$\begin{aligned} \gamma_{y7088} = & \underset{(1.109)}{0.010} - \underset{(-2.25)}{6.46 \times 10^{-3}} GDP60 + \underset{(2.09)}{0.0439} SEC60 \\ & + \underset{(2.24)}{0.0247} PRIM60 - \underset{(-0.39)}{0.0439} REV \\ & - \underset{(-1.69)}{65.7} ASSASS - \underset{(-2.225)}{1.436} WARCAS \\ & - \underset{(-2.204)}{0.064} MARTAX. \end{aligned} \quad (5)$$

57. The inclusion of the marginal tax rate variable has a major effect on the value of the coefficient on assassinations. The coefficients on the other variables do not change dramatically in significance but the coefficient on initial GDP in 1960 is reduced. The effect of the marginal tax rate has the expected negative sign.

58. From a number of regressions involving different combinations of these variables, Easterly and Rebelo (1993b) conclude: "The evidence that tax rates matter for economic growth is disturbingly fragile".

**Table 6: Significance of marginal tax rates**

Tax rate	Significance level
<i>Tax rates computed using regression</i>	
Koester-Kormendi (1989) marginal tax rate	0.194
Marginal income tax rate from regression on GDP	0.047
Marginal tax rate from regression of total revenue on GDP	0.121
<i>Tax rates computed as ratios of tax revenue to tax base</i>	
Taxes on income, profits, and capital gains/GDP	0.353
International trade taxes/Imports plus exports	0.243
Individual income taxes/Personal incomes	0.098
<i>Sicat-Virmani statutory tax rates</i>	
On first bracket	0.432
On 0.75 × average family income	0.386
On 2 × average family income	0.958
On 3 × average family income	0.587
On highest bracket	0.687
<i>Easterly-Rebelo (1993a) marginal tax rate</i>	0.880

59. A further analysis of the significance of a tax rate variable is undertaken in Mendoza, Milesi-Ferretti and Asea (1997). The clear finding is that when initial GDP is included in the regressions, the tax variable is insignificant. Evidence contrary to this is presented in Leibfritz, Thornton and Bibbee (1997). Their regression of average growth rates for OECD countries over the period 1980-1995 against three measures of the tax rate (average tax rate, marginal tax rate and average direct tax rate) showed that a 10% increase in tax rates would be accompanied by a 0.5 percentage point reduction in the rate of growth, with direct taxation reducing growth marginally more than indirect taxation.

60. Additional work on similar lines has been undertaken by Dowrick (1993) and de la Fuente (1997). These papers considered the more general issue of how the structure of fiscal policy affects growth. In particular, they investigated how the rate of growth is related to the composition and level of public sector spending. Dowrick studied a number of OECD countries and showed that personal income taxation had a negative effect on growth but corporate taxes had no effect. The results of de la Fuente showed that if public spending (measured as the share of total government expenditure in GDP) increases, growth is reduced (a reduction in government spending of 5% of GDP reduces growth by 0.66 percentage points) whereas an increase in public investment will raise growth. These results confirm the negative coefficient on government consumption expenditure.

61. Padovano and Galli (2001) also construct marginal tax rates by regressing tax revenue on GDP but improve on Koester and Kormendi by including level and slope dummies to allow for changes in the tax rate over the sample period. The regression equation for construction of the marginal tax rate variable is

$$REV = \alpha_0 + \alpha_1 GDP + \alpha_2 TAXREF + \alpha_3 (TAXREF \times GDP), \quad (6)$$

where  $REV$  is government revenue, and  $TAXREF$  is a dummy for tax reform. The estimated regression equations have an average  $R^2$  of 0.96 (the value of which suggests there may be spurious regression issues) and almost always have a value of  $\alpha_1$  that is significant at the one percent level. However, the estimates for  $\alpha_1$  show significant intertemporal variability for individual countries which seems larger than known changes in tax systems would suppose. For instance, the values for the UK are 0.285 (1950s), 0.449 (1960s), 0.324 (1970s), and 0.367 (1980s).

62. The estimated marginal tax is then used in a growth regression for OECD countries. The decade-average growth rate is regressed on per capita income, population growth, average rate of physical and human capital accumulation, the constructed marginal tax variable, plus other conditioning variables. The sample of results reported in Table 7 show that the marginal tax variable is negatively and significantly correlated with growth.

**Table 7: Regression results**

*t* statistics in parentheses

Constant	0.027 (6.67)
Marginal tax	-0.012 (-2.79)
Base year GDP	$-1.42 \times 10^{-6}$ (-6.32)
Population growth	1.062 (3.6)
Ratio of physical investment to GDP	0.0002 (1.84)
Investment in human capital	0.0004 (0.1)
Government consumption	$-3.13 \times 10^{-6}$ (-0.02)
Inflation	-0.08 (-3.02)
$R^2$	0.53

63. It has been noted that some tax regressions employ the average rate of tax, while others attempt to construct a measure of the marginal rate of tax. The consequence of this modelling choice is investigated by Padovano and Galli (2002) for data on 25 industrialised countries over the period 1970-1998. The basic argument is that individual choices are at the heart of endogenous growth theories. The relevant variable for choices is the marginal rate of tax and not the average rate. For this reason the average rate of tax

should not be significant in a growth regression. In addition, the average rate of tax is also related to government expenditure and so may even enter a growth regression with positive sign. The marginal rate of tax, and measures of tax progression, should enter the growth regression with a negative sign.

64. The first step in the analysis is to regress tax revenue on a constant, GDP, a dummy for tax reforms, and the interaction of the dummy and GDP. The coefficient from this regression is interpreted as an approximation of the marginal tax rate. There is no attempt to disaggregate the data to find the marginal effect of different taxes. The average value for the constructed marginal tax rate across the sample of countries is 33% and the average tax 29%.

65. The effect of a range of variables other than the tax rates is tested by “progressive inclusion” to ensure robustness. When the average tax rate and the marginal tax rate are included separately in regressions the average tax rate is insignificant but the marginal tax is significant. A sample of the results is shown in Table 8 (*t* statistics in parentheses). Models II and III enter the tax variables separately. The lack of significance of the average tax rate is clear. Including both the average tax and the marginal tax is claimed to represent the effect of progressivity: holding the average tax rate constant while the marginal tax rate is increased represents an increase in progressivity. The results for Model VI show that when both tax variables are included the coefficient on marginal tax remains negative and significant but average tax is not significant. The results of Model III show that a 10 percentage point increase in the marginal tax rate reduces growth by 0.23 percentage points.

66. An approach designed to circumvent the difficulties involved in defining marginal tax rates can be found in Easterly (1993). Rather than look at tax rates directly, Easterly places the focus on the distortions generated by those tax rates. These distortions are found by using the data of Summers and Heston (1988) on 1980 price data for 151 commodities in 57 countries relative to the US. The variance of the prices within countries is then taken as a measure of the relative degree of distortion that exists in those economies due to taxation, quotas, price restrictions and other forms of intervention. After controlling for other determinants of growth (such as initial country income and school enrolment) the reported estimates show that the variance of input prices is a statistically significant variable in the determination of growth. In fact, increasing the variance of prices from the mean by one standard deviation lowers growth by 1.2 percentage points. This is clearly an interesting approach but it does have two deficiencies. First, the variance of prices is not proven to be a good proxy for the degree of distortion in the economy, it is merely assumed to be so. Secondly, there is no immediately obvious way to translate the effect of price variation into the effect of changes in tax rates. To do so would require knowledge of how taxes feed, through market equilibrium, into prices.

67. Engen and Skinner (1996) focus their discussion around the effect of a 5 percentage point cut in marginal tax rate using three methods: (1.) by studying the US historical record; (2.) by reviewing empirical evidence on cross-section studies for large samples of countries; and (3.) compiling evidence from microlevel studies. The review of US history does not suggest any concrete conclusion. Instead, the interest in the exercise lies in the demonstration that a minor change in the period under review can reverse the conclusion. This is a clear warning against making simple inferences from data.

**Table 8: Regressions on average and marginal taxes**

Variable	Model II	Model III	Model VI
Average tax	0.005 (0.2)		0.0039 (0.89)
Marginal tax		-0.023 (-3.45)	-0.0342 (-3.82)
Population growth rate	1.302 (2.897)	1.556 (3.42)	1.096 (4.578)
Investment in physical capital	-0.0003 (-0.324)	-0.0005 (-0.237)	0.0028 (1.379)
Investment in human capital	0.006 (3.73)	0.005 (7.1)	0.004 (4.08)
Initial GDP	-0.0001 (-1.839)	-0.0004 (-8.86)	-0.0001 (-5.571)
Inflation			-0.232 (-4.883)
$R^2$	0.567	0.66	0.65

68. After reviewing the results of some of the papers described above, Engen and Skinner deduce four problems with the cross-country studies. First, even if taxation has a negative effect on growth the revenues it finances may have an offsetting positive effect. Second, when a large range of heterogeneous countries are analyzed the data may be of very variable quality. Third, there may be reverse causality causing bias in the estimated coefficients. Finally, countries may differ in their taste for expenditure and in the ease of raising revenue (and both of these may be correlated with growth).

69. One possible route out of the difficulties of defining the appropriate tax rate is to adopt a different method of determining the effect of fiscal policy. Engen and Skinner (1996) label the regressions described above as “top-down” since they work with aggregate measures of taxation. Instead of doing this, they propose a “bottom-up” method which involves calculating the effect of taxation on *labour* supply, investment and productivity, and then summing these to obtain a total measure. Doing this suggests that a cut of 5 percentage points in all marginal rates of tax and 2.5 percentage points in average rates would raise the growth rate by 0.22 percentage points. The third paper considers aspects of this bottom-up approach.

70. An alternative set of issues are addressed in Kneller *et al.* (1999). They note that there are specification problems in the regressions because of government budget balance. If the implications of budget balance are not handled correctly the regression equation is actually determining the difference of the effect of tax variables. This can be seen by writing the basic regression equation as

$$\gamma_y = \alpha + \sum_{i=1}^k \beta_i Y_i + \sum_{j=1}^m \theta_j X_j + \varepsilon, \quad (7)$$

where  $Y_i$  are the non-fiscal conditioning variables and  $X_j$  the fiscal variables. If the fiscal variables are comprehensive then the government budget constraint requires

$$\sum_{j=1}^m X_j = 0. \quad (8)$$

71. If the regression is estimated with all fiscal variables included then it will suffer from multicollinearity. Alternatively, if one fiscal variable, say the  $m$ th, is excluded the equation for estimation becomes

$$\gamma_y = \alpha + \sum_{i=1}^k \beta_i Y_i + \sum_{j=1}^{m-1} (\theta_j - \theta_m) X_j + \varepsilon, \quad (9)$$

so the test of significance for  $\theta_j - \theta_m \neq 0$  is actually a test of  $\theta_j \neq \theta_m$ . This suggests omitting a variable where the theory suggests that  $\theta_m \equiv 0$ , so that the estimated coefficient is approximately the effect of the included variable.

72. These observations are implemented by breaking taxes into distortionary and non-distortionary, and expenditures into productive and non-productive. Regressions are then conducted with one of the categories omitted. The data used is for 22 OECD countries over the time period 1970-1995. The estimation procedure employs a two-way fixed effects model on a panel of five-year averages. A sample of the results is presented in Table 9. These results are interpreted as providing strong support for the Barro model: distortionary taxation reduces growth, productive expenditure enhances growth, and non-productive expenditures have an insignificant effect. The key assumption is that taxes are measured by the revenue raised as a percentage of GDP. Hence, the estimation is implicitly using the average tax rate rather than the marginal tax rate. This choice is subject to the criticisms already raised above.

73. This analysis is extended by Bleaney *et al.* (2001) to consider whether the five-year averaging technique commonly used for these regressions is valid. The test of validity is undertaken by running the regression for five-year averages and then running again but allowing for lagged effects of the fiscal variables. The lagged effects are found to be collectively significant. The appropriate lag length is then found by using annual data instead of averaging and extending the number of lags until the Wald  $\chi^2$  test demonstrates insignificance. This reveals that eight lags are required so long-run effects are important. The estimation results for eight lags (with each coefficient being the sum of current and lagged effects) are summarised in Table 10. The omitted variable is non-distortionary taxation. This is presumed to have a coefficient of zero in the regression so the stated coefficients can be interpreted as the effect and not the difference in effects. The key finding here is the large negative and significant coefficient on distortionary taxation. The definition of this variable includes all taxes other than consumption taxes. Consumption taxes are treated as non-distortionary on the grounds that they do not distort intertemporal decisions.

**Table 9: Regression results***t* statistics in parentheses

Omitted fiscal variable	Non-distortionary taxation	Non-productive expenditures
Initial GDP	-0.490 (2.79)	-0.490 (2.79)
Investment	-0.020 (0.33)	-0.020 (0.33)
Labour force growth	-0.327 (1.09)	-0.327 (1.09)
Lending minus repayments	0.417 (1.829)	0.380 (2.13)
Other revenues	-0.154 (0.81)	-0.117 (1.12)
Other expenditures	<b>Error! Objects cannot be created from editing field codes.</b>	0.279 (2.42)
Budget surplus	0.446 (2.79)	0.410 (4.60)
Distortionary taxation	-0.446 (2.79)	-0.410 (4.21)
Non-distortionary taxation		0.0370 (0.23)
Productive expenditures	0.290 (1.98)	0.253 (1.95)
Non-productive expenditures	0.037 (0.239)	
Adjusted $R^2$	0.602	0.602

**Table 10: Yearly estimation with eight lags***t* statistics in parentheses

Investment ratio	0.120 (4.21)
Labour force growth	- 0.350 (-2.67)
Other revenues	- 0.041 (-0.32)
Other expenditures	0.013 (0.10)
Budget surplus	0.109 (1.012)
Distortionary taxation	- 0.393 (-2.92)
Productive expenditures	0.337 (3.67)
Non-productive expenditures	0.045 (0.499)
Net lending	- 3.865 (-4.03)
Lagged growth	- 2.062 (-9.11)
Adjusted $R^2$	0.758

74. Taxes can be levied on personal income and on corporate income. A personal income tax bears upon the allocation of time between labour supply and leisure, and on the allocation of income between consumption and saving. There are grounds (which are covered in the third paper) for suspecting that the labour supply effect will be the larger of these two. An increase in hours of work can raise output but cannot lead to a sustained higher level of growth. In contrast, the corporate income tax affects both investment and the incentive to supply entrepreneurial skills. The margins on which these taxes operate suggest that it will be informative to trace the potentially distinct growth effects of personal and corporate income taxes.

75. Widmalm (2001) investigates the effect of the tax structure on growth using cross-section data on 23 OECD countries from 1965 - 1990. The methodology follows that of Levine and Renelt (1992) but used four basic variables (initial income, investment to GDP ratio, population growth, and average tax rate). The share of different tax instruments in revenue is considered first (corporate income tax, personal income tax,

property tax, taxes on goods and services, and taxes on wages). A progressivity measure is constructed from the regression

$$\ln T = \alpha_0 + \alpha_1 \ln GDP + \varepsilon . \quad (10)$$

The elasticity  $\alpha_1$  is taken as the measure of progressivity.

76. The results of the extreme bounds analysis of robustness are summarised in Table 11. The proportion of tax revenue from taxing personal income has a negative and robust correlation with growth. There is also some evidence that progressivity affects growth.

**Table 11: Results of extreme bounds analysis**

Variable	Bound	$\beta$	$t$ ratio
Taxes on corporate income	High	0.027	1.03
	Base	0.009	0.38
	Low	0.001	0.05
Taxes on personal income	High	-0.023	-2.30
	Base	-0.027	-2.81
	Low	-0.033	-3.19
Taxes on property	High	0.018	0.44
	Base	0.018	0.43
	Low	-0.031	-0.62
Taxes on goods and services	High	0.052	3.44
	Base	0.022	1.98
	Low	0.021	1.54
Taxes on wages	High	0.014	1.34
	Base	0.004	0.42
	Low	0.001	0.16
Progressivity	High	-0.737	-1.83
	Base	-0.822	-2.04
	Low	-1.063	-2.52

77. The theoretical models identify the different routes through which household choices and corporate choices can affect the growth rate. These results suggest that taxation of the household and taxation of the corporation may differ in how they influence the growth rate. This hypothesis is addressed in Lee and Gordon (2005) who conduct a tax regression using the top corporate marginal tax rate and top personal marginal tax rate to capture the effects of taxation. They justify this choice by an appeal to entrepreneurial activity being the driver of growth, and the top marginal rate being the one that is likely to be applicable to successful entrepreneurs. This choice can be referred back to the issues in the previous literature that debated the representation of the marginal tax rate.

78. The results reported in Table 12 are for a panel regression based on averages for three five-year periods (1980 - 1984, 1984 - 1989, 1990 - 1994) and one three-year period (1995-1998). The annualised growth rate is regressed on the corporate tax rate in the initial year for each observation. The variable ICRG index is a measure of the quality and corruption of bureaucrats. The final column of the table shows the effect of including both corporate and personal taxes. The standard errors (in parentheses) show that the corporate tax is significant in all three of the regressions. It remains significant when the personal tax rate is included, but the personal tax is not significant. This supports the conclusion that it is corporate taxes that are most damaging for growth since they reduce entrepreneurial activities and lessen the incentive for innovation. Cutting corporate tax rate by 10 percentage points can increase annual growth rate by 1.1 percentage points.

**Table 12: Corporate and personal taxes**

Standard errors in parentheses

Estimation method	OLS	Country dummies +IV	Country dummies +IV
Corporate tax rates	-0.058 (0.019)	-0.171 (0.034)	-0.182 (0.046)
Personal tax rates			0.001 (0.026)
GDP per capita	-1.078 (0.223)	-4.321 (1.067)	-5.247 (1.282)
Primary school enrolment	0.026 (0.011)	0.017 (0.020)	0.031 (0.023)
Average openness	2.672 (0.480)	1.358 (0.713)	1.352 (0.772)
Average ICRG index	0.527 (0.201)	0.211 (0.523)	-0.115 (0.586)
Population growth rates	-0.730 (0.227)	-1.086 (0.460)	-0.952 (0.5237)

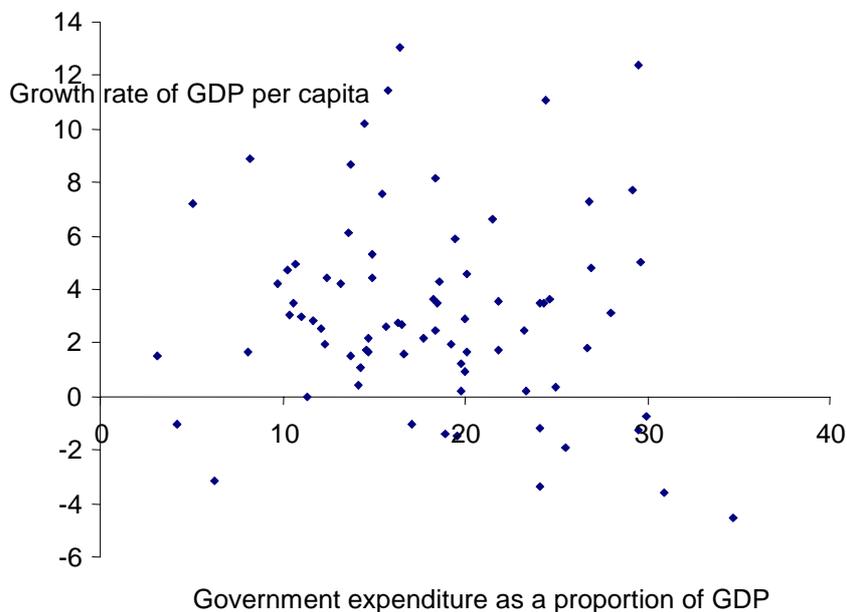
Average inflation rates	-0.0026 (0.000)	-0.001 (0.000)	-0.001 (0.000)
Constant	70719 (2.030)		
Adjusted $R^2$	0.323	0.651	0.665

**3.3 Limitations**

79. Slemrod (1995) is a key paper for understanding the limitations of the methodology of tax regressions. The paper first presents simple scatter plots of the relationship between tax revenue as a proportion of GDP and the rate of growth. Across the OECD countries there is no obvious relationship and the scatter appears almost random. When a larger range of countries is considered some evidence for a positive relationship emerges but this is mainly a consequence of the relatively high growth levels in the high-revenue OECD countries. An updated version of this data is presented in Figure 5. This plots growth in GDP per capita against government expenditure as a proportion of GDP for 78 countries in 2004 using data from the latest version of the Penn World Tables. As observed by Slemrod there is no discernible pattern in this data. If there were a strong link between government and growth it is surprising it does not appear in the figure.

**Figure 5: Growth and government expenditure 2004**

Data: Penn World Tables Version 6.2



80. As noted by Slemrod (1995) the basic method of the regressions is to use national income,  $Y$ , as the left-hand-side variable and government expenditure,  $G$ , as the right-hand-side variable (or the average tax rate which is closely linked to  $G$  through the government budget constraint). In contrast, economic theory provides convincing arguments that there is causality running in the opposite direction: government expenditure is determined by the preferences of the population for public goods as expressed through the political system. A simple version of this view is captured in Wagner's law which relates government expenditure to national income via the income elasticity of demand for government-provided goods and services.

81. This argument is taken one step further by Slemrod who models the simple fact that  $Y$  influences  $G$ , and  $G$  influences  $Y$ . In essence, it is the interaction of the two structural relationships that generates the observed data. The estimation methodology has not adequately resolved the simultaneity between these two relationships and therefore the estimated coefficients do not represent the underlying structural equations. Moreover, if the level of  $G$  is chosen optimally given  $Y$  then the first-order effect of changes in  $G$  upon  $Y$  should be zero. Hence, there will be little variation for the data to capture. If there are any differences in the relationship between  $Y$  and  $G$  across countries then, combined with optimisation, this will make for an even less meaningful relationship in the data.

82. The basic point here is concern about the lack of structural modelling in these tax regressions and the consequent lack of any clear idea of what the estimated regression equation is representing. The lack of structural modelling is also criticised by Brock and Durlauf (2001). Although these authors make the point in connection to Barro regressions it is equally true with the tax regressions. This is an area of research in which no progress appears to have been made.

83. Slemrod (1995) then provides a brief review of the literature up to the mid 90s and argues that the results of Barro and Plosser are not robust. The paper proceeds to discuss the tax elasticity of individual choices and provides a range of arguments why they may not be large. Also, the problem of defining marginal tax rates is discussed. Analysts use revenue to infer rates, but the link between rates and revenue depends on the ability to move into the hidden economic sector. Therefore, there is a lack of comparability of this data across countries. The comments by Easterly reinforce this generally negative perspective. These comments are especially valid given the role of Easterly in this research area.

84. Some of the observations of Slemrod and Easterly are captured in Table 13. Notice how the tax ratio is much higher in Sweden but the VAT rate is not that much larger. The difference is caused by the compliance rate. In Sweden compliance is very high but in Peru it is low. Even though the tax ratio is high in Sweden it has grown faster. The point of Easterly is that it is difficult to see how this information can be adequately captured in a regression analysis. The data also illustrate the argument of Slemrod that tax increases can cause switches into hidden economic activity. This is evidenced by the size of the informal sector in Peru.

**Table 13:** Key indicators for Peru and Sweden

Indicator	Peru	Sweden
Real per capita growth, 1970 – 90	-1.1	1.8
Tax ratio to GDP, average 1970 – 90	7	47
VAT rate, 1990 – 93	18	23
VAT compliance ratio, 1990 – 93	32	95
Informal sector share in labour force, 1990 - 93	56	

85. There is a further difficulty with trying to determine the effect of taxation via these regressions methods. What should matter for the economic outcome is the distortion caused by the tax (how much it changes decisions). An aggregate measure of the tax rate can never capture the varying degrees of distortion that individuals or firms with different incomes will face. This is more than just the distinction between average and marginal rate. Account must also be taken of the tax base, the existence of exemptions, and the ability to move into alternatives (such as tax-free choices or the hidden economy). Having said this, it still remains the case that all of the regressions are limited by the fact that they are unable to work with the rate of tax that affects individual decisions. For decisions at the margin we would think of the marginal rate of tax as being important. But there are discrete choices (such as choice of location) for which the average rate matters. What the regressions end up using is an aggregate average rate, or constructed marginal rate, that probably does not affect the rate that any particular economic decision maker is facing.

### 3.4 Observations

86. This review of the empirical evidence produced by tax regressions leads to the following observations. A visual inspection of tax rates and growth rates suggests that there is little relationship between the two. This is weak evidence but it does find support in some more detailed investigations in which regression equations that include previously identified determinants of growth, especially initial income, reveal tax rates to be insignificant as an explanatory variable. Other regressions find a small, but significant, tax effect.

87. Despite this weak evidence there remains a belief that taxes must be damaging for growth and that the evidence will eventually confirm this fact. As an example, Karabegovic *et al.* (2004) survey some of the literature and observe that “Two recent papers ... confirm the negative effects of high marginal tax rates on economic growth.” The basis for this belief is the simple economic theory that the marginal rate of tax is the relevant value for creating distortions in choice, and that the distortions caused by taxation mean lower growth. Despite the compelling nature of this argument no reading of the empirical work can justify such a confident conclusion. As observed by Slemrod, (1995) “If the cost of government is so large, why is this cost so difficult to discern in time-series or cross-country studies?”

88. All of these results are hampered by the difficulties in actually defining marginal rates of tax and in their lack of an equilibrium relationship. More success is likely to be found in analyzing the individual choices and testing each to find the responsiveness to policy. Engen and Skinner (1996) label the regressions described in this and the preceding section as “top-down” since they work with aggregate

measures of taxation. Instead of doing this, they propose a “bottom-up” method which involves calculating the effect of taxation on labour supply, investment and productivity, and then summing these to obtain total measure. Their application of the bottom-up method suggests that a cut of 5 percentage points in all marginal rates of tax and 2.5 percentage points in average rates would raise the growth rate by between 0.2 and 0.3 percentage points. The next section and the third paper will discuss the analysis that is behind the deduction of these values.

#### 4. Growth Accounting

89. The discussion of growth theory has identified the channels through which growth can occur. In essence, these can be reduced to the accumulation of capital, the accumulation of labour, technical progress, and the improvement of market functioning. The question of the relative importance of these channels for different countries then arises. Knowing which channel matters provides guidance on how policy can best be designed. For instance, a fixed government budget may be better spent on subsidising investment rather than education if it is capital accumulation that is driving growth.

90. There is a substantial literature that attempts to allocate growth to the alternative components. This literature has become known as growth accounting and a brief description of the methodology is provided in the appendix to this section. The result that the analysis provides is the identity

$$g_Y = \alpha_K g_K + \alpha_L g_L + SR. \quad (11)$$

This equation states that the growth rate of output,  $g_Y$ , is equal the sum of the growth rate of capital stock,  $g_K$ , and the growth rate of labour,  $g_L$ , weighted by their shares in national output, plus the Solow residual,  $SR$ . The Solow residual is that part of output growth not attributable to growth in inputs, so it captures a range of effects including technical progress and improvements in market functioning. The residual has also become known as total factor productivity (*TFP*).

91. Table 14 from Maddison (1987) summarises the degree of productivity growth for a range of developed countries. It can be seen from this table that productivity growth accounts for a substantial fraction of growth. The table shows that the increase in growth during 1950 - 1973, and the subsequent slow-down, is due to productivity growth and not variations in factors of production. These figures also emphasise how much the endogenous growth models have to explain (and, conversely, how much the Solow model does not explain).

92. A detailed application of growth accounting to a range of countries is of interest for several reasons. First, it can reveal if there have been differences in the growth process between countries. Simple economic growth models imply that all countries will develop in the same way (although possibly at different times). Data that show this is not the case will emphasise the need to treat existing models with caution and to seek better models. Second, if countries have developed differently then policy responses need to take this into account. If there is more than one way to achieve growth the best method has to be selected for each country.

**Table 14: Real GDP growth and productivity**

	1913 - 1950		1950 - 1973	
	GDP growth	Productivity	GDP growth	Productivity
France	1.20	1.42	5.10	4.02
Germany	1.30	0.86	5.90	4.32
Japan	2.20	1.10	9.40	5.79
Netherlands	2.40	1.25	4.70	3.35
UK	1.30	1.15	3.00	2.14
US	2.80	1.99	3.70	1.85
Average	1.87	1.30	5.30	3.58

	1973 - 1984	
	GDP growth	Productivity
France	2.20	1.84
Germany	1.70	1.55
Japan	3.80	1.21
Netherlands	1.60	0.81
UK	1.10	1.22
US	2.30	0.52
Average	2.12	1.19

#### ***4.1 East Asian Growth***

93. The rapid growth of the East Asian economies in the 1980s provided the motivation for a number of growth accounting studies. These studies aimed to determine the source of growth in the East Asian countries and to compare this with the experience of Industrialised Western countries. The alternative hypotheses were that the East Asian growth could be due to capital accumulation, the assimilation of technical progress made abroad, or an increase in human capital. The example of these countries provided the data for testing the alternative hypotheses.

94. The work of Kim and Lau (1996) is typical of the research in this area. The analysis is based upon the meta-production function approach that permits countries to have different levels of technology. The quality adjusted stock of capital,  $K_{it}^*$ , is given by

$$K_{it}^* = A_{ik} (1 + c_{ik})^t K_{it}, \quad (12)$$

where  $A_{ik}$  is the level of augmentation and  $c_{ik}$  is the rate of growth of augmentation. The method is implemented by normalising  $A_{ik}$  (and  $A_{iL}$ ) to unity for one of the countries in the sample and then estimating the remaining  $A$ s and  $c$ s. The generality of this approach is that it permits countries to have different growth experiences unlike a more basic model which would impose the same growth pattern on all countries.

95. Kim and Lau apply this methodology to ten Asian Pacific countries and to four industrialised Western countries. Table 15 summarises the standard finding in the work of Lau and his co-researchers. The Asian Pacific Countries, with the exception of Japan, obtained most of their growth from the accumulation of capital. For example, accumulation of capital accounted for 99.5% of growth in output in the Philippines. Among the Asian Pacific Countries only Japan, Hong Kong, and Singapore experienced substantial benefits from technical progress. In contrast, the figures for the four Industrialised Western Countries at the foot of the table show that these countries obtained most of their growth from technical progress. A further important result arises which will be discussed further in the third paper, namely, that the analysis also shows technical progress is purely capital augmenting. That is, technical progress is not enhancing the efficiency-equivalent quantity of labour.

96. The finding that much of the economic growth in East Asian countries is explained by capital accumulation and not through technical progress has received much attention. The conclusion is supported by the work of Tsao (1985) on Singapore manufacturing in the 1970s, and by the analysis of Young (1992) of Hong Kong and Singapore. The same conclusion is also reached in Young (1994) which regressed the output growth rate per worker on a constant and the growth of capital per worker for the period 1970 - 1985 using cross-country data from Penn World Tables. This demonstrated that total factor productivity growth in Hong Kong was relatively high, not so high in South Korea and Taiwan, and very low in Singapore. Fischer (1993) used the growth accounting framework to obtain a negative total factor productivity growth rate for Singapore and low rates of growth for Taiwan. The conclusions were generalised to a range of East Asian countries by Young (1995) and also supported by Krugman (1994).

97. Counter-evidence was provided by the World Bank (1993). However, the World Bank study imposed constant returns to scale and neutrality of technical progress. Both these assumptions were shown to be rejected by Kim and Lau (1996). The World Bank also assumed competition which was also rejected by Kim and Lau.

98. Hayami and Ogasawara (1999) took a much longer time perspective on growth. Their data went back to 1880 and permitted the development process for Japan to be traced over an extended period. The paper advanced the hypothesis that for much of this period Japan continued to depend more heavily on physical capital accumulation due to its characteristic of borrowed-technology based economic growth. The longer time horizon provides a perspective on Japan relative to the more recently developed East Asian economies.

**Table 15: Sources of Growth**

Country	Capital	Labor	Technical Progress
China	92.2	9.2	-1.4
Hong Kong	55.8	16.0	28.2
Indonesia	115.7	11.5	-27.2
Japan	62.9	4.7	32.4
Malaysia	70.9	18.7	10.5
Philippines	99.5	22.6	-17.5
Singapore	60.0	20.9	20.1
South Korea	86.3	12.7	1.0
Taiwan	88.9	8.6	2.5
Thailand	71.9	12.7	15.3
France	37.8	-1.3	63.5
West Germany	43.7	-6.3	62.6
United Kingdom	46.0	3.7	50.3
United States	32.9	26.2	41.0

99. Crafts (1999) provides a broad survey on growth accounting applied primarily to East Asian countries. The paper notes the various estimates of the growth of total factor productivity. It also discusses the role of a range of factors in catching-up such as institutional structures. It reports some efforts at incorporating the role of schooling as a measure of the increase in human capital. From this follows the claim that after taking account of schooling the Western countries have performed better in total factor productivity growth than predicted while most Asian countries have performed worse (with some exceptions). This strengthens the previous conclusions.

100. The application of growth accounting confirms that there has been a variety of growth experiences across the range of countries considered. There may be some remaining issues concerning the precise size of the effects but there is little doubt that some countries have grown through capital accumulation while others have grown through increases in *TFP*.

#### **4.2 Extensions**

101. The applications of growth accounting described to this point have followed the standard methodology of assuming an identical production function for all countries. This is an assumption that can, and should, be tested. More recent work has taken this possibility into account.

102. The innovation of Senhadji (2000) is to take the value of  $\alpha$  in the production function as potentially different between countries. The estimation results provide support for this relaxation and show that  $\alpha$  is generally higher in industrialised countries, but not always so. The level of human capital is based on the Barro and Lee (1993) methodology of a weighted average of shares of population attaining each of seven levels of educational attainment. The weights are computed using data on observed relative earnings of the different educational groups.

103. The estimated values of  $\alpha$  are summarised in Table 16. The first value in each column is the estimate of the production function in levels. The value in parentheses is the estimate using first differences. The two estimates are fairly similar with the exception of East Asia which could be important in understanding the source of the rapid growth in East Asia. The values of  $\alpha$  reveal that there are significant differences between countries and that an average value of  $\alpha$  would hide these large variations. These results are evidence that imposing a single value of  $\alpha$  is a poor approximation. The paper also notes that  $\alpha = (\partial Y / \partial K)(K / Y)$ , so the value is a combination of marginal product  $(\partial Y / \partial K)$  and capital output ratio  $(K / Y)$ . This means there is no simple reason for expecting any correlation with type of country since a low-capital country will have a high  $\partial Y / \partial K$  but low  $K / Y$ .

**Table 16: Estimate of Cobb-Douglas Production Function**

Region	$\alpha$
Sub-Saharan Africa	0.43 (0.50)
Middle East and North Africa	0.63 (0.54)
Latin America	0.25 (0.62)
East Asia	0.48 (0.30)
South Asia	0.56 (0.42)
Industrial	0.64 (0.58)

104. These estimates are used to decompose output growth into the various factors for countries grouped into six regions. The values in Table 17 are obtained using the level estimates. For East Asia the first difference estimates are given in parentheses since the two estimates of  $\alpha$  are widely different. In all cases the level estimates show that growth in the capital stock is the most important factor. The growth in human capital (measured as an average schooling variable) is the least important contributor. But note for East Asia how the first difference estimate (using  $\alpha = 0.30$  rather than  $\alpha = 0.48$ ) provides a different insight into the growth of *TFP*. This is low for the level estimate (0.28) but much larger (1.34) for the first

difference estimate. There is a clear methodological point here that the explanation of growth in East Asia through capital accumulation requires further confirmation.

**Table 17: Decomposition of Growth 1960-1994**

Region	<i>dTFP</i>	<i>dk</i>	<i>dl</i>	<i>dh</i>	<i>dy</i>
Sub-Saharan Africa	-0.56)	1.79	1.39	0.22	2.83
Middle East and North Africa	-0.03	3.99	0.84	0.25	5.05
Latin America	-0.39	2.31	1.22	0.28	3.42
East Asia	0.28 (1.34)	4.50 (2.86)	1.27 (1.71)	0.44 (0.59)	6.49 (6.49)
South Asia	0.55	2.87	0.99	0.25	4.66
Industrial	0.06	2.87	0.99	0.25	4.66

105. The final exercise in the paper is to regress the total factor productivity of each country relative to that in the US on a range of variables. These variables capture initial conditions (*TFP*: TFP2R\_0, human capital: HKR\_0, physical capital: KR\_0, life expectancy: LIFE), external shocks (terms of trade: TOT), macroeconomic situation (inflation: INFL, public consumption: Cg, real exchange rate: RER, reserve-import ratio: RESM, external debt-GDP ratio: DEBT), trade regime (current account convertibility (dummy): CACON, capital account convertibility (dummy): KCON), and political stability (war casualties: DEATH) plus dummies of sub-Saharan Africa, East Asia, South Asia, Middle East and North Africa, and Latin America. The results reported in Table 18 show that initial conditions are important in explaining relative *TFP*. The variables TFP2R\_0 and HKR\_0 have positive and significant coefficient. In particular, human capital has an important role to play here in explaining relative total factor productivity (its coefficient is ten times that on physical capital and both variables are relative to the US value and in logs).

**Table 18: Explanation of relative *TFP***  
Standard errors in parentheses

TFP2R_0	0.93041 (0.00574)
HKR_0	0.2756 (0.06065)
KR_0	0.03223 (0.0274)
LIFE	0.00167 (0.00070)
TOT	0.03765 (0.01386)
INFL	$-2.63 \times 10^{-5}$ ( $7.42 \times 10^{-6}$ )
Cg	-0.03510 (0.01218)
RER	-0.07403 (0.01090)
RESM	0.93041 (0.00574)
DEBT	0.00247 (0.00134)
CACON	-0.00651 (0.01150)
KCON	-0.04722 (0.01252)
DEATH	-0.12187 (0.01568)
DUMAFR	0.23209 (0.04793)
DUMEA	0.09298 (0.04454)
DUMSA	0.05698 (0.04186)

DUMME	0.25446 (0.04428)
DUMLA	0.12846 (0.04449)
$R^2$	0.998

106. Vandenbussche *et al.* (2006) aim to provide a model to explain the Krueger and Lindahl (2001) result (further description is in Section 4.4 below) that the effect of the initial level of education on the rate of growth was highly heterogeneous between rich countries (including OECD members), low-income and middle-income countries, and that it was not positive for the richest countries in the sample. The theory divides labour into two groups: skilled and unskilled. The dynamics of a country's production frontier depend on the distance from the world frontier, and the division of skilled and unskilled labour between innovation and imitation. The equilibrium growth rate then becomes dependent on how these are allocated. The marginal effect of having more high-skill workers increases the closer is the economy to the frontier but the marginal effect of more low-skill workers is reduced by proximity. This can explain the difference in findings for low-income and high-income countries. Note that this analytical model has no trade and no investment in education, but just an exogenous allocation of low- and high-skill to workers.

107. The econometric analysis then explores this model by essentially using an interaction term between proximity to the US frontier and the proportion of the workforce that are skilled. This is applied to 19 OECD countries. Two different education measures are used because of the ongoing debate on how to represent education. Lagged public expenditure on education is the main instrument for education (this is needed because of the endogeneity issue identified by Bils and Klenow (2000)). The initial regression is not very successful, so the countries are grouped and dummies are used for the groups. Education is categorised into tertiary and below, and divided into pre- and post-1985 to reflect the information technology revolution. The estimates show that holding the quantity of low-labour constant, the growth-enhancing effect of more high-skilled labour is larger the closer to the frontier is the country. Table 19 provides a sample of the findings. Years PS and Years T are the number of years of primary/secondary education (PS) and tertiary education (T) of the average adult. The proximity threshold shows that for a country with *TFP* more than 35% below that of the US an increase in higher education will reduce growth. The results show that there was a strong proximity effect on the value of tertiary education prior to 1985 but that this declined post-1985.

**Table 19: Proximity to frontier and value of education**

Standard errors in parentheses

Proximity	-0.09 (0.2)
Years PS	-0.029 (0.02)
Years PS post 1985	0.015 (0.012)
Years T	0.418 (0.18)
Years T post 1985	-0.113 (0.124)
Proximity*Years PS	-0.053 (0.045)
Prox*Years PS post 1985	-0.039 (0.038)
Proximity*Years T	1.2 (0.58)
Prox*Years T post 1985	-0.167 (0.5)
Country dummies	Groups
Proximity threshold	-0.348 (0.046)
Threshold post 1985	-0.295 (0.06)

108. An alternative approach to estimation of *TFP* is to employ non-parametric analysis. The advantage of this approach is that it avoids any need to impose a functional form on the production function. It also avoids the assumption that the elasticities are equal to factor shares.

Iwata *et al.* (2003) base their estimation procedure on the conditional expectation of  $\ln(Y_t)$  which is given by

$$m(\ln K, \ln L, t) \equiv E[\ln Y | \ln K, \ln L, t] = a(t) + F^*(\ln K, \ln L). \quad (13)$$

The shares of capital and labour are the derivatives of this mean function

$$s_K \equiv \frac{\partial \ln F}{\partial \ln K} = \frac{\partial F^*}{\partial \ln K}, \quad (14)$$

$$s_L \equiv \frac{\partial \ln F}{\partial \ln L} = \frac{\partial F^*}{\partial \ln L}. \quad (15)$$

109. The basis of the nonparametric approach is local averaging. The smoothness of the estimated curve depends on the extent of averaging. Averaging over the entire sample gives a straight line. The Iwata *et al.* paper employs three different methods of averaging to ensure that the results are not unduly dependent on the method chosen.

110. The paper estimates *TFP* growth for nine East Asian countries. The estimates provided do differ a little from earlier estimates. Generally, they show higher *TFP* growth for the East Asian countries than previously calculated. Table 20 reports the results of nonparametric estimation for a sample of countries obtained by using the traditional method based on the income share of labour used by Young (1995), and the income share set equal to 0.65 as in Collins and Bosworth (1996). Hong Kong is an exception to the general finding of higher *TFP* using the nonparametric approach. *TFP* growth in Singapore is much higher with the nonparametric estimation.

**Table 20: Nonparametric and conventional estimates of *TFP* growth**

	Conventional		Nonparametric
Country	Young	Collins	
Hong Kong	4.1	4.1	3.4
Korea	2.8	2.3	3.7
Singapore	0.5	1.8	3.7
Taiwan	3.8	2.1	3.8

111. Table 21 reports the nonparametric estimates of elasticities and income shares. For both capital and labour the elasticities differ quite significantly from the factor shares. However, the sum of the elasticities is close to 1 so the aggregate production function is not far from having constant returns to scale.

**Table 21: Nonparametric estimates of elasticities and shares**

	Capital		Labor	
Country	Elasticity	Income share	Elasticity	Income share
Hong Kong	0.41	0.37	0.71	0.63
Korea	0.18	0.29	0.81	0.71
Singapore	0.17	0.49	0.63	0.51
Taiwan	0.19	0.26	0.76	0.74

112. Iwata *et al.* focus on the debate between assimilation (of technology) and accumulation (this is the Lau perspective). The empirical estimates support the conclusion that the growth has come from a combination of these sources. But note that this does not test whether the changes are neutral, or capital augmenting, or labour augmenting. Hence, the paper does not really address the true sources behind the growth in total factor productivity.

113. Jones (2002) looks again at the model of endogenous growth through ideas. The starting point is the observation that US growth has been steady at an average of 1.8% over the past 125 years and that there is no time trend in US real interest rate of capital-output ratio. These facts have been used as evidence that US is on its steady-state balanced growth path. There are other observations that tell a different story. The time spent in education in the US has increased and the fraction of workers in R&D has increased from 0.25% of the workforce in 1950 to 0.75% of the workforce in 1993. These changes should have caused an increase in the growth rate. Jones suggests that the competing observations can be rationalised by distinguishing between a constant growth path and a balanced growth path. He argues that it is possible to have a constant growth rate above the balanced growth rate for a sustained period of time but with eventually levelling off.

114. The formal model of this idea is set in a multi-country world with physical capital accumulation and human capital accumulation. Ideas spread internationally. The number of researchers relative to employment is used as a measure of R&D intensity. The paper conducts a growth accounting exercise to find the contributing effects to growth. The key part of the paper is to try to reconcile long-run dynamics and transition dynamics. It is claimed that what is currently being observed are transition dynamics.

115. The basis of the model is a production function

$$y = \left( \frac{K}{Y} \right)^{\frac{\alpha}{1-\alpha}} \ell_Y h A^{\frac{\sigma}{1-\alpha}}, \quad (16)$$

where  $\ell_Y$  is the proportion of the workforce engaged in productive employment (the remainder are employed in the production of ideas),  $h$  the level of human capital, and  $A$  is the total stock of ideas. The stock of ideas grows according to the worldwide employment in the production of ideas. The rate of growth on the balanced growth path is  $\gamma$ , so in the long run

$$g_y = \frac{\sigma}{1-\alpha} g_A = \mathcal{M}. \quad (17)$$

The growth accounting is based on the growth version of the production function

$$\hat{y} = \frac{\alpha}{1-\alpha} (\hat{K} - \hat{Y}) + \hat{h} + \hat{\ell}_Y + \left( \frac{\sigma}{1-\alpha} \hat{A} - \mathcal{M} \right) + \mathcal{M}, \quad (18)$$

where  $\hat{y} = \frac{1}{t} (\ln(y_t) - \ln(y_0))$  for some base year 0. If the economy is on a balanced growth path all terms except the last should be zero. The results of the application are summarised in Table 22. (These numbers are computed assuming  $\sigma = 1 - \alpha$ .)

**Table 22: Growth accounting US 1950 - 1993**

$\gamma$	$\hat{y}$	$\frac{\alpha}{1-\alpha} (\hat{K} - \hat{Y})$	$\hat{h}$	$\hat{\ell}_Y$	$\hat{A} - \mathcal{M}$	$\mathcal{M}$
0.050	0.020	-0.0007	-0.0001	0.0063	0.0140	0.0006

116. On the basis that output growth was 2% annually over the sample period and that the capital-output ratio is almost constant the value attached to  $\frac{\alpha}{1-\alpha} (\hat{K} - \hat{Y})$  in Table 22 shows a unit increase in the capital-output ratio leads to a -0.07 percentage point fall in growth. Employment has a similarly small effect. The growth in educational attainment contributed 0.63 percentage points to growth. The largest contributor to growth (explaining 70% of growth) is the rise in the stock of ideas. Note that in the long run growth will come only from  $\mathcal{M}$ . In the short run this factor explains only 20% of growth. In any case, the growth accounting shows that transition dynamics associated with educational attainment and research intensity account for 80% of growth. Rising employment counts for 15%.

117. Hsieh (2002) computes dual estimates of the growth in total factor productivity. Dual refers to the fact that price data is used, not data from national accounts. It is argued that the claimed growth in capital in the East Asian countries would have reduced the return to capital if there was no growth in total factor productivity. If this had occurred then the capital stock growth would not have happened. Alternatively, the data in national accounts on the capital stock is not giving the correct picture, so price data should be used instead.

118. The method is based on the observation that an improvement in technology will shift out the factor price frontier. Alternatively, if real wage growth is due only to capital accumulation then the return to capital must fall at the same rate as wages grow. If this does not happen then there must be an increase in total factor productivity. The results presented in the paper for Korea are consistent with earlier studies, but for Singapore the growth in total factor productivity is higher.

119. The change in technology can also be understood by looking at the production frontier. Han et al (2002) use a varying coefficients production frontier model to look at four Asian countries. Total factor productivity growth is separated into technical efficiency change and technological progress. The results

show there is evidence for growth being generated partly through an increase in inputs causing partly through growth in technical efficiency. There is weak, or negative, evidence of technological progress. The data cover the interval from 1987 to 1993, so this is a fairly short time period for judging technical progress.

120. The production frontier model is applied by Han *et al.* (2004) to a wider range of countries. The larger set of countries implies the frontier must be further out (or at least no further in), so there is more scope for inefficiency. The empirical results again support the hypothesis that the four best performers during 1970 - 1990 (Japan, Singapore, South Korea, Taiwan) do not stand out from other countries around the world in terms of their growth in *TFP*. It is input growth that appears to be the main contributor to their growth performance. The paper also concludes that these countries are behind the US in terms of technical efficiency. Some arguments concerning market institutions are provided to explain this finding.

#### ***4.3 Testing for Endogeneity***

121. Information on total factor productivity can, in principle, be used to test whether the data has been generated by an economy with endogenous or exogenous growth. If growth is truly exogenous then changes in *TFP* should be independent of any economic variables. Regressing *TFP* on variables such as saving, investment, and human capital accumulation should generate estimated coefficients that are statistically insignificant. Conversely, if growth is endogenous then some economic variables will have significant explanatory power when used in a regression for *TFP*.

122. Mankiw *et al.* (1992) claim evidence for the Solow model with exogenous growth in productivity, especially if the production function is augmented with a human capital variable. What is meant by evidence is that the estimated model fits the data well: the coefficients are significant, with the correct sign, and generally satisfy the restrictions imposed by the model. The model also explains almost 80% of the variation in output within the sample of 98 countries (but performs much worse on the sub-sample of 28 OECD countries). Furthermore, the regression results imply a share of capital in output that is close to the observed value.

123. The empirical analysis regresses the log of GDP per capita on the log of investment/GDP (as a measure of saving), the log of the sum of population growth rate, technology growth rate and depreciation and the log of participation in secondary schooling. It is important to note the dependent variable is the level of per capita output and not the growth of output. The regression results for the augmented model are given in Table 23 (with standard errors in parentheses).

**Table 23: Testing the Solow model**

Constant	6.89 (1.17)
$\ln(I / GDP)$	0.69 (0.13)
$\ln(n + g + \delta)$	-1.739 (0.41)
$\ln(SCHOOL)$	0.66 (0.07)
$\bar{R}^2$	0.78

124. As pointed out by Bernanke and Gurkaynak (2001) the results of Mankiw *et al.* do not constitute a formal test of the Solow model against alternative growth models. The basis of this claim is that the estimation framework of Mankiw *et al.* is broadly consistent with any growth model that permits a balanced growth path. So, Mankiw *et al.* do not actually test the Solow model as a distinct alternative to other models but only test the existence of a balanced growth path.

125. Given this, Bernanke and Gurkaynak argue that it is necessary to test the Solow prediction that long-run growth is due only to exogenous technical change and should therefore be independent of other variables (such as the aggregate saving rate, schooling rates, and the growth rate of the labour force).

The next step is to see if growth is endogenous. If it is, then it will be correlated with some other economic variables. A test of this is undertaken by evaluating *TFP*, then regressing *TFP* on saving for physical capital, saving for human capital, and the growth rate of population. The results for a sample of 50 countries are in Table 24. Here  $s_K$  is the share of output devoted to gross investment in physical capital,  $s_H$  is the share of output devoted to gross investment in human capital, and  $n$  is the growth rate of population. The return on education is assumed to be equal to 7%. The results show that these variables, particularly the saving rate for physical capital, are significant for explaining the growth in *TFP*. Strong statistical evidence is found against the predictions of the Solow model. The rate of investment is strongly correlated with growth. Human capital accumulation and the rate of population growth are less strongly correlated with growth. The Solow model that growth determines savings does not seem to fit the data. This is evidence that technical progress is not exogenous but can be explained by variables in the model.

**Table 24: Regression for TFP**

Standard errors in parentheses

Constant	-0.01 (0.00)	-0.01 (0.01)	0.02 (0.00)	-0.01 (0.01)	0.00 (0.00)	0.01 (0.01)	0.00 (0.01)
$s_K$	0.07 (0.02)			0.07 (0.02)	0.05 (0.02)		0.05 (0.02)
$s_H$		0.14 (0.06)		0.06 (0.06)		0.08 (0.06)	0.03 (0.05)
$n$			-0.45 (0.11)		-0.32 (0.10)	-0.41 (0.117)	-0.31 (0.11)
$R^2$	0.28	0.08	0.26	0.28	0.39	0.27	0.38

126. Islam (1995) examines how the results of Mankiw *et al.* are modified when the data are treated as a panel. The analytical innovation is to take the constant in the standard Cobb-Douglas production function as a country-specific effect and use panel data methods to estimate the growth regression. The key point of the estimation is that the individual effect that is ignored in standard regressions is correlated with the included explanatory variables and causes omitted variable bias. The adoption of the panel approach generates a much higher rate of convergence and a lower elasticity of output with respect to capital. The estimated elasticity is closer to the empirically-observed value. This is shown in the results reported in Table 25. This estimated equation is restricted to have the same coefficient (but with opposite signs) on  $\ln(s)$  and  $\ln(n+g+\delta)$ . In addition, the value of  $\lambda$  measures the rate of convergence through the relationship

$$\frac{d \ln \hat{y}(t)}{dt} = \lambda [\ln \hat{y}^* - \ln \hat{y}(t)], \quad (19)$$

where  $\hat{y}(t)$  is income per effective worker at time  $t$  and  $\hat{y}^*$  is the steady state level of income per effective worker.

**Table 23: Fixed effects estimate**

Standard errors in parentheses

	NONOIL	INTER	OECD
$y_{i,t-1}$	0.7919 (0.0349)	0.7954 (0.0387)	0.6294 (0.0495)
$\ln(s) - \ln(n + g + \delta)$	0.1634 (0.0238)	0.1726 (0.0524)	0.0954 (0.0581)
$R^2$	0.7368	0.8251	0.9642
Implied $\lambda$	0.0467 (0.0088)	0.0458 (0.0097)	0.0926 (0.0157)
Implied $\alpha$	0.4398 (0.0545)	0.4575 (0.0575)	0.2047 (0.1042)

127. Including human capital in the form of average schooling years in the population aged over 25 does not change the results significantly. In all the estimation results the value of the fixed effect is significant. This is interpreted as capturing all the technological factors that make countries different. Countries tend to be placed where expected, such as all the African countries having a very low value for the fixed effect, and Hong Kong having the highest value. The implication of the significant fixed effect is that countries should seek to influence its value by choice of policy.

128. The issue of whether growth is endogenous or exogenous is an important one for policy. It would seem natural to presume that it is endogenous. The apparent surprise in the work of Mankiw *et al.* is the evidence that seems to suggest that the Solow model provides a compelling explanation of differences in per capita output across a broad set of countries. However, their analysis does not function as a test of the Solow model but only as an explanation of differences in balanced growth paths. The evidence of Bernanke and Gurkaynak strongly points to the growth in *TFP* being explicable by economic variables.

#### **4.4 Education and TFP**

129. There has been a small literature assessing the effect of education on *TFP*. One perspective is that education, in the form of human capital, enters as a stock in the production function. In a simple specification the product of human capital and hours of labour supply constitute the effective labour input. A more general specification would see human capital entering as a variable distinct from hours of labour. An alternative model is to enter education directly as a determinant of total factor productivity. Hence, an increase in education would raise total factor productivity.

130. Krueger and Lindahl (2001) provide a survey of the modelling of the returns to education. The focus of the paper is on the Mincer (1974) formulation of the returns to education: the earnings-education relation is log-linear. It is claimed that there is no evidence to show that this is not the case. The Mincer model implies that the change in a country's average level of schooling should be the determinant of growth. However, the regressions reviewed above have all used the initial level of education as the explanatory variable. The explanation for this choice in the growth literature is that Benhabib and Spiegel (1994) showed that the change in education is not a determinant of the growth rate. Krueger and Lindahl

conclude that this result emerges because there is no signal in the education data of Benhabib and Spiegel when conditioned on the growth in the stock of capital. It is claimed the Krueger and Lindahl analysis suggests the change and initial level are positively correlated with growth.

131. This line of reasoning is developed further in Ferreira *et al.* (2004). The issue they consider is the correct specification of the production function. They represent the Mankiw *et al.* formulation that underlies most of the growth analysis as having human capital enter the production function in the general form

$$Y = AK^\alpha H^\phi (Le^{gt})^\beta . \quad (20)$$

In this formulation human capital is an input and there is exogenous labour-augmenting technical progress. The alternative form of production function is based on Mincer (1974) and has human capital (measured in terms of years of schooling,  $h$ ) entering directly into the determination of the rate of growth

$$Y = AK^\alpha (e^{\phi h} Le^{gt})^\beta . \quad (21)$$

When these alternative productions functions are logged the human capital variable enters in log form for the first and in level form for the second. Ferreira *et al.* then estimate an equation with a flexible functional form which nests these two hypotheses. The empirical testing shows that the Mankiw *et al.* form is rejected but the Mincer form cannot be rejected. Therefore, this analysis provides evidence that supports endogenous growth theory with human capital directly determining the increase in *TFP*.

#### 4.5 Observations

132. The purpose of growth accounting is to determine the separate contributions of labour growth, capital growth, and innovation. This is a coarse division but it is still able to provide interesting insights.

The comparative studies demonstrate a variety of growth experiences. This is important since the basis of growth regressions is that the cross-country data represent different draws from the same underlying process. The fact that countries differ in the routes they have followed to growth undermines this assumption and provides a further reason for questioning the results of growth regressions, particularly when applied to heterogeneous sample of countries.

133. The growth regressions also confirm that it is possible to achieve very high short-term growth rates by capital investment alone when early in the development process. This is the clear message from the analysis of the East Asian economies during the 1980s. This point also demonstrates that technical innovation - the route emphasised by the endogenous growth literature - is not the only way to achieve growth. The evidence does demonstrate that there has been technology-driven growth in the industrialised Western countries. The confirmation that the growth experience has differed across countries is an important observation when framing policy responses. It is unlikely that the same policy will be equally successful for all. For instance, the encouragement of innovation is of limited value if an economy has no research base and has relied upon the importation of technology. What the growth accounting has not achieved is any demonstration of the role of increases in human capital relative to increases in the quality of physical capital. Both of these are captured in the Solow residual. Obtaining this information would be of considerable value for policy purposes.

134. The results of growth accounting exercises leave important questions unanswered. It is clear that *TFP* differs between countries but the reason why is not. Prescott (1998) argues that the difference in *TFP* cannot be explained by differences in saving rates, stocks of physical capital, or stocks of human capital. If

it is assumed that all countries have access to approximately the same level of technical knowledge the only remaining explanation is that some countries simply exploit the known technology better. The explanation of why this might be the case remains to be provided.

135. Overall growth accounting is a well established methodology that delivers broad characterisations of the contributions to growth. These are of some value but much more detail is needed of the processes that are occurring behind these broad brush observations.

## **5. Conclusions**

136. The initial promise that growth regressions would reveal the causes of growth has not been realised. Very few variables are robustly correlated with economic growth and those variables that are offer little guidance for the design of a growth-increasing tax policy. This points to the fact that individual country studies should be more informative about the causes of growth than cross-country aggregate analysis.

137. Tax systems are complex and multi-dimensional so tax regressions face a difficult task in constructing an empirical equivalent of “the marginal tax rate”. As a result many regressions use instead a measure of the average rate of tax. This is despite the fact that economic theory predicts that the average rate is not the relevant variable for most decisions. A number of alternative methods have been proposed for constructing a representative marginal rate of taxation.

138. Empirical evidence for the hypothesis that the level of taxation affects economic growth is very weak. This applies both when measures of the average rate of tax are used in the regression and when measures of the marginal rate of tax are used. However, tax regressions deliver better results when each form of tax is included separately. There is evidence that income taxes are damaging for growth relative to consumption taxes. None of this analysis escapes the fundamental observation that the lack of structural modelling limits the interpretation of the estimated equations and leaves the causality issue unresolved.

139. Growth accounting identifies the contributions of capital, labour, and technical innovation to productivity growth. Applications of growth accounting have provided convincing evidence of different growth experiences across countries. Some countries have achieved growth almost entirely through capital accumulation whereas other countries have achieved growth through a combination of capital accumulation and productivity improvement. The change in total factor productivity has been shown to depend on a range of economic variables. This provides evidence in favour of the endogenous growth model. It also suggests that a disaggregated analysis of these individual components will be informative. Such analysis is surveyed in the third paper in this series.

## APPENDIX 1. EXTREME BOUNDS ANALYSIS

140. The method of extreme bounds analysis is used to test the sensitivity of regression estimates to the choice of conditioning variables. As described by Leamer (1983, 1985) there are many regression equations that have equal theoretical legitimacy. The difficulty for the investigator is to choose between the candidates. One important consideration in this choice is that the estimated coefficients are robust to different selections of conditioning variables.

141. Assume that we wish to estimate which variables are robustly correlated with economic growth. The data set is divided into two sets of variables. The first are those which have proved to be basic in explaining economic growth such as the share of investment in GDP. This set of variables is labelled  $I$ . The second set of variables comprises those that are potentially important for explaining growth. These could, for example, have been indicated as important in previous econometric studies.

142. Next we identify our variable of interest, denoted  $M$ . This variable is included in a base regression along with the set of variable  $I$ . Hence the regression

$$y = \alpha + \beta_i I + \beta_m M + u, \quad (\text{A1})$$

is estimated. Here  $I$  is a vector of the basic variables and  $\beta_i$  is a corresponding vector of parameters. This establishes an initial estimate of  $\beta_m$ .

143. This leaves the remaining pool of potential regressors. Then the regression

$$y = \alpha + \beta_i I + \beta_m M + \beta_z Z + v, \quad (\text{A2})$$

is run for every subset of variables  $Z$  from this pool. What we are hoping to find is that the estimated value of  $\beta_m$  will remain significant and of the same sign for all choices of  $Z$ .

144. More formally, the maximum and minimum values of the estimated coefficient  $\hat{\beta}_m$  over all choices of  $Z$  are then found that are significantly different from zero at the 5% level. This is checked by adding two standard deviations to the maximum and minimum values estimated.

If  $\beta_m$  is significant for all choices of variables  $Z$  and  $\hat{\beta}_m$  plus or minus two standard deviations retains the same sign then the estimated partial correlation of this variable with economic growth is said to be *robust*. The estimated parameter is *fragile* if the value changes sign or becomes insignificant.

145. The point of this method is that if there is really a relationship then the parameter estimator should be robust. A fragile parameter estimate is more likely to be an artefact of the data. Further discussion can be found in Levine and Renelt (1992).

## APPENDIX 2. GROWTH ACCOUNTING

146. Growth accounting is a method used to determine the contribution of each factor to the growth of output. Any growth unexplained by factor growth is viewed as attributable to technical progress.

Consider the production function

$$Y = F(A, K, L), \quad (\text{A3})$$

where  $Y$  is output,  $A$  is the level of technical progress,  $K$  is quantity of capital employed, and  $L$  is the quantity of labour employed. If we view each of the variables as a function of time,  $t$ , we can write

$$Y(t) = F(A(t), K(t), L(t)). \quad (\text{A4})$$

Differentiating with respect to time

$$\frac{dY}{dt} = F_A \frac{\partial A}{\partial t} + F_K \frac{\partial K}{\partial t} + F_L \frac{\partial L}{\partial t}. \quad (\text{A5})$$

If the markets for factors are competitive then the marginal products are equal to factor rewards, so  $F_K = r$  and  $F_L = w$ . Hence

$$\begin{aligned} \frac{dY}{dt} &= F_A \frac{\partial A}{\partial t} + r \frac{\partial K}{\partial t} + w \frac{\partial L}{\partial t} \\ &= F_A \frac{\partial A}{\partial t} + rK \frac{1}{K} \frac{\partial K}{\partial t} + wL \frac{1}{L} \frac{\partial L}{\partial t}. \end{aligned} \quad (\text{A6})$$

Now define the growth rates of output, capital, and labour by

$$g_Y = \frac{1}{Y} \frac{\partial Y}{\partial t}, \quad (\text{A7})$$

$$g_K = \frac{1}{K} \frac{\partial K}{\partial t}, \quad (\text{A8})$$

and

$$g_L = \frac{1}{L} \frac{\partial L}{\partial t}. \quad (\text{A9})$$

Dividing (A6) by  $Y$  and using the definitions of the growth rates

$$\frac{1}{Y} \frac{\partial Y}{\partial t} = \frac{rK}{Y} \frac{1}{K} \frac{\partial K}{\partial t} + \frac{wL}{Y} \frac{1}{L} \frac{\partial L}{\partial t} + \frac{F_A}{Y} \frac{\partial A}{\partial t}, \quad (\text{A10})$$

becomes

$$g_Y = \alpha_K g_K + \alpha_L g_L + SR, \quad (\text{A11})$$

where  $\alpha_K = rK/Y$  is the share of capital in national income,  $\alpha_L = wL/Y$  is the share of labour in national income, and  $SR$  is the ‘‘Solow residual’’. The Solow residual is the part of growth that cannot be attributed to growth in the stock of capital or labour. This can be interpreted as the underlying growth in productivity due to technical progress.

147. This expression can be further refined. If the production function has constant returns to scale in capital and labour then the shares  $\alpha_K$  and  $\alpha_L$  sum to 1. The key relation can then be written

$$\begin{aligned} SR &= g_Y - \alpha_K g_K - (1 - \alpha_K) g_L \\ &= g_Y - g_L - \alpha_K (g_K - g_L). \end{aligned} \quad (\text{A12})$$

The growth of the output labour ratio,  $Y/L$ , satisfies

$$g_{Y/L} = g_Y - g_L, \quad (\text{A13})$$

and the growth of the capital-labour ratio,  $K/L$ , satisfies

$$g_{K/L} = g_K - g_L. \quad (\text{A14})$$

These allow the Solow residual to be expressed as

$$SR = g_{Y/L} - \alpha_K g_{K/L}. \quad (\text{A15})$$

A second refinement is to consider the measure of labour that enters the production function as being the product of quality ( $h$ ) and quantity ( $L$ ). Here quality is meant to be human capital, often proxied by the number of years of schooling. The production function becomes

$$Y(t) = F(K(t), h(t)L(t), A(t)). \quad (\text{A16})$$

Repeating the steps above gives

$$g_Y = \alpha_K g_K + \alpha_L g_L + \alpha_L g_h + SR, \quad (\text{A17})$$

where the labour share is now defined in payments to quality labour hours

$$\alpha_L = \frac{whL}{Y}. \quad (\text{A18})$$

Under the assumption of constant returns this gives the Solow residual

$$SR = g_Y - \alpha_K g_K - (1 - \alpha_K)g_L - (1 - \alpha_K)g_h. \quad (A19)$$

148. Much of the econometric analysis described in the main body of the report is concerned with determining the contribution of each factor to growth and the value the technical progress as identified by the Solow residual.

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