EXOGENOUS AND ENDOGENOUS MODELS
OF ECONOMIC GROWTH

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Thesis submitted for the degree of Master of Economics by Research,
Department of Economics, University of Western Australia, 1995.
Abstract

The focus of this thesis is the examination of cross-country and time series data to distinguish between specific classes of exogenous and endogenous models of economic growth. Chapter 1 describes the broad trends in the data, emphasising the wide variation in growth rates, both cross-country and over time. Chapter 2 investigates the theoretical models of growth, focusing on the differences between exogenous and endogenous specifications. Chapter 3 surveys the empirical literature relating to cross-country estimates of growth. Four related issues are addressed, namely convergence, human capital, physical capital, and the role of government policy. It is argued that this evidence is insufficient to differentiate between exogenous and endogenous models of growth. Chapter 4 presents new time series evidence, based on data in Maddison (1993) for 8 industrialised countries. Specifically, it examines the properties of output series to test between stochastic variants of Solow’s (1956) neoclassical, exogenous growth model, and Rebelo’s (1991) constant returns, endogenous model of economic growth. Chapter 5 presents the conclusions of this thesis.
I wish to thank Professor Michael McAleer for his supervision and his invaluable comments at all stages of this project. I would also like to thank Les Oxley (University of Edinburgh) for his time and his helpful suggestions.

Finally, I am grateful for the financial support provided by the Commonwealth Government, in the form of an Australian Postgraduate Research Award, which gave me the freedom to undertake this research.
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4.9 Tests for cointegration on postwar GDP using Johansen’s (1988) techniques 182
The resurgence of interest in economic growth in recent years has been noted by numerous authors (see, e.g., Stern (1991), Dowrick (1993) and Sala-i-Martin (1994)). Although the specific focus of these efforts has been varied, it is based upon the common assumption that the growth rate of a given country is closely related to the welfare of the citizens of that country. Moreover, since there has clearly been great diversity in levels and growth rates of income over time and across countries, the importance of investigating the determinants of growth cannot be overemphasised.

The purpose of the thesis is to compare the empirical evidence arising from alternative modelling strategies. This first chapter provides a brief introduction to the broad trends in growth. Chapter 2 presents an examination of theoretical models of economic growth, and describes two alternative specifications that are to be investigated, namely exogenous and endogenous models of economic growth. Although the explicit differences between these two strategies will be expanded upon later, exogenous growth models can be characterised by their reliance upon an unexplained process of technological progress to generate growth in per capita income, while endogenous growth models focus upon economic agents’ deliberate actions in response to economic incentives. Chapter 3 surveys the extensive cross-country evidence presented in the literature to differentiate between these two specifications of growth. In order to structure the analysis, four issues are addressed, namely convergence, human capital, physical capital, and the role of government policy. In Chapter 3, it is argued that the available cross-country evidence cannot distinguish between exogenous and endogenous specifications of growth, and notes that there has been little research that has examined the time series properties of the data to distinguish between these two classes of models. Chapter 4 presents time series evidence from 8 industrialised countries. Finally, Chapter 5 presents the conclusions of the thesis.
As already noted, although the empirical component of the thesis is directed toward analysing the time series properties of output, it is instructive to examine the broad trends in the data. This is important, not only in terms of placing the recent postwar experience in context, but also to provide a background for the survey of the theoretical literature, that is, to examine why the exogenous, neoclassical growth model is seen as unsatisfactory by a number of researchers. Hence, this chapter presents a broad picture of the "facts" of economic growth, giving an overview of both the levels and growth rates of GDP per capita, population growth rates, and rates of investment in both physical and human capital.

The first observation to be made is that the rate of growth of output per capita has increased over time. Table 1.1 identifies the country with the highest level of output per hour worked over each given time period and estimates the rate of productivity growth for that country.

**Table 1.1 Productivity growth rates for the wealthiest country over the past three centuries**

<table>
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<th>Lead Country</th>
<th>Interval</th>
<th>Annual Average Growth Rate of GDP per Man-Hour (%)</th>
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Source: Maddison (1982)

Although adequate data are only available after 1700, Northern Italy and Flanders led the world in terms of productivity and technology from 1400 to 1600, The Netherlands from 1600 to 1820, the United Kingdom from 1820 to 1890, and the United States in the century since then. The trend observed in Table 1.1 is suggestive; indeed, Romer (1986) took this as evidence for the
existence of increasing returns to production. Whether or not this can, in fact, be reasonably concluded, Table 1.1 does imply that the growth rate of GDP per capita has shown no tendency to decline over the past three centuries. Furthermore, it also indicates that Western nations have been technological world leaders for over 300 years. Maddison (1993) suggests a number of reasons why the West established an early lead in development:

(i) The Western scientific tradition emerged and impregnated the educational system during the Renaissance and Enlightenment.

(ii) The ending of feudal constraints on the free purchase and sale of land led to a series of developments which provided incentives for economic entrepreneurship.

(iii) The emergence of a political system of nation states in close proximity, with similar traditions stimulated competition and innovation.

Further trends can be observed by examining more recent cross-country evidence. Table 1.2 contains the level of real GDP per capita for 43 countries, over the period 1820 to 1989. The data used to derive these estimates, from Maddison (1993), are a merger of four types of information: historical national accounts built up from academic research, postwar official national accounts, purchasing power parity converters provided by the joint International Comparisons Project (ICP), and estimates of population which are still subject to significant errors in poor countries.

It is clear that the European capitalist core and its offshoots began the period richer, on average 22% wealthier than the nearest rival group, the European periphery, and 164% richer than the group of African nations. By the beginning of the postwar period, 1950, the European core was 102% wealthier than the European periphery, and 361% wealthier than the African group. At the end of the period of analysis, 1989, the European core was still the wealthiest group; however, at this point they were 79% richer than the European periphery, still the closest rival, and 757% richer than the African
sub-group.

Over the period 1820 to 1989, the ranking of the five sub-groups remained remarkably similar; European core, followed by European periphery, Latin America, Asia and Africa. Only in 1989 did the average of the Asian nations surpass that of Latin America.
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Notes: (a) rough guesses, assuming no progress in the nineteenth century.

Table 1.3 presents the average growth rates of real GDP per capita for the same set of countries over an identical period, 1820 to 1989. Again, the European core began the period growing faster than any other sub-group, 50% faster on average than the European periphery, and 800% faster than the Asian group. However, over the period 1913 to 1950, the Latin American average grew faster than the European core: over 1950 to 1973, the European periphery grew faster and Asia grew at the same rate, while Asia grew faster over 1973 to 1989. Another remarkable point is the period 1950 to 1973, described by Maddison (1993) as the "golden age" of growth. Over this period all subgroups grew at a faster rate than previously recorded. However, the period 1973 to 1989 led to a slow-down in growth for all groups except Asia, which continued to grow 20% faster than over the previous period. Notably, the African group showed negative growth over 1973 to 1989, with real GDP per capita shrinking at an average rate of 0.3% a year. To emphasise the spectacular postwar growth of some of the Asian nations, Table 1.4 contains growth data on some of the NICs not included in Maddison’s (1993) data set.
Table 1.3 Growth rate of GDP per capita, 1820 to 1989

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Hence, Tables 1.3 and 1.4 show that there has been remarkable variation in growth rates both over time and cross-country; the worldwide, postwar boom, the slowdown post-1973, the extraordinary growth of some of the Asian NICs, and the negative performance of many of the African and Latin American countries.

Table 1.3 (continued)

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Table 1.4 Growth rates of GDP per capita for four Asian NICs, 1950 to 1990

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Source: Pack (1994)
Looking now to the basic factors of production, Table 1.5 contains estimates of population growth since 1820. This data set suggests that population growth rates of the European core and periphery have been similar over the entire period. Australia, Canada and the U.S. had higher growth rates at the beginning of the period due to large scale immigration. However, although they are still above European standards, they are lower than Asian, African or Latin American averages. Asian countries, with the exception of Japan, have had a faster rate of increase since 1950 than Europe. Japan's population, in contrast, has grown at much the same rate as European standards.

Reviewing the data after 1950, the period 1950 to 1973 saw population growth rates ranging from 2.8% a year in Africa, to 0.6% a year in the European periphery. Between 1973 and 1989, growth rates ranged between 3.1% a year in Africa to 0.44% a year in the European core, a difference of 600%. There is, however, no obvious connection between population and income per capita growth rates. Although the slowest growing group, Africa, also had the fastest rate of population growth, the fastest growing group post-1973, Asia, had population growth rates substantially higher than those in the European periphery and core.

Turning now to rates of physical investment, Table 1.6 contains estimates of the ratio of investment to GDP derived from the International Monetary Fund's *International Financial Statistics*. Over the period 1950 to 1973, the European periphery was the fastest growing group on average, followed by the European core and Asia with similar averages, then Latin America and Africa. Turning to the figures on investment before 1973, the European periphery again appears to have the highest relative level of investment, followed by the European core and Asia with similar levels, then Latin America and Africa.

After 1973, Asian relative investment levels are far higher than any
other group, which coincides with the discrepancy between Asian and other growth rates. Investment ratios in the European core and periphery fell during this period, again coinciding with the slowdown in growth observed in these two groups. African and Latin American investment ratios are at all times much lower than the averages for the other groups, which accords with their relative growth performances.
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*Source: Maddison (1993)*
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Although the trends observed above are suggestive, analyses such as this cannot infer directions of causation; that is, although the data support the hypothesis that higher investment levels lead to improved growth performance, the data also support the reverse, that higher economic growth leads to more investment. This issue is considered in greater depth in Chapter 3.

Finally, Table 1.7 presents information on human capital over the postwar period. Specifically, it is derived from Barro and Lee (1993), which estimates the highest levels of educational attainment over the period, broken down on a regional basis. There are a number of trends that can be observed from the data. First, the average years of schooling for developing countries doubled between 1960 and 1985, while that in the OECD increased by only 30%. However, by 1985 the value for OECD countries was still more than double the average for developing countries. Of the developing countries, average years of schooling increased by the largest amount, 244%, in the group representing the Middle East and North Africa; the next largest increase, 130%, was in East Asia and the Pacific. However, by 1985 average years of schooling in the Middle East and North Africa was still only 40% of the OECD average, compared to 60% for East Asia and the Pacific. Hence, the second observation is the considerable degree of variation apparent in levels of education in developing countries. For example, in 1985 the average years of schooling in East Asia and the Pacific, the most educated developing country group, was 94% higher than that in Sub-Saharan Africa, the least educated. Notably, Sub-Saharan Africa showed the lowest absolute increase in human capital over the period.

The third observation is that the centrally planned economies consistently had the highest average number of years of schooling over the period, although in 1985 the figure was only 3% higher than that for OECD countries. However, a noticeable difference between these two groups is the percentage of students entering higher education, with the figure for the OECD being almost double that for the centrally planned economies over the period.
Table 1.6 Investment as a Percentage of GDP, 1965-1985

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*Source: IMF's International Financial Statistics*
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## Table 1.7 Trends in educational attainment by region

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<th>Secondary total (comp.)</th>
<th>Higher total (comp.)</th>
<th>Av. years of school</th>
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<td>1985</td>
<td>436</td>
<td>69.0</td>
<td>13.7 (4.8)</td>
<td>14.1 (5.3)</td>
<td>3.2 (2.3)</td>
<td>2.81</td>
</tr>
</tbody>
</table>

### South Asia (7 countries)

<table>
<thead>
<tr>
<th>Year</th>
<th>Pop. over 25 (mil.)</th>
<th>No school</th>
<th>Primary total (comp.)</th>
<th>Secondary total (comp.)</th>
<th>Higher total (comp.)</th>
<th>Av. years of school</th>
</tr>
</thead>
</table>

19
Table 1.7 (continued)

<table>
<thead>
<tr>
<th>Year</th>
<th>Pop. over 25 (mil.)</th>
<th>No school</th>
<th>Primary total (comp.)</th>
<th>Secondary total (comp.)</th>
<th>Higher total (comp.)</th>
<th>Av. years of school</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OECD (23 countries)</td>
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</tr>
<tr>
<td>1960</td>
<td>362</td>
<td>6.4</td>
<td>61.0 (33.8)</td>
<td>25.5 (9.8)</td>
<td>7.0 (4.1)</td>
<td>6.71</td>
</tr>
<tr>
<td>1965</td>
<td>383</td>
<td>6.0</td>
<td>58.0 (33.7)</td>
<td>27.9 (11)</td>
<td>8.2 (4.8)</td>
<td>7.03</td>
</tr>
<tr>
<td>1970</td>
<td>404</td>
<td>5.2</td>
<td>54.0 (31.4)</td>
<td>31.3 (13)</td>
<td>9.5 (5.6)</td>
<td>7.42</td>
</tr>
<tr>
<td>1975</td>
<td>435</td>
<td>5.4</td>
<td>47.7 (25.3)</td>
<td>34.2 (16)</td>
<td>12.8 (7.3)</td>
<td>7.88</td>
</tr>
<tr>
<td>1980</td>
<td>467</td>
<td>4.6</td>
<td>39.4 (19.9)</td>
<td>40.2 (22)</td>
<td>15.9 (9.1)</td>
<td>8.65</td>
</tr>
<tr>
<td>1985</td>
<td>501</td>
<td>3.3</td>
<td>37.7 (18.3)</td>
<td>40.8 (20)</td>
<td>18.2 (10)</td>
<td>8.88</td>
</tr>
<tr>
<td></td>
<td>Centrally planned economies (10 countries)</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1960</td>
<td>183</td>
<td>5.0</td>
<td>68.9 (26.0)</td>
<td>22.3 (9.0)</td>
<td>3.9 (3.4)</td>
<td>6.83</td>
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<tr>
<td>1965</td>
<td>202</td>
<td>5.3</td>
<td>62.1 (25.7)</td>
<td>27.6 (10)</td>
<td>5.0 (4.3)</td>
<td>7.29</td>
</tr>
<tr>
<td>1970</td>
<td>208</td>
<td>4.0</td>
<td>53.4 (22.7)</td>
<td>36.3 (14)</td>
<td>6.4 (5.5)</td>
<td>7.97</td>
</tr>
<tr>
<td>1975</td>
<td>221</td>
<td>3.7</td>
<td>47.9 (20.2)</td>
<td>40.9 (16)</td>
<td>7.5 (6.5)</td>
<td>8.33</td>
</tr>
<tr>
<td>1980</td>
<td>237</td>
<td>2.7</td>
<td>39.4 (17.0)</td>
<td>49.9 (12)</td>
<td>8.0 (6.9)</td>
<td>8.78</td>
</tr>
<tr>
<td>1985</td>
<td>253</td>
<td>2.3</td>
<td>36.1 (14.3)</td>
<td>51.9 (20)</td>
<td>9.8 (8.4)</td>
<td>9.17</td>
</tr>
</tbody>
</table>

Source: Barro and Lee (1993)

Hence, the tables presented above provide a preliminary picture of economic growth. The broad facts that emerge are as follows:

(i) Over the very long-run, average growth rates have tended to increase.

(ii) There has been a great deal of variation in growth rates, both cross-country and over time, which needs to be accommodated by an adequate model of economic growth.

(iii) On the surface, there appears to be no direct connection between population and income per capita growth rates. However, the relationships between growth and investment in
both physical and human capital appears suggestive.
"What this language primarily describes is a picture. What is to be done with the picture, how it is to be used, is still obscure. Quite clearly, however, it must be explored if we want to understand the sense of what we are saying. But the picture seems to spare us this work: it already points to a particular use." Wittgenstein (1953, p.184).

1. Introduction

The proliferation of endogenous models of economic growth over the past decade has been remarkable. In its essentials, this work can be distinguished from neoclassical models in its emphasis on economic growth as an endogenous outcome of an economic system, rather than as a result of forces that act outside this system. Dowrick (1992) identifies two sources of this resurgence: Romer's (1986) paper entitled *Increasing Returns and Long-Run Growth*, and the publication of a comprehensive cross-country data set in Summers and Heston (1988, 1991), which contains a consistent set of national accounting aggregates for more than 100 countries since 1950. Stern (1991, p.122) suggests an additional factor of importance, "the progress in the microeconomic theories of industrial organisation, invention and innovation, and human capital which have made the discussion of the advancement of knowledge and its relation to markets more coherent." However, these stimuli only became relevant due to the perceived deficiencies of the neoclassical model in accounting for observed growth patterns. This chapter presents a brief introduction to some of the facets of endogenous growth models. It begins, however, with Solow's (1956) neoclassical, exogenous model of economic growth, before describing some of the ways in which the driving force of economic growth has been endogenised.
While Chapter 1 provides an overview of some of the trends in aggregate-level data, it is important to emphasise the two observations that have motivated researchers to produce alternative models to the neoclassical paradigm. The first is the consistent increase in income per capita since the industrial revolution. Second, it is clear that different countries have had very different growth experiences over long periods of time. Neoclassical theory can only explain the first observation by assuming exogenous technological progress, which is unsatisfactory if, as is generally believed, this technological change has been an important determinant of economic growth. As for the second observation, neoclassical theory can only account for cross-country differences in the long-run by postulating differences in preferences or production technology.

2. The Neoclassical Model

While the exogenous model of Solow (1956) was not the first contribution to the theory of economic growth, as it was specifically related to the Harrod-Domar model, it did produce a set of implications that are seminal to the literature. Consider a simple closed economy that combines capital and labour, denoted $K$ and $L$, respectively, to produce a single homogeneous commodity, $Y$, with a level of technology denoted by $A$. It is assumed that output takes the simple Cobb-Douglas form, so that the production function of this economy can be written as:

$$ Y = A(t)K^{1-\beta}L^\beta $$

(1)

where $\beta$ is assumed to be positive and less than one. The fact that $A$ is a function of time is a standard assumption of neoclassical models; technology improves for reasons left unexplained by the model.

The commodity produced by this economy can either be consumed by households, or costlessly saved and invested to produce more capital. It is assumed that a constant fraction of net output, $s$, is saved, and because it is
assumed that the economy is closed, s is also the ratio of investment to output. Furthermore, it is assumed that the labour supply grows at a constant rate, n. Hence, if \( y = Y/L \) denotes output per worker, \( k = K/L \) denotes capital per worker, and a circumflex denotes an exponential growth rate, then the equilibrium growth path of the economy can be described as:

\[
y = (1-\beta)\hat{k} + \hat{A}
\]

The first line of this equation indicates the procedure used in growth accounting for determining the technology residual. This way of examining growth, suggested in Solow (1957), provides the basis for the growth accounting tradition which was pursued in, for example, Denison (1962). As an example, Solow (1957) fitted this type of model to U.S. data over the period 1909 to 1949. This is achieved by calculating the growth of output per worker, then subtracting the rate of growth of the capital labour ratio multiplied by the share of capital income in total income. The result is known as the technological residual, that is, the proportion of growth that is left unexplained by the model. From this analysis, Solow (1957) infers that only about one-eighth of the total increase in output over this period was due to increased capital per man hour, leaving the remaining seven-eighths as explained by technical change. This observation "stimulated a great deal of research and re-oriented the discussions on growth policy from a crude emphasis on saving to a much better appreciation of the importance of education, research and development, etc." (Dixit, 1990, p.11).

The second line of (2) implies two different modes of economic growth. First, in the steady state, consumption, investment, output and capital all grow at the same rate, determined by the rate of technological progress. Second, if an economy is off the steady state path implied by this model, it may grow at a rate that exceeds the rate of technological progress as it converges to its steady state growth path. The neoclassical implication of convergence has generated much controversy. However, the empirical
evidence for and against this phenomenon is considered further in Chapter 3.

Although the tendency for poor countries to grow faster than rich ones is an empirical issue, it suggests further implications for the behaviour of economies off their steady state growth paths. Romer (1994) presents an example under the assumption that economies are perfectly competitive. This implies that $\beta$, the share of income paid to labour, can be calculated from national accounts as being approximately 0.6. Hence, Romer (1994, p.6) suggests selecting:

"a country like the Philippines that had output per worker in 1960 that was equal to about 10 percent of output per worker in the United States. Because $0.1^{1.5}$ is equal to about 30, the equation suggests that the United States would have required a savings rate that is about 30 times larger than the savings rate in the Philippines for these two countries to have grown at the same rate...The evidence shows that these predicted savings rates for the United States are orders of magnitude too large."

However, this analysis assumes that the level of technology is the same in both countries. It should be noted that increases in savings, and hence investment, will only lead to additional growth for a finite period. This is the case because, as the capital-labour ratio increases, the marginal product of capital will fall, due to the diminishing returns to capital implied by the production function. Hence, after an initial increase in growth from an increase in the savings rate, the economy evolves back into the steady state in which growth in income per worker is determined by the rate of technological improvement. Pack (1994, p.56) suggests that this growth in technology can be interpreted in many ways: "as improvements in knowledge such as organization routines, rearrangement of the flow of material in a factory, better management of an inventory, or other changes that do not require knowledge to be embodied in new equipment. A different view holds that changes in knowledge are embodied in equipment." However, the important point is that these technological
improvements are left unexplained by the model.

Evidence presented in King and Rebelo (1993) also suggests that the transitional dynamics of the neoclassical model cannot account for the observed sustained variation in growth rates. It is argued that the model's transitional dynamics occupy an important role in explaining cross-country differences in growth, since within the steady state growth path of the neoclassical model these differences can only be explained by postulating different rates of technical progress. To this end, King and Rebelo (1993) conduct dynamic simulations of the neoclassical model, using a range of conventional parameter values within the public finance and macroeconomic literature. It is found that the neoclassical model's predictions are inconsistent with the observed variations in interest rates, asset prices and factor shares. They link this result to the central assumption of the neoclassical thesis, namely the diminishing marginal product of capital, and suggest that the endogenous growth models proposed by Romer (1990) and Lucas (1988) form a more appropriate paradigm.

The specific methodology adopted by King and Rebelo (1993) is to examine how the neoclassical model evolves through time if the initial capital stock is low relative to its steady state level. It is assumed that the transitional dynamics should explain one half of U.S. growth in the post-World War II period, with the remainder being attributed to technological change. However, the version of the neoclassical model considered differs slightly from what is conventional in that, rather than assuming that saving is a fixed fraction of income, it is determined by optimal choices of consumption over time. The calibration of the model assumes that the production function is of the Cobb-Douglas form, the labour-share of income is ¾, the average per capita hours devoted to work is 0.2, the depreciation rate is 0.10, the steady state real interest rate is 6½ percent,
and that the annual growth rate of the population is 1.4 percent. The result of this simulation is that, first, in order for transitional dynamics to explain sustained differences in growth rates, agents need to have a low intertemporal elasticity of substitution in consumption. However, even if this assumption is made, the requirement that the marginal product of capital must be very high in the early stages of development for transitional dynamics to be important implies that interest rates and asset prices are implausibly high relative to historical observation.

Although the above exposition on the neoclassical model has been brief, it has outlined the perceived inadequacies of the model in accounting for observed behaviour. First, if it is argued that it is the steady state growth path that is relevant, the neoclassical model implies that all economies, if they have the same parameters for preferences and production technology, should be growing at the same rate. As wide variation over long periods of time is a notable feature of observed growth rates, the neoclassical model provides no explanation of this phenomenon. However, it is generally argued that economies remain off their steady-state growth paths for long periods of time. In this case, the analyses of Romer (1994) and King and Rebelo (1990, 1993) suggest that the neoclassical model is still unable to account for the cross-country variation without generating counterfactual implications for factor prices or factor shares.

The sources of these figures are given as follows: the labour-share parameter is from Maddison (1987); the proportion of per capita hours devoted to work is from King et al. (1988); the depreciation rate is from Maddison (1987); the steady state real interest rate figure corresponds to the average real return on equity for the postwar United States; the population growth rate is the average value for the United States over the period 1950 to 1980.

King and Rebelo (1993) note that, for the postwar Japanese convergence towards U.S. income levels to be due to transitional dynamics, the Japanese real interest rate would have been over 500 percent in 1950.
At this stage, it is appropriate to recognise some of the criticisms that have been made, both of the aggregate production function approach to growth modelling, and of the particular form it takes in the neoclassical model (for a comprehensive discussion, see Stiglitz (1974)). The most contentious issue revolves around the use of the aggregate capital stock to represent the sum total of heterogeneous capital goods, as was evidenced by the Cambridge-Cambridge controversy. While this dispute seems to have been decided in favour of the Massachusetts approach, it is worthwhile mentioning the issues involved. The economists of Cambridge, England, such as Joan Robinson, noted that what is described as the aggregate capital stock is, in fact, a heterogeneous group of capital goods that differs according to how long it takes labour and other types of capital to produce them. Hence, the longer the period of time required to construct each type of new capital, the higher are the interest costs as a proportion of total production costs. Consequently, when the relative wage-rental cost of capital changes, different techniques, involving different capital goods, become cost minimising. This implies the possibility of "reswitching", in that a given technique can be that of least cost at both high and low interest rates, but not in between. As such, discontinuities and reversals are possible within the equilibrium solutions of the model.

Hicks (1973) develops the two cases where the aggregate of physical goods known as capital can be represented by a single quantity without error: one is the case in which all components of the capital stock change proportionately, the other is when the relative price ratios between the capital goods, or their marginal rates of substitution, remain constant. The first condition will never be satisfied in a dynamic economy, as the aggregate of capital at the end of any given period will contain different types of goods from the aggregate of goods at the beginning of that period. The objection to the second condition is based on the inference from the production function that, if the capital-labour ratio were to increase, the
marginal product of capital must fall. However, this fall in the marginal product implies a fall in the interest rate, which in turn implies that the capitalised values of goods of differing durability must change disproportionately. Hence, the marginal rates of substitution between these goods cannot remain constant. Hicks argues that, given these objections, a technological relation between capital and total output, with capital arbitrarily valued, carries no conviction. As noted by Scarth (1988, p. 185), however, most macroeconomists have taken a pragmatic approach to problems such as those above:

"If aggregate models seem consistent with the macroeconomic 'facts', then, no matter how restrictive the aggregation requirements (needed to preclude such things as reswitching) seem, analysts conclude that not too much is lost by assuming that the economy operates as if these restrictions were appropriate."

Hence, Dixit (1990) views these rival positions purely as different research strategies, reflecting the trade-off that must be made in a real world of many capital goods, whose quantities and prices can decay at different rates. The two sides merely adopted different simplifications, so it is not a question of which approach is correct, but rather what theoretical constructions are useful.

Although this summary skims over a number of important issues, the basic structure of the neoclassical model has been outlined, along with a number of criticisms. What has been made clear is that there are a number of basic facts about growth that the neoclassical model fails to explain. According to Romer (1994, p.10):

"Everyone agrees that the conventional neoclassical model with an exponent of about one-third on capital and about two-thirds on labour cannot fit the cross-country or cross-state data. Everyone agrees that the marginal product of investment cannot be orders of magnitude smaller in richer countries than in smaller countries."
Furthermore, growth rates since the industrial revolution have been increasing rather than decreasing, and patterns of migration and wage differentials cannot be reconciled with the standard neoclassical model.3

The following sections contrast this neoclassical model, driven by exogenous technological change, with a representative selection of models in which growth is determined by the behaviour of rational, optimising agents, rather than determined outside the model. Dowrick (1992, p.108) suggests that "[m]ost, but not all, models of endogenous growth are based on increasing returns to scale in production." This description is accurate for models such as Lucas (1988), which assumes increasing returns to the production of human capital. However, many of the models described in this chapter exhibit constant returns to production, such as Rebelo (1991), which can also generate long-run growth.

Section 2 of this chapter describes the basic endogenous growth model in Rebelo (1991) as the simplest alternative to the neoclassical model. Furthermore, it is this 'generic' endogenous model that forms the basis of the new empirical work in Chapter 4. Sections 3 to 7 analyse some of the more complicated formulations that have been developed in the literature. In particular, these models demonstrate the long-run effect of the inclusion of such influences as public expenditure, human capital, research and development, and inflation into an endogenous modelling framework.

3. Endogenous growth and constant returns to production

In order to provide an introduction to endogenous growth, the model presented in Rebelo (1991) (hereafter denoted as Rebelo-type) will be developed. This outline is also useful for the new empirical work contained

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3 See Lucas (1988) for a full discussion.
in section 4 of this thesis, which explicitly attempts to distinguish between a Rebelo-type endogenous growth specification and the exogenous alternative. Hence, this exposition develops the implications of an economy with standard preferences but incorporating a production technology which is linear in the stock of capital.

Consider an economy in which there are two factors of production: those that are reproducible, such as physical and human capital, denoted by \( Z_r \), and those whose quantities are fixed, such as land, denoted by \( T \). These factors are used to produce output in two different sectors, the consumption good and capital sectors. The production of consumption goods, \( C_r \), is based on a Cobb-Douglas production function given by:

\[
C_r = B(\phi_t Z_r)^{\alpha} T^{1-\alpha}
\] (3)

where \( B \) is a constant, \( \phi_t \) is the fraction of the reproducible capital goods used to produce consumption goods, and \( 0 < \alpha < 1 \). In contrast, the production of capital goods takes place with a technology that is linear in the capital stock, so that:

\[
I_t = AZ_r (1-\phi_t)
\] (4)

where \( A \) is a constant. If it is assumed that capital depreciates at a rate \( \delta \), then the change in the stock of reproducible factors is described by:

\[
\dot{Z}_r = I_t - \delta Z_r
\] (5)

Hence, along the steady state growth path, (3) and (4) imply that:

\[
\gamma_c = \alpha \gamma_z
\] (6)

where \( \gamma_x \) is the growth rate of a variable \( x \).

On the demand side of this economy, the representative agent is assumed to be maximising utility given by:
where $\rho$ is the rate of time preference and $\sigma$ is the coefficient of relative risk aversion, both of which are assumed to be positive. Hence, this specification of preferences implies that the growth rate of consumption at any point in time, $\gamma_c$, will be given by:

$$\gamma_c = \frac{r_t - \rho}{\sigma}$$

where $r_t$ is the real interest rate at time $t$.

In order to solve for the competitive equilibrium of this economy, Rebelo (1991) initially examines the conditions required for equilibrium in the supply side. It is clear that firms, in order to be profit maximising, must be indifferent about whether the last unit of reproducible capital is used to produce consumption goods or capital goods, so that:

$$p_t A = \alpha B(\phi Z)^{\alpha - 1}$$

where $p_t$ is the relative price of capital goods. Furthermore, because the fraction of capital used in the production of consumption goods, $\phi_c$, must be constant in the steady state, (9) implies that the relative price of capital declines at a rate given by:

$$g_p = (\alpha - 1)g_c$$

This, in turn, implies that the real interest rate for loans denominated in capital goods, $r_{zt}$, is different to the real interest rate for loans denominated in consumption goods, $r_{ct}$, such that:

$$r_{ct} = r_{zt} + \gamma_p$$

The magnitude of the interest rates will be determined by the marginal productivity of capital: specifically, the constant marginal productivity of
capital in the capital goods sector implies that:

\[ r^e = A - \delta. \] (12)

Hence, substitution of (10) and (12) into (11) implies that:

\[ r^e = A - \delta + (\alpha-1)\gamma^e. \] (13)

This is the interest rate faced by consumers optimising the growth rate of consumption given in (8). Finally, given that net income, \( Y^t \), given by:

\[ Y_t = C_t + p_tI_t - \delta Z_t \] (14)

is denominated in consumption goods, this implies that the growth rate of output, \( \gamma^t \) is given by:

\[ \gamma^y = \alpha \frac{A - \delta - \rho}{1 - \alpha(1 - \omega)}. \] (15)

Hence, (15) represents the competitive equilibrium growth rate of output under this endogenous specification and generates long-run growth, provided that \( (A - \delta - \rho) \) is positive, that is, assuming that the net marginal productivity of capital goods in the capital sector is greater than the rate of time preference. Note that \( B \), the productivity coefficient in the consumer goods sector, and \( T \), the quantity of non-reproducible factors, do not enter (15), suggesting that differences in natural endowments of resources do not affect the equilibrium growth rate of this economy.

Although Rebelo (1991) proceeds further to develop the model outlined above, this analysis makes clear the basic properties of this type of endogenous growth model. First, the model exhibits long-run growth without the necessity of including exogenously evolving technological change. This result is demonstrated in (15). Second, the mechanism which allows this long-run growth "is a 'core' of capital goods that can be produced without the direct or indirect contribution of factors that cannot be accumulated, such as land" (Rebelo (1991, p.500). Third, the specification
of constant returns to production suggests that technological shocks to this economy will have permanent effects. This aspect is developed further in Chapter 4, and forms the basis of the new empirical work to be presented.

The remainder of this chapter describes some other ways in which growth has been endogenised, and examines the effect that public expenditure, human capital, research and development, and inflation can have on equilibrium growth paths of these models.

4. Human Capital and Growth

It has been argued by Lucas (1988) that one possible driving force of economic growth may be the accumulation of human capital, for which spillover effects may be postulated. This notion is supported by the cross-country evidence presented in Barro (1991) and Mankiw et al. (1992), which find a significant correlation between measures of human capital and average growth rates of per capita income. There are, however, a number of interpretations that can be made of this evidence. Romer (1989) views human capital as the accumulation of effort devoted to schooling and training, which is typically measured in the empirical literature by enrolment ratios in primary and secondary schools. However, Nelson and Wright (1992) has emphasised the importance of higher education in sustaining U.S. industrial leadership during the twentieth century, so that Greasley and Oxley (1994a) measure human capital by the number of Bachelors degrees awarded.

In contrast, human capital in Lucas (1988) refers simply to a given individual's general skill level. Therefore, any worker with human capital equal to $h$ units is twice as productive as one with human capital of $\frac{1}{2}h$ units. The dynamics of the model are such that they focus on the fact that the way a given individual allocates time between the production of further human capital and the production of goods affects productivity in future
periods. In addition to this, an externality is introduced in that not only does human capital influence a given worker’s productivity, but the average skill level of all workers affects the productivity of all factors in the production function.

In the model itself, it is assumed that there are N workers in total, each having identical skill level h. If a worker with skill level h devotes the fraction u(h) of non-leisure time to current production, the remaining 1 - u(h) is used to accumulate human capital. This means that the effective labour force will be \( N_e = uhN \). Thus, if output, as a function of total capital K and effective labour \( N_e \), is \( F(K, N_e) \), the hourly wage of a worker at skill level h is \( F_N(K, N_e)h \).

Lucas introduces an additional effect of human capital to that of the increase in an individual’s own productivity, namely, the average level of human capital, \( h_a \), also contributes to the productivity of all factors of production. Lucas describes this effect as external, in contrast to the internal effect mentioned above.

Hence, the description of the technology of goods production is given by:

\[
N(t)c(t) + \dot{K}(t) = AK(t)^{\beta}[u(t)h(t)N(t)]^{1-\beta}h_a(t)\gamma
\]

(16)

where c is consumption per capita, the technology level A is assumed to be constant, and the index of time, t, indicates the value of a variable at any given moment of time. The equation describing the accumulation of human capital is given by:

\[
\dot{h}(t) = h(t)\delta[1-u(t)].
\]

(17)

This formulation implies that there are no diminishing returns to the accumulation of human capital but, as Lucas notes, diminishing returns appear to exist in observed individual patterns of human capital.
accumulation. The alternative explanation given for this observation is simply that, as an individual's life is finite, returns to increments fall with time.

It is further assumed that the population grows at the fixed rate $\lambda$, and households have preferences given by:

$$\int_0^\infty e^{-pt} \frac{1}{1-\sigma} [c(t)^{1-\sigma} - 1] N(t) dt$$

(18)

where the discount rate, $\rho$, and the coefficient of relative risk aversion, $\sigma$, are both positive. Lucas derives both the optimal and equilibrium paths for this economy; as it is the latter that is of particular interest, the optimal path will not be considered further. The notion of an equilibrium path is complicated by the presence of the external effect of human capital. Following the approach in Arrow (1962), it is assumed that a time path of $h_a$ is given. Confronted with this state, the private sector faces the problem of choosing $h(t)$, $k(t)$, $c(t)$ and $u(t)$ so as to maximise (18) subject to the constraints (16) and (17), taking $h_a(t)$ as exogenously given. When the solution path $h(t)$ coincides with the given path $h_a(t)$, so that actual and expected behaviour are the same, then the system is said to be in equilibrium.

Lucas (1988) solves this system by using the current-value Hamiltonian, with prices $\nu_1(t)$ and $\nu_2(t)$ used to value increments to physical and human capital, respectively, so that:

$$H(K, h, \nu_1, \nu_2, c, u, t) = \frac{N}{1-\sigma} (c^{1-\sigma} - 1) + \nu_1 [AK^\gamma (uNh)^{1-\beta} - Nc]$$

$$+ \nu_2 [\delta h (1-u)].$$

(19)

There are two decision variables in this model, $c(t)$ and $u(t)$, and these are chosen so as to maximise (19), giving the first-order conditions:
\[ c^{-\sigma} = v_1 \quad (20) \]

and

\[ v_1 (1 - \beta)AK^\beta (uNh)^{-\beta Nh^{1+\gamma}} = v_2 \delta h. \quad (21) \]

These two conditions can be understood to mean that, at the margin, goods must be equally valuable in their two uses, consumption and capital accumulation, and time must be equally valuable in its two uses, production and human capital accumulation.

The rates of change of the two prices of capital are given by:

\[ \dot{u}_1 = \rho u_1 - v_1 \beta AK^{\beta-1} (uNh)^{1-\beta} h^\gamma \quad (22) \]

and

\[ \dot{u}_2 = \rho u_2 - v_1 (1 - \beta)AK^\beta (uN)^{1-\beta} h^\gamma - v_2 \delta (1 - u). \quad (23) \]

Since market clearing implies that \( h(t) = h_2(t) \) for all \( t \), (23) can be rewritten as:

\[ \dot{u}_2 = \rho u_2 - v_1 (1 - \beta)AK^\beta (uN)^{1-\beta} h^\gamma - v_2 \delta (1 - u). \quad (24) \]

To derive the balanced growth path for this economy, let \( \kappa \) be equal to the growth rate of consumption, so that (21) and (22) imply the marginal product of capital condition:

\[ \beta AK(t)^{\beta-1} \big( u(t)h(t)N(t) \big)^{1-\beta} h(t)^\gamma = \rho + \sigma \kappa. \quad (25) \]

If \( \theta \) is equal to the growth rate of human capital stocks then, from (19):

\[ \theta = \delta (1 - u) \quad (26) \]

and, from differentiating (25), the common growth rate of consumption and capital per capita is:
\[ \kappa = \left( \frac{1 - \beta + \gamma}{1 - \beta} \right) \theta. \]  

(27)

To determine the growth rate of human capital, the first order conditions are differentiated, giving:

\[ \frac{\dot{u}_2}{u_2} = (\beta - \sigma) \kappa - (\beta - \gamma) u + \lambda. \]  

(28)

Along the equilibrium growth path, (21) and (24) yield:

\[ \frac{\dot{u}_2}{u_2} = \rho - \delta \]  

(29)

so that the equilibrium growth rate, \( \theta \), is given by:

\[ \theta = \left[ \sigma(1 - \beta + \gamma) - \gamma \right]^{-1} \left[ (1 - \beta)(\delta - (\rho - \lambda)) \right]. \]  

(30)

Hence, the growth rate of this economy can be seen to be simply a function of the structural parameters of the model. This solution for the equilibrium growth rate cannot be directly estimated, as the parameters are not identifiable. However, Lucas shows that the model can be made to fit reasonably to the U.S. time series estimates of the parameters generated in Denison (1962). Specifically, Lucas (1988) takes Denison's estimates for four parameters in order to infer the values of \( \rho, \sigma, \gamma \) and \( \delta \) from (27) and (30), which are determined to be of suitable orders of magnitude.

This model produces endogenous growth by incorporating human capital into the production function of the economy, and by postulating that the accumulation of human capital has a spillover effect on the productivity of other workers, which leads to increasing social returns to human capital investment. In so doing, Lucas (1988) stresses the internal effects of human capital, where the return accrues to the individual, as opposed to the external effects, where the average skill level contributes to the productivity of all factors of production.
It should be noted, however, that incorporating the effect of human capital does not necessarily produce endogenous growth; it is the postulated spillover effects that enable this model to exhibit long-run growth in per capita output. As an example, Chapter 3 describes the neoclassical model of Mankiw et al. (1992), which incorporates human capital into a production function with neoclassical properties. Hence, as suggested in Chapter 3, evidence for the importance of human capital in explaining cross-country growth does not necessarily support either the neoclassical or endogenous conception of growth.

5. Public Expenditure in Models of Growth

The notion that public policy can affect long-run growth rates has a long history. Indeed, Schultz (1981) argued that many public policies contain disincentives for growth due to the effect taxation has on reducing the incentives to accumulate capital. Empirical evidence also suggests an important role for public policy although, as Sala-i-Martin (1994) observes, it is difficult to distinguish exactly which policy variables are important.

In developing this idea, Barro (1990) and Rebelo (1991) introduce the public sector into a model of the economy, and by so doing suggest an explicit mechanism whereby government policy may influence economic growth. These models are endogenous in the sense that growth occurs in the absence of exogenous increases in productivity, due to constant returns to scale in production technology.

Consider the model suggested in Barro (1990). Government expenditure is separated into two components, namely expenditure which is productive, and expenditure which only influences the utility of consumers. Letting $g$ denote the quantity of productive public services provided to each household/producer, for which there are no user charges or congestion effects, implies that the production function can be written as:
given that production is assumed to exhibit constant returns to scale in the two arguments, k and g, and that y and k represent output and capital per worker, respectively. The functional form of \( \Phi \) is assumed to be such that it has positive and diminishing marginal products. The flow of public services, g, need not correspond to government purchases, as is the case when the national accounts omit the imputed rental income on public capital. Despite this fact, Barro suggests that it is conceptually more satisfactory to think of the government as owning no capital and simply purchasing goods from the final sector, which then become inputs for the private sector production function. A further complication arises if public services are non-rival for their users. In this case, it is the total purchases, rather than the amount per capita, that is relevant for consumers. However, Barro (1990) suggests that few actual government services are non-rival, and thus does not continue the analysis along these lines.

It is assumed that the representative, infinite-lived household in a closed economy maximises utility given by:

\[
U = \int_0^\infty u(c, h) e^{-\rho t} dt
\]

(32)

where c is consumption per capita, h is the quantity of public consumption services per capita, \( \rho \) is the positive and constant rate of time preference, and the population is constant. The utility function is assumed to be of the form:

\[
u(c, h) = \frac{(c^{1-\beta} h^\beta)^{1-\sigma} - 1}{1 - \sigma}
\]

(33)

where \( 0 < \beta < 1 \), and marginal utility has constant elasticity equal to \(-\sigma\), which is less than one. The government is assumed to finance its
expenditures contemporaneously by way of a flat-rate income tax, so that:

$$g + h = T = (\tau_g + \tau_h)y$$

(34)

where $\tau_g$ is the government's expenditure ratio for productive services, and $\tau_h$ is the ratio for consumption services. The household's decentralised choices for consumption and saving now imply a growth rate given by:

$$\gamma = \frac{1}{\sigma}[(1 - \tau_g - \tau_h) \phi(\frac{g}{k})(1 - \eta) - \rho]$$

(35)

where $\eta$ is the elasticity of $y$ with respect to $g$. Intuitively, the term $\phi(g/k)$ $(1 - \eta)$ represents the marginal return to capital. However, as households are taxed in order to finance government expenditure, the relevant expression for the private return to capital is the marginal return multiplied by $(1 - \tau_g - \tau_h)$. In this way, government size has a number of effects upon the growth rate. First, for a given value of $g/y$, an increase in $h/y$ lowers the growth and savings rates of the economy, as it has no effect on private sector productivity yet leads to a higher income tax rate, thereby lowering the private return on capital. On the other hand, an increase in the level of productive government services has two opposing effects on the growth rate. An increase in $g/y$ raises the marginal return on capital, and hence tends to increase the growth rate. However, this increase in government services must be financed by an increase in the tax rate, which tends to lower the growth rate. Typically, Barro states, the first force dominates when the size of government is relatively small, and the second when it is large. It is possible to determine the optimal size of productive government services in this model; assuming that the aggregate production function were to be of the Cobb-Douglas form, then the government should set $g/y$ to be equal to the share it would receive if public services were a competitively supplied input of production.

The implications of this model are, to some extent, empirically testable. Increases in public consumption expenditure unambiguously
decrease the growth rate of an economy. Empirical evidence from regression analysis in Barro (1990, 1991) and Grier and Tullock (1989) suggests that average government consumption expenditure is significantly negatively correlated with cross-country growth rates over the postwar period, although it is not clear that this conclusion is robust to alternative model specifications. However, these empirical questions are considered further in Chapter 3. The empirical relevance of the hypothesis regarding productive government services is somewhat more problematic; indeed, as Barro (1990) demonstrates, the response of the growth rate to increases in the quantity of productive government expenditure relative to GDP is likely to be non-monotonic.

The general framework presented in Barro (1990) can also be used to describe the distortionary effects of taxation in a model of two capital goods. Easterly (1993) develops just such a model, showing that subsidies to one type of capital that are financed by taxation on another type lower the growth rate of total output. Production, as in Barro (1990), is assumed to exhibit constant returns to scale in reproducible capital. There are two types of capital goods, denoted $K_1$ and $K_2$, which Easterly interprets as representing formal and informal sector capital, and population is assumed to be fixed. Total output, $Y$, is produced by a technology given by:

$$Y = A(\gamma K_1^e + (1-\gamma)K_2^e)^{1/e} \quad (36)$$

where $A$ is a constant representing the level of technology, and the elasticity of substitution is equal to $1/(e-1)$. Both types of capital goods can be costlessly converted into the consumption good, $C$. Preferences are of the form:

$$U = \int_0^\infty e^{-\rho t} \frac{C^{1-\sigma} - 1}{1-\sigma} \, dt \quad (37)$$

in which $\rho$ is the positive rate of time preference, and $1/\sigma$ is the intertemporal elasticity of substitution. Hence, the identical, infinite-lived
household/producers of this economy attempt to maximise utility, \( U \).

It is assumed that the government levies a sales tax on capital good \( K_1 \) only, so that consumption is equal to:

\[
C = Y - (1 + \tau)I_1 - I_2 + T \tag{38}
\]

where \( \tau \) is the tax rate on capital good 1, and \( T \) is the lump sum transfer of tax revenues to consumers. The accumulation of the two capital goods is determined by:

\[
\dot{K}_1 = I_1 - \delta K_1 \tag{39}
\]

and

\[
\dot{K}_2 = I_2 - \delta K_2 \tag{40}
\]

where the depreciation rate, \( \delta \), is assumed to be the same for both types of capital. Given the tax on capital good 1, the ratio of the marginal products of the two capital types, \( \Phi \), will be given by:

\[
\Phi = \frac{K_2}{K_1} = \left[ \frac{(1-\gamma)(1 + \tau)}{\gamma} \right]^{\gamma(1-\delta)} \tag{41}
\]

Hence, the tax on capital good 1 induces more of capital good 2 to be held than is socially optimal. The balanced growth path for this economy can be solved by observing that consumption and output must grow at the same rate, \( g \), given by:

\[
g = r_2 - \delta - \rho \tag{42}
\]

where \( r_2 \) is the marginal product of capital good 2, and is determined as:

\[
r_2 = A(1- \gamma)(\gamma \Phi^{-\delta} + 1 - \gamma)^{\delta-1} \tag{43}
\]

This outcome differs from that in Barro (1990) only in the effect on the net marginal product of capital, due to the assumption of capital depreciation and the way taxation is specified. However, the resulting growth rate is
affected in the same way; an increase in the tax rate leads to a decrease in growth. This occurs because increasing the tax rate on capital good 1 leads to an increase in the ratio of capital good 2 to capital good 1 in equilibrium. Increasing this ratio leads to a decrease in the marginal product of capital good 2, \( r_2 \), which leads to a decrease in the growth rate.

Easterly (1993) notes that the magnitude of the distortionary effect introduced by the specified tax depends upon the elasticity of substitution of the two capital types. Essentially, if the elasticity of substitution is greater than one, then positive growth is still possible with a tax rate equal to one, as neither input is essential to production. However, if the elasticity of substitution is less than or equal to one, the rate of return of capital good 2 approaches zero as the tax rate approaches one. This implies there will be a negative growth rate equal to \((\delta + \rho)\sigma\). It is further noted that, since this model assumes that the labour supply is exogenous while an investment tax will lower growth, a tax on consumption will not lower growth. Easterly also considers the situation in which the proceeds from the tax on capital good 1 are used to subsidise investment in capital good 2 at rate \( s \). This implies that the first-order condition for the ratio of type 2 capital to type 1 becomes:

\[
\Phi = \frac{K_2}{K_1} = \left[\left(\frac{1-\gamma}{\gamma}\left(\frac{1+\tau}{1-s}\right)\right)^{1/(1-\epsilon)}\right]
\]  

so that the assumption that this transfer is self-financing implies that:

\[
\frac{K_2}{K_1} = \frac{\tau}{s}. 
\]  

Hence, the growth rate of this economy now becomes:

\[
g = \frac{r_2/(1-s)-\delta-\rho}{\sigma}. 
\]  

The growth rate defined by (46) implies that an increase in the self-financing subsidy will have two different effects on the growth rate:
although the subsidy makes capital good 2 more attractive, the tax necessary to finance the subsidy outweighs this effect. Hence, whether the proceeds from the taxation of capital good 1 are spent on consumption or are used to subsidise other capital goods is irrelevant for the direction of the effect of an increase in the investment tax: it will always lead to a decrease in the growth rate.

The two models presented in this section provide examples of the ways in which public expenditure and taxation can be incorporated within an endogenous growth model. The effect of public spending is generally negative in both models; Barro (1990) suggests that increases in government consumption expenditure lead to decreases in the growth rate of output, whereas Easterly (1993) suggests that increases in the tax rate on investment lead to decreases in growth. However, both models assume perfectly functioning markets and no externalities. As these are the reasons most often used to justify government intervention, the results obtained are perhaps not surprising.

6. Models Incorporating the Effects of Research and Development

Romer (1990) develops a model in which spillovers from the production of knowledge generate endogenous growth. This emphasis on the role of knowledge production is supported in Grossman and Helpman (1990), which focuses on the way in which knowledge can lead to expanding product variety or rising product quality. However, the essential feature of Romer (1990), as highlighted in Stern (1991), lies in identifying a sector that specialises in the production of ideas. In this model, increases in the level of technology are defined as being dependent both on the amount of human capital invested in research and the total stock of knowledge already available. The distinction between the roles played by human capital and the stock of knowledge in the production process is an important one. Romer introduces two concepts used in the public finance literature, those
of the degree of rivalry and excludability in the use of economic goods. Since human capital is specific to a given person, it can be treated as both rival and excludable. In the case of technology, or ideas, the appropriate specification is as a non-rival good due to the fact that, once these new ideas are discovered or created, they can be used as frequently as is desired. Romer acknowledges that although, in general, a design or idea will be tied to a physical object, in the way that a computer program is tied to the disc on which it is stored, or an industrial blueprint is tied to the paper on which it is written, the cost of replicating the design is trivial compared with the initial cost of creation. The fact that knowledge is treated as being non-rival has two important implications for this model. First, since knowledge is non-rival, it can be accumulated without bound on a per capita basis, whereas the stock of human capital is lost upon the death of the individual in which it is manifested. This provides a mechanism through which unbounded growth may be generated. Second, the non-rival nature of knowledge means that it will be incompletely excludable, which will generate externalities in the model. This stems from the fact that if a non-rival input has productive value, then output cannot be a constant returns to scale function in which all inputs are paid their marginal products. Romer (1990) argues as follows. If $F(A, X)$ represents a production technology based on rival inputs, $X$, and non-rival inputs, $A$, then, by the replication argument, $F(A, \lambda X) = \lambda F(A, X)$. If $A$ is also productive, then $F$ cannot be concave, because $F(\lambda A, \lambda X) > \lambda F(A, X)$. Hence, a firm with this type of production possibilities could not survive as a price-taker. If output is sold at marginal cost, then revenue would only equal rental payments on capital and labour, so that if all inputs were paid the value of their marginal products, the firm would suffer losses.

The model presented by Romer (1990) has four inputs: capital

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4 A rival good is such that its use by one individual precludes its use by another, whereas a good can be considered excludable if its owner can prevent others from using it.
(measured in units of consumption goods), labour (the number of workers), human capital (years of education and training that are person-specific), and the level of technology (measured in the number of non-rivalrous designs). As mentioned previously, the economy contains three sectors: the research sector uses human capital and the existing stock of designs to produce new designs; the intermediate goods sector uses the designs produced by the research sector, together with foregone output, to produce the producer durables used in the production of final goods; and the final goods sector uses labour, human capital and the stock of producer durables to produce final output.

A number of simplifying assumptions are introduced to make the model mathematically tractable, in that the population, labour supply, and the total stock of human capital are treated as fixed. However, the proportion of the stock of human capital devoted to the research and final goods sectors is dependent upon the relative wages offered in these two sectors. The assumption of a fixed stock of human capital is an important one, given that it is reasonable to imagine the stock of human capital as evolving over time. While the assumption is made in order to make the equilibrium conditions of the model mathematically tractable, it is unclear how the results would be affected were Romer to allow human capital to change in the way suggested by Lucas (1988). In this case, the proportion of an individual's time spent investing in further human capital would be dependent upon the return to that investment, which would depend upon the rate of interest. It is not obvious how this would affect the equilibrium growth rate given in (51), even though it is of interest. There are some further analytical points of interest that are implicit in the specification of the model. Since capital is simply foregone output, the production of capital goods uses the same production technology as the final goods sector. In addition, while it is reasonable to suggest that research is relatively knowledge- and human capital-intensive, Romer has developed this sector with labour and physical capital not entering into the production technology.
The production function for the final goods sector is assumed to be of the Cobb-Douglas form, both for analytical tractability and because all inputs entering the production technology are rival and excludable. This second point suggests that the replication argument applies, and hence justifies the assumption of constant returns to scale. Capital has been disaggregated into an infinite number of different types of producer durables, in order to avoid the problem of integer constraints when solving the system of equations. Thus, the function is of the form:

\[
Y(H_Y, L, x) = H_Y^\alpha L^\beta \int_0^1 x_i^{1-\alpha-\beta} di
\]

where \(x_i\) is the quantity of producer durable \(i\), \(L\) is the quantity of labour, \(H_Y\) is the amount of human capital devoted to the production of final goods, and \(\alpha + \beta\) is assumed to be less than one. The production function is expressed as an additively separable function of the different types of capital goods, so that an increase in \(x_i\) has no effect on the marginal productivity of \(x_j\), for \(i \neq j\). This is in contrast to the conventional specification whereby capital goods tend to be treated as perfect substitutes. Since the final goods production function specified in (34) is homogeneous of degree one, output in this sector is derived from a single, price-taking firm.

The measure of total capital, which is simply cumulative foregone output, evolves according to:

---

5 If all inputs are rival and excludable, then doubling all inputs will double output. This can be thought of in terms of replication: to double the output of a given factory, one could simply build another identical one.
\[ \dot{K}(t) = Y(t) - C(t) \]  

(48)

where \( C(t) \) denotes aggregate consumption at time \( t \). As it takes \( \eta \) units of foregone consumption to create one unit of any producer durable, the total capital stock of the economy is given by:

\[ K = \eta \sum_{i=1}^{A} x_i \]  

(49)

where the time subscript, \( t \), has been dropped for convenience, and \( A \) is the total number of designs.

The research sector of this economy is devoted to the production of new designs for producer durables, the production of which is specified to be of the form:

\[ \dot{A} = \delta H_A A \]  

(50)

where \( H_A \) is the amount of human capital employed in the research sector, and \( \delta \) is a productivity parameter. Hence, it is assumed that the greater is the quantity of human capital employed in this sector, and the larger the total stock of designs, the greater will be the productivity of the research sector. In addition, the form of (50) is such that it is linear in both \( H_A \) and \( A \). It is this assumption of linearity that is crucial for unbounded growth to be possible in this model since, if the marginal productivity of human capital in the research sector does not continue to grow in proportion to \( A \), then human capital initially employed in research would shift into the production of final goods.

Stern (1991) criticises Romer on the basis that it is difficult to identify anything approximating a knowledge-producing sector in real economies. This, however, seems to miss the point of economic modelling, in general; the assumption of a sharply delineated research sector in the Romer (1990) model is an abstraction made in order to isolate the influence of R&D on
growth. It is clear that firms and governments do, in fact, invest in R&D and, as such, it is simply a convenient simplification to assume that this takes place in a separate sector of the economy.

Prices are measured in units of current output, \( r \) represents the interest rate denominated in goods, \( P_A \) is the price that firms in the intermediate sector must pay for new designs, and \( w_H \) is the rental rate for each unit of human capital. Since it is assumed that any worker in the research sector can take advantage of the entire stock of ideas, it follows that the wage paid in this sector is equal to:

\[
w_H = P_A \delta A.\quad (51)
\]

Note that the intermediate goods sector cannot be treated in terms of a single, price-taking firm, as it is assumed that there is a single firm producing each durable. That firm must purchase the design at price \( P_A \), after which it can convert \( \eta \) units of final output into one unit of durable good \( i \). Once the firm has produced the durable from the new design, it can obtain an infinitely-lived patent and, as such, it will face a downward sloping demand curve for the durable, which it then lends at the rate \( p(i) \). As the durables are assumed not to depreciate, they are valued at the present discounted value of the infinite rental stream they produce.

The demand curve faced by firms in the intermediate sector can be determined as follows. Since each durable can only be obtained from a single supplier, if the final goods producer takes the values of \( L \) and \( H_Y \) as given, then the aggregate demand for producer durables can be derived from the maximisation problem defined by:

\[
\max_{\gamma} \int [H_Y^\gamma L^\beta x(i)^{1-\alpha-\beta} - p(i)x(i)]di.\quad (52)
\]

Differentiating yields the inverse demand function for producer durables as:
\[ p(i) = (1 - \alpha - \beta) H^\alpha L^\beta x(i)^{-\alpha - \beta}. \] (53)

The inverse demand curve is that faced by the intermediate sector firm when choosing a profit maximising price. When faced with given values of \( H, L \) and \( r \), a firm that has already incurred the fixed cost of the investment in the new design, \( P_A \), will choose a level of output to maximise revenue minus variable cost, so that the profit function is of the form:

\[
\pi = \max p(x)x - \eta x
\]

\[ = \max (1 - \alpha - \beta) H^\alpha L^\beta x^{1-\alpha - \beta} - \eta x. \] (54)

Marginal cost, equal to \( \eta x \), is constant and, as the firm faces a constant elasticity demand curve, the resulting price is simply a mark-up over marginal cost, giving the profit maximising price:

\[ \hat{p} = \frac{\eta}{1 - \alpha - \beta}. \] (55)

The decision to produce a new producer durable depends upon a comparison between the discounted revenue stream and the initial cost of the design, \( P_A \). Assuming that the market for designs is perfectly competitive, then it follows that the relation:

\[ \int_t^\infty \exp \left[-\int_t^\tau r(s)ds\right] \pi(\tau)d\tau = P_A(t) \] (56)

must hold in equilibrium, as \( P_A \) is constant. Differentiating (56) with respect to time gives:

\[ \pi(t) - r(t) \int_t^\infty \exp \left[-\int_t^\tau r(s)ds\right] \pi(\tau)d\tau = 0. \] (57)

Substituting the expression for \( P_A \) from (56) into (57) gives the more intuitive result that:
\[ \pi(t) = r(t)P_A. \] (58)

Hence, at every point in time, the excess of revenue over variable cost is equal to the interest cost of the initial investment in the design.

Given the symmetry of the intermediate goods sector, all producer durables will be supplied at the same level, \( x' \), in order to maximise profits. This implies that the capital stock can be expressed in the form:

\[ K = \eta A x^*. \] (59)

and, hence, output in the final goods sector can be rewritten in the form:

\[ Y(H_A, L, x) = H_A^a L^b A \left( \frac{K}{\eta A} \right)^{1-\alpha-\beta} \]

\[ = (H_A)^a (LA)^b (K)^{1-\alpha-\beta} \eta^{\alpha+\beta-1}. \] (60)

As in the neoclassical model, output in the final goods sector exhibits diminishing returns to capital. However, in the case of this model, non-convexities arise because the non-rival good, A, is a productive input. In Romer's (1990, p. 889) view, there is:

"little doubt that much of the value to society of any given innovation or discovery is not captured by the inventor ... yet it is still the case that private profit-maximising agents make investments in the creation of new knowledge and that they earn a return on these investments by charging a price for the resulting goods that is greater than the marginal cost of the producing the goods."

It now remains to present the derivation of the model's balanced growth path, in which the variables \( A, K \) and \( Y \) all grow at exponential rates, and remark upon the empirical relevance of these results. The price of a new design, \( P_A \), must equal the present discounted stream of profits, as it is assumed that the market for designs is perfectly competitive. This implies that:
Furthermore, the income that human capital receives from the research sector, \( w_H \), will be equal to that paid in the production of final goods when the model is in equilibrium, so that:

\[
w_H = P_A \delta A = \alpha H_y^{\alpha-1} L^\beta Ax^{(1-\alpha-\beta)}. \tag{62}
\]

From (61) and (62), the quantity of human capital devoted to the research sector can be solved as:

\[
H_y = \frac{1}{\delta} \frac{\alpha}{(1-\alpha-\beta)(\alpha+\beta)} r. \tag{63}
\]

Since a fixed stock of human capital has been assumed, the implied growth rate for \( A \) is equal to \( \delta H_A \). From the solution of the monopoly pricing problem facing firms in the intermediate goods sector, it can be observed that \( x^* \) will be constant if the interest rate, \( r \), is also constant. An examination of the form of the production function for the final goods sector shows that output will grow at the same rate as the stock of ideas if \( L, H_y \) and \( x^* \) are fixed. If \( x^* \) is fixed, then the capital stock must grow at the same rate as \( A \), because total capital usage is \( Ax^* \eta \). Letting \( g \) denote the common growth rate of \( A, Y \) and \( K \), then the constraint \( H_y = H - H_A \) implies that:

\[
g = \delta H_A = \delta H - \frac{\alpha}{(1-\alpha-\beta)(\alpha+\beta)} r. \tag{64}
\]

The intuition behind (64) is that the opportunity cost of human capital invested in research is the wage that could otherwise be earned (in this case, the wage earned in the final goods sector), and the return to investing human capital in research is the revenue stream that the production of a new idea generates. Thus, if the interest rate were to increase, the present value of this income stream will be reduced and less human capital will be devoted to the research sector, so that the growth rate of the economy will
be reduced.

A similarity between this model and Lucas (1988) is that they both suggest that growth will be suboptimal, since the benefits arising from the production of new knowledge or human capital are freely available to all. Shaw (1992) suggests that this provides a role for government subsidies, either of the relevant R&D sectors or of the acquisition of human capital generally. However, an examination of the form of (51) in Romer (1990) indicates that it provides two additional conclusions. First, it suggests that the rate of growth should be positively correlated with the stock of embodied human capital, H. This conclusion finds empirical support in Barro (1991) and Levine and Renelt (1992), although it was made clear in the previous section that this observation cannot be used to distinguish between exogenous and endogenous models of growth. A further implication of a significant role played by human capital is that it suggests that there are advantages to be gained from greater involvement in international trade and economic integration. Second, Romer (1990) indicates a clear role for the rate of interest in partially determining growth rates. However, this effect does not appear to have been analysed in the empirical literature.

7. Inflation and Growth

Modelling the impact of inflation on economic growth gives rise to complications not previously encountered in the models previously considered; inflation is, of course, a monetary phenomenon, whereas until now it has been assumed that prices are denominated in terms of consumption goods. The introduction of both money stocks and credit instruments in De Gregorio (1993) provides a means by which the influence of inflation within an endogenous growth model may be assessed.

The traditional Phillips curve approach to the analysis of inflation and
growth suggests a positive short-run relationship between these two variables. However, the single-equation growth estimates of Grier and Tullock (1989) imply that, for non-OECD countries, inflation is negatively correlated with long-run growth. A number of mechanisms of causation have been proposed as to the role of inflation. The Tobin-Mundell hypothesis is such that increases in anticipated inflation cause portfolio adjustments between money and bonds which lower the real interest rate, thereby increasing investment and growth. In contrast, Stockman (1981) suggests that inflation reduces capital accumulation by increasing the cost of capital, which leads to a reduction in the growth rate. It can also be argued that, in many developing countries, inflation is often caused by political crises which tend to reduce growth.

In the model analysed by De Gregorio (1993), increases in the inflation rate reduce investment due to the effect that the inflation rate has on the actual price of capital goods. The actual price includes both the market price of capital and the opportunity cost of holding money in order to purchase additional capital. This is similar to the mechanism suggested by Stockman (1981), as firms require money balances to purchase capital goods, so that a reduction in firms’ real balances increases the cost of purchasing additional capital.

It is assumed that the economy is closed, and comprises three sectors, namely households, firms and government. Capital is the only factor of production, which exhibits constant returns to scale, and is assumed not to depreciate. Two points can be made regarding this assumption about the production function: (i) it is identical to that made in Rebelo (1991), but contrasts with the neoclassical assumption of diminishing marginal returns to capital; (ii) the assumption of constant returns to scale generates endogenous growth in the model, thereby rendering superfluous the requirement of the neoclassical model to have an exogenously evolving productive variable to ensure continued growth. Hence, De Gregorio (1993)
does not require an increasing labour force or technological progress to produce unabated growth.

In the household sector, consumers maximise the present discounted value of consumption, given by:

$$\max \int_{0}^{\infty} \frac{c_{t}^{1-\sigma}}{1-\sigma} e^{-\rho t} dt$$  \hspace{1cm} (65)

where \( c_{t} \) denotes real consumption in time period \( t \), and \( \rho \) is the constant rate of time preference. The form of the utility function is the same as those considered in the previous sub-sections and has been chosen so that marginal utility has a constant elasticity, equal to \( -\sigma \). Although not explicitly stated in the paper, it is conventional to assume that both \( \rho \) and \( \sigma \) are greater than zero. Households are also subject to the flow budget constraint, given by:

$$\dot{M}_{t} + P \dot{b}_{t} + C_{t}[1 + h(m/c_{t})] = (1-\tau)(r_{t}P_{t}b_{t} + D_{t}) - E_{t}$$  \hspace{1cm} (66)

where upper and lower case letters denote nominal and real variables, respectively. The variable \( M \) signifies money balances, \( C \) is nominal consumption, \( b \) is the value of indexed bonds yielding a return denoted by \( r \), \( D \) is the value of dividends received, \( \tau \) is the proportional income tax rate, and \( E \) is a lump sum tax which, by assumption, is used to ensure that the tax base is equal to total income. In any given period, therefore, the net income received by households is used either to increase money balances or bond holdings, or to purchase consumption goods. It is assumed that holding money reduces the transaction costs incurred in the purchase of consumption goods, so that the function \( h \) is chosen to be decreasing and convex.

Real financial wealth is defined as \( v = b + m \), so that (66) can be rewritten as:
\[ \dot{v} = (1-\tau)(rv + d) - c[1 + h(m/c)] - Im - e \quad (67) \]

where \( I = r(1 - \tau) + \pi, \pi \) signifies the inflation rate, and time subscripts have been omitted. The necessary conditions for maximisation are given by:

\[ -h'(m^h/c) = I \quad (68) \]

and

\[ \frac{\dot{c}}{c} = \frac{1}{\sigma}[r(1 - \tau) - \rho] \quad (69) \]

where the superscript \( h \) relates to households. These two conditions can be interpreted as the households’ money demand function and growth rate of consumption, respectively. The expression (69) is familiar from previous models: \( r(1 - \tau) \) is the private return from capital, which must be greater than the intertemporal rate of substitution for there to be a positive growth rate. This is intuitively appealing, as investment will only take place if the value of foregone consumption is greater than the rate at which it is discounted over time.

Firms produce a single consumption good, which can be transformed without cost to capital with constant returns to scale technology, so that:

\[ y_i = ak_i \quad (70) \]

where \( a \) is the constant marginal productivity of capital. It is this assumption of constant returns to capital that implies that long-run growth is driven from within the model, that is, it does not require an exogenously evolving technological improvement to generate long-run growth. De Gregorio (1993) notes that capital, \( k \), refers to both its human and physical components; this implicitly assumes, in contrast to Lucas (1988) and Romer (1990), that there are no externalities involved in the accumulation of human capital.
In much the same way as households require money in order to purchase consumption goods, firms require money to purchase additional capital. This is modelled so that the cost of investing $i$ units of capital is equal to $i[1 + s(m/i)]$, where the function $s$ has the same properties as the function $h$, given in (66). The representative firm invests to maximise the present discounted value of cash flows, given by:

$$\max \int_0^\infty [ak - i(1 + s(m/i)) - m\pi - m\]e^{-\gamma t}dt$$  \hspace{1cm} (71)

where the last two terms in the square brackets represent the implicit tax caused by inflation, and it is assumed that firms can borrow and lend at the interest rate $\gamma$. This expression is subject to the constraint that:

$$k = i$$  \hspace{1cm} (72)

which implies that the necessary conditions for optimality are:

$$-s'(m/i) = R$$  \hspace{1cm} (73)

and

$$\frac{\dot{q}}{q} = r - \frac{a}{q}$$  \hspace{1cm} (74)

where $R$ is equal to $\gamma + \pi$, the superscript $f$ denotes the firm's variable, and $q$ is given by:

$$q = 1 + s\left(\frac{m^f}{i}\right) - \frac{m^f}{s'(m^f)}.$$  \hspace{1cm} (75)

These two expressions of the first-order conditions for the firm have a similar interpretation to those for households; (73) is the firm’s money demand function, and (74) is the arbitrage condition, where $q$ is the shadow price of the capital already installed. It can be shown that $q$ is equal to the present discounted value of the marginal product of capital, which will exceed one due to the existence of transaction costs.
Assuming constant values for both \( r \) and \( \pi \), (73) implies that there will be a unique equilibrium value of \( m^f/i \). Substituting this value into (75) indicates that \( q \) is constant when \( r \) and \( \pi \) are constant. Therefore, assuming a constant inflation rate, the real interest rate will be constant, and is determined by \( r = a/q \).

In order to close the model, de Gregorio assumes that firms finance investment exclusively by retained earnings, which implies that dividends are equal to cash flows, net of the implicit inflation tax. Under this assumption, households do not save and, consequently, \( b \) is equal to zero; consumption can be increased only through increasing the flow of dividends. It is further assumed that the variable \( e \) in (67) is such that the tax base is always equal to \( y \). Therefore, (68) implies that households' real balances grow at the same rate as consumption, and (73) implies that firms' real balances grow at the same rate as investment. Furthermore, (70) implies that output and capital grow at the same rate. From the households' budget constraint, with the assumption that \( b = 0 \), and using the expression for dividends and the lump sum tax, the following expression is obtained:

\[
y = c[1 + h(m^h/c)] + k[1 + s(m^f/i)] + g
\]

(76)

where

\[
g = \tau y + \dot{m}^f + \pi m^f + \dot{m}^k + \pi m^h
\]

(77)

in which \( g \) is the total tax burden. Hence, from (76), output is consumed, invested, spent in transactions, or paid to the government. Under the assumption that government spending is a constant fraction of output, it follows that consumption must grow at the same rate as output, so that the steady state rate of growth of the economy is given by (69). Hence, under the given assumptions, an exogenous increase in inflation leads to a decrease in the growth rate of output. When inflation increases, firms will be induced to reduce real balances, thereby increasing transaction costs. This increase in transaction costs raises the shadow cost of installed capital,
leading to a reduction in investment and growth.

Hence, De Gregorio (1993) shows that, within an endogenous specification of the growth process, increases in inflation lead to decreases in the growth rate. This view, in its generalities, is supported by Fischer (1991, 1993), which suggests that a stable macroeconomic framework is conducive to economic growth. While the regression evidence used to support this view is analysed in Chapter 3, Fischer (1993, p.486) presents some suggestive anecdotal evidence:

"In Latin America, the recovery of economic growth in Chile and Mexico was preceded by the restoration of budget discipline and the reduction of inflation. By contrast, the ongoing growth crisis in Brazil coincides with high inflation punctuated by stabilization attempts and continued macroeconomic instability. The fast growing countries of East Asia have generally maintained single- or low double-digit inflation, have for the most part bavoided balance of payments crises, and when they have had them - as for instance in Korea in 1980 - moved swiftly to deal with them."

8. Financial Systems and Economic Growth

The notion that financial systems can affect the pace of economic growth was suggested in Schumpeter (1911), which emphasised the role financial intermediaries play in "mobilizing savings, evaluating projects, managing risk, monitoring managers, and facilitating transactions" (King and Levine (1993a, p.717)). In contrast, Lucas (1988) and Stern (1989) argue that the relationship between financial and economic development has been over-stressed. This view echoes that of Robinson (1952), which considers finance to be the 'handmaiden of industry', responding passively to factors which actually produce differences in growth. While the importance of financial development is a question that can only be resolved by empirical evidence, it is useful to review some of the more informal arguments for its role in facilitating growth before progressing to a formal model.
Goldsmith (1969) argues that financial institutions can promote growth by increasing the aggregate volume of investment, or by increasing the returns to investment. For these factors to influence growth in the long-run, it is clear that capital cannot exhibit diminishing returns. This was demonstrated in the analysis of the neoclassical model, where it was shown that changes in savings rates or the level of investment could only affect the level of output, not its growth rate. Hence, it can be argued that if empirical evidence suggests that differences in financial development appear to be significantly correlated with cross-country growth rates, then this supports the endogenous conception of growth. However, evidence such as this can hardly be regarded as decisive, as Barro and Sala-i-Martin (1992) and Sala-i-Martin (1994) have concluded that the rate of convergence to steady state growth paths is very slow. Thus, again, it seems impossible to distinguish empirically between the inferences of exogenous and endogenous models of growth.

In order to examine the implications of financial development in an endogenous framework, a very basic model such as Pagano (1993) can be analysed. Consider a model of a closed economy, in which aggregate output, $Y$, is a linear function of the aggregate capital stock in any given period, $t$, such that:

$$Y_t = AK_t.$$  

(78)

Note that it is this assumption of constant returns to capital that provides endogenous growth in the model; as there are no diminishing returns to accumulated factors, the return on capital investment never falls. It is assumed that the population is constant, and that a single good is produced, which can be consumed or costlessly invested. If the capital stock depreciates at a rate of $\delta$ per period, then gross investment, $I$, is given by:

$$I_t = K_{t+1} - (1-\delta)K_t.$$  

(79)

As it is assumed that this economy is closed, gross savings, $S$, must equal
gross investment. This implies that:

\[ \phi S_t = I_t \]  \hspace{1cm} (80)

where a proportion \((1-\phi)\) of savings is lost in the process of financial intermediation. These funds are taken by banks as the spread between lending and borrowing rates, or as explicit fees by other financial intermediaries, and it is assumed that these funds are spent entirely on consumption. From (78), the steady state growth rate of output is equal to the steady state growth rate of capital, and by substituting (79) and (80), the steady state growth rate, \(g\), can be described as:

\[ g = A \frac{I}{Y} - \delta = A\phi s - \delta \]  \hspace{1cm} (81)

where \(s\) is the gross savings rate, \(S/Y\). Pagano (1993) suggests that there are three ways in which financial development can affect economic growth; namely by reducing the proportion of savings lost in financial intermediation, by increasing the marginal productivity of capital, or by changing the private savings rate.

First, the proportion of savings lost in financial intermediation can be decreased through competition between intermediaries or by a reduction in restrictive taxation or regulation of these institutions. Second, Pagano (1993, p.615) suggests that there are two ways in which financial intermediaries can increase the marginal productivity of capital: by "collecting information to evaluate alternative investment projects", and by "inducing individuals to invest in riskier but more productive technologies by providing risk sharing." This informational role of financial intermediaries is supported by King and Levine (1993b, p.515), whereby "financial systems influence decisions to invest through two mechanisms: they evaluate prospective entrepreneurs and they fund the most promising ones." Finally, intermediaries can affect economic growth by changing the savings rate. However, the sign of the relationship is ambiguous as financial development
may also reduce savings; as capital markets develop, households tend to be better insured against shocks, better diversified against rate-of-return risk, and credit becomes more widely and cheaply available.

While the model presented is rather simplistic, it does summarise some of the key notions underlying the effect of financial services on growth. More rigorously, King and Levine (1993b, p.515) develop a model which emphasises the role financial institutions play "in evaluating, managing, and funding the entrepreneurial activity that leads to productivity growth." In this conception, financial development can lead to productivity improvements, and hence increases in the growth rate, in four ways (p. 515):

"First, financial systems evaluate prospective entrepreneurs and choose the most promising projects. Second, financial systems mobilize resources to finance promising projects. Third, financial systems allow investors to diversify the risk associated with with uncertain innovative activities. Fourth, financial systems reveal the potential rewards to engaging in innovation, relative to continuing to make existing products with existing techniques."

In contrast to Pagano (1993), the model in King and Levine (1993b) does not suggest that financial institutions influence growth by primarily increasing the rate of physical capital accumulation. Instead, it is suggested that productivity growth is the main result of financial development.

9. Conclusions

While this chapter does not exhaust the variety of ways in which growth has been endogenised (see, for example, Stokey (1988), Aghion and Howitt (1992), and Kremer (1993)), it provides an overview of some aspects of the literature. Importantly, it emphasises that it is the assumption of constant or increasing returns to capital in endogenous growth models that implies that policy variables can have long-term effects on the growth rate of the economy. Equally importantly, it stresses the role played by the
production of knowledge, in its human capital or R&D form, in determining growth.

However, the importance of these contributions has been criticised in Pack (1994, p.69), which suggests that while the "major contribution of endogenous growth theory has been to reinvigorate the investigation of the determinants of long-term growth ... in this task, endogenous growth theory has led to little tested empirical knowledge." This skepticism is partially supported by Solow (1994, p.51), which criticises the branch of endogenous growth theory that assumes constant returns to capital:

"This branch of the new growth theory seems unpromising to me on straight theoretical grounds. If it found strong support in empirical material one would have to reconsider and perhaps try to find some convincing reason why Nature has no choice but to present us with constant returns to capital."

However, Solow (1994) does suggest that the real value of endogenous growth theory will emerge from the attempt to model technological progress as an integral part of the theory of economic growth.

Despite these criticisms, the way in which endogenous growth theory has focused attention on the determinants of growth has been valuable. This chapter, though, has argued that these models have been structured in such a way so as to make it impossible for empirical evidence to distinguish between the neoclassical and endogenous conceptions of growth. This view, however, has been criticised in Romer (1994, p.20):

"Economists often complain that we do not have enough data to differentiate between available theories, but what constitutes relevant data is itself endogenous. If we set our standards for what constitutes relevant evidence too high and pose our tests too narrowly, we will end up with too little data. We can thereby enshrine the economic orthodoxy and make it invulnerable to challenge."
As to what constitutes relevant data, Romer (1994) notes that he finds Lucas’s (1988) observation, that people with human capital migrate from places where it is scarce to places where it is abundant, as powerful a piece of evidence as all the cross-country regressions combined. The following chapter examines the empirical evidence that is available in these cross-country regressions.
CHAPTER 3 ECONOMIC GROWTH: A SURVEY OF THE CROSS-COUNTRY EVIDENCE

1. Introduction

The previous chapter provided an introduction to exogenous and endogenous models of economic growth, concentrating on two issues. First, it described the differences between exogenous and endogenous concepts of economic growth. Second, it specifically highlighted some of the suggested mechanisms of causation through which various macroeconomic aggregates can affect the growth rate of output in endogenous models of economic growth. This chapter surveys the empirical literature, focusing on four different, but interrelated, questions. Section 3 considers the evidence for and against convergence. This question is considered to be important in deciding whether the neoclassical approach is an appropriate model for economic growth, since the neoclassical assumption of diminishing returns to capital implies that countries with relatively lower amounts of capital will grow faster. Section 4 looks at how human capital should be incorporated into an empirical investigation. Papers such as Lucas (1988) and Mankiw et al. (1992) emphasise the importance of human capital, yet it is unclear how it can best be measured. Section 5 examines the effect of investment in physical capital on growth, and Section 6 analyses the effect of government policy on economic growth.

The vast number of papers providing empirical evidence about the determinants of growth make it difficult to derive any conclusions amid the conflicting results. However, this confusion is due to two faults common to the papers surveyed. The first is the general absence of adequate diagnostic testing of models, particularly in regard to structural change and model fragility. Section 2 expands on this issue, suggesting that it is difficult to place much confidence in estimates from models whose statistical properties
are unreported. The second problem is one of data quality and quantity, rather than of estimation. It is argued that, despite the value of data sets such as those of Summers and Heston (1988, 1991), the data available simply do not contain enough information to distinguish between hypotheses involving highly correlated variables. This issue is particularly relevant to those estimates of the effects of government policy on economic growth, as many policy variables are highly correlated with each other. This notion finds support in Sala-i-Martin (1994, p.742):

"For example, countries with high inflation rates tend to have very distorted trade regimes and repressed financial sectors. They are also countries that tend to be politically and socially unstable. None of the variables is a perfect measure of the phenomenon that matters: a government in disarray affects the nation's growth performance adversely."

Furthermore, it is suggested that, in the reliance on postwar data generally exhibited in the literature, much of the interesting information contained in longer time series data is lost. This issue is taken up in Chapter 4, which examines the long-run time series properties of the data in order to distinguish between the neoclassical and endogenous specifications of growth.

2. Cross-country Growth Models: Econometric Problems

This survey presents a thematic summary of many of the results reported in the literature, from which it can be observed that the lack of adequate testing of published models leaves the reader unsure as to how much confidence can be placed in the results. However, this section expands upon the issue, suggesting that an absence of diagnostic testing is not the only econometric problem.

A more fundamental criticism of cross-country estimation has been made in Easterly et al. (1993), which suggests that the focus on country
characteristics is misguided. It is argued that observed growth rates are highly unstable over time, whereas country characteristics are highly persistent: 1 it is suggested that shocks, "especially terms of trade shocks, statistically explain as much of the variance in growth rates over 10-year periods as do country policies" (Easterly et al. (1993, p.481)). They note that, despite exceptions such as the Four Asian Tigers, countries that have high growth over one decade are generally disappointments in the next. Substantial evidence is presented to support this proposition. First, while for each of the last two decades the standard deviation of growth rates has been over 2.5 percent, the correlation of real GDP per capita between 1960 and 1988 was 0.92. Table 3.1 presents the correlations of the least squares growth rates 2 of GDP per worker between the 1960s, 1970s and 1980s, from which it can be inferred that persistence is low for several subsamples of countries. The only exception is the high correlation between the 1960s and 1970s in the OECD countries.

These figures indicate that economic growth rates are highly unstable over time. To compare the persistence of growth rates with country characteristics, Easterly et al. (1993) present a table showing the cross-decade correlation between 12 variables, such as school enrolment rates, initial income and inflation. The magnitude of these correlation coefficients is between 0.4 and 0.95, with most being over 0.7. Furthermore, characteristics such as culture and geography will be even more persistent. Hence, it appears that these country characteristics are far more persistent across time than are economic growth rates, which leads Easterly et al. (1993) to hypothesise that perhaps shocks, such as changes in the terms of

1 They note that the correlations across decades of country growth rates of per capita GDP are between 0.1 and 0.3, while most country characteristics have correlations across decades between 0.6 and 0.9. The data source is Summers and Heston (1991).

2 Easterly et al. (1993) use least squares growth rates to reduce the sensitivity to end points, and note that conventional compound growth rates are even less persistent.
trade, are important determinants of growth over 10-year periods. They present evidence to suggest that shocks such as changes in the terms of trade, and changes in war casualties, have low persistence over time. The average change in a given country’s terms of trade, included as an explanatory variable in a regression model similar to that of Barro (1991), is estimated to be positive and significant. However, as no diagnostic tests are provided, it is unclear whether any weight should be attached to this result.

Table 3.1 Simple and rank correlations of growth rates across periods

<table>
<thead>
<tr>
<th>Sample</th>
<th>Sample size</th>
<th>Correlation coefficients for 60s and 70s</th>
<th>Correlation coefficients for 70s and 80s</th>
</tr>
</thead>
<tbody>
<tr>
<td>All countries</td>
<td>100</td>
<td>0.212</td>
<td>0.313</td>
</tr>
<tr>
<td>All non-oil</td>
<td>89</td>
<td>0.153</td>
<td>0.301</td>
</tr>
<tr>
<td>OECD</td>
<td>22</td>
<td>0.729</td>
<td>0.069</td>
</tr>
<tr>
<td>Developing countries, non-oil</td>
<td>67</td>
<td>0.099</td>
<td>0.332</td>
</tr>
</tbody>
</table>

Source: Easterly et al. (1993)

The mechanism that Easterly et al. (1993) suggest to be responsible for the transmission of these changes in the terms of trade is that of factor movements. In the example given in Easterly et al. (1993, p.471-2):

"labor or capital might flow within the country to the sector receiving a favourable shock, capital might flow in from abroad to the export sector, or domestic savings might

3 Easterly et al. (1993) measure the change in the terms of trade by the growth in dollar export prices multiplied by the initial share of exports in GDP, minus the growth in import prices multiplied by the initial share of imports in GDP.
respond to improved export opportunities. In order to generate large growth effects through factor movements, however, factors and export demand must be elastic, and terms of trade shocks must be at least somewhat persistent."

However, while this evidence appears to suggest that changes in the terms of trade are possibly important in explaining variations in economic growth, there is no reason to suggest that country characteristics are not also important.

To emphasise the effect on estimation of substantial random shocks, Easterly et al. (1993) present a stylised growth model in which the effects of random shocks are propagated through time. Within this specification, the long-run growth rate of a given country, \( g_u \), is equal to the world average growth rate, \( g \), plus a country-specific component, \( \varepsilon_i \), plus a country-specific, period-specific shock, \( \varepsilon_{it} \), so that:

\[
g_u = g + \varepsilon_i + \varepsilon_{it}, \quad \text{var}(\varepsilon_i) = \sigma_i^2, \quad \text{var}(\varepsilon_{it}) = \sigma_{it}^2.
\]  

If it is assumed that \( \varepsilon_i \) and \( \varepsilon_{it} \) are independent normal variables, and \( \varepsilon_{it} \) is uncorrelated over time, then the persistence coefficient, \( \rho \), is given by:

\[
\rho = \frac{\text{cov}(g_{it}, g_{i,t-1})}{\sqrt{\text{var}(g_{i,t}) \text{var}(g_{i,t-1})}} = \frac{\sigma_i^2}{\sigma_i^2 + \sigma_{it}^2}
\]  

so that the best forecast of a country's growth rate is a weighted combination of its past growth rate and the average growth rate of all other countries. Even though this model assumes country-effects are fixed, low persistence implies that the expected R² of any growth regression will be about 0.6. This can be shown by examining the expected R² from regressing growth over \( n \) periods on accurately measured country-specific policies, so that:

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\[ E[R^2(n)] = E[1 - \frac{(y- \beta x)^2}{(y- \bar{y})^2}] = 1 - \frac{n \sigma_u^2}{n^2 \sigma_i^2 + n \sigma_u^2} \]  

which can also be written as:

\[ E[R^2(n)] = \frac{\sigma_i^2}{\sigma_i^2 + (\sigma_j^2/n)} \]  

Hence, from the definition of the persistence coefficient, \( \rho \), the expected value of \( R^2 \) can be described as:

\[ E[R^2(n)] = \frac{\rho n}{\rho n + 1 - \rho} \]  

If it is assumed that \( \rho \) is equal to \( \frac{1}{6} \), and a period is 10 years then, over the 30-year time period used in much of the empirical literature, the expected value of \( R^2 \) is 0.6. It is worth noting that Levine and Renelt (1992, p.947) report \( R^2 \) values ranging from 0.46 to 0.62 over the period 1960 to 1989.

This formulation suggests that the variation explained by any regression is not likely to surpass 0.6, even if a model of economic growth can be completely specified and the variables accurately measured.\(^4\) This should be borne in mind when analysing the \( R^2 \) values presented in the literature.

2.1 Problems in Empirical Estimation of Growth Relationships

While this section expands upon the econometric problems that are found in many of the papers surveyed, many of which are due to inadequate testing, there are also limitations imposed by the quantity, and in some cases, the quality of the data.

\(^4\) Easterly et al. (1993) note that if there is negative serial correlation in shocks, then country-specific variables would play a greater role in explaining variations in growth rates.
instances, the quality, of data. These problems arise due to the fact that, despite being interested in the influences of long run growth, most published papers employ data sets that do not start before 1950, which presents a number of problems for interpretation. Cross-country estimation uses averages for the period in question, usually 1950 to the late 1980s. In this case, the estimated coefficients represent the partial correlations between the variable in question and the average economic growth rate over this period, which is usually measured by the rate of growth of real GDP per capita. The direction of causation cannot be inferred from this analysis, since observations relate simply to either thirty-year averages or initial values of any given variable. Furthermore, cross-country estimates can arise from fairly small data sets. The largest data set available, at present, is that in Summers and Heston (1991), containing observations for 115 countries, which are given a rough subjective quality ranking by the authors based on "the error patterns displayed in checking consistency in multiple benchmark years and in the residual patterns" (Summers and Heston (1991, p.348)). The use of this data set implies that cross-country estimation will have a maximum of 115 observations. However, if estimation is restricted to high quality data, or is estimated over sub-sets such as OECD and non-OECD countries, then this drastically reduces the degrees of freedom available. This data restriction poses problems in evaluating the various hypotheses that have been proposed in the literature; as noted in Levine and Renelt (1992), over 50 variables have been found to be statistically significant in at least one published regression. Given the high degree of correlation between many of these variables, cross-country estimates are unlikely to be able to distinguish between competing hypotheses. It has been suggested by Sala-i-Martin (1994) that this problem is of particular relevance to the issue of the effect of government policy variables on growth, since many policy variables are highly correlated.
2.2 Diagnostic Testing of Models

The absence of diagnostic testing of published regression estimates should be regarded as the most serious problem found in the papers surveyed. As noted in Beggs (1988, p.81), "[d]iagnostic testing in applied econometrics is concerned with establishing whether an estimated model is an adequate description of an economic phenomenon." This notion of adequacy is important: diagnostic tests are simply one source of information with which an estimated model may be compared. McAleer et al. (1985, p306) emphasise the role of diagnostics as check-lists: "[o]nly if a model passes all items on the list should it be seriously considered as augmenting our knowledge", which highlights the essentially negative role of diagnostic testing. The fact that a given model is not rejected by a battery of diagnostic tests does not imply that it is 'correct'. However, if it is rejected by one or more of the diagnostic tests applied, then this does imply that the specification is inadequate. Beggs (1988, p.82) states that:

"The new rubric is this: subject the estimated model to a large number of diagnostic statistical tests (including the common sense test) at conventional levels of statistical significance, and if it passes all these tests it is an adequate model."

While the role of diagnostic testing is quite clear within this methodology, what is not clear is the specific diagnostic tests to be used. A comparison of particular tests will not be entered into here; this is a matter for theoretical econometrics, and is beyond the scope of this thesis. However, there are a number of problems that should be examined in any model (see McAleer (1992)), namely:

(i) correct functional form
(ii) no heteroscedasticity
(iii) no serial correlation

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(iv) explanatory variables are exogenous
(v) normality of the errors
(vi) constant structure
(vii) stationarity
(viii) adequacy in the presence of alternative non-nested models
(ix) robustness.

There are other questions that also need to be asked when subjecting a model to a battery of diagnostic tests, such as the number of tests that should be used, or the power of the tests. These points, however, will not be considered further in this thesis. Suffice it to say that most papers surveyed do not include the results of any diagnostic tests, which makes it difficult to accept the adequacy of any of the published regressions. A notable exception to this is Castles and Dowrick (1990), which examines the robustness of the preferred regression estimates with respect to problems of sample selection, heteroscedasticity, endogeneity and functional form. It is suggested in Levine and Renelt (1992), however, that many of the contradictory inferences reported in the literature, especially those regarding government policy variables, are due to either omitted variable bias or structural instability.

The problems caused by omitted variables can be demonstrated quite simply. Suppose that the model being estimated is given by:

\[ y = X\beta + u \]  \hspace{1cm} (6)

where \( y \) and \( u \) are \( n \times 1 \) vectors, \( \beta \) is an \( m \times 1 \) vector and \( X \) is an \( n \times m \) matrix. Suppose, however, that the "true" model is given by:

\[ y = X\beta + Wy + \mu \]  \hspace{1cm} (7)

where \( y \) is a \( k \times 1 \) vector and \( W \) is a \( n \times k \) matrix. The OLS estimate of \( \beta \) in (6) is given by:
\[ \hat{\beta} = (X'X)^{-1}X'y. \] (8)

However, since \( y \) is given by (7), combining (7) and (8) yields:

\[ \hat{\beta} = \beta + (X'X)^{-1}X'W\gamma + (X'X)^{-1}X'\mu \] (9)

so that:

\[ E(\hat{\beta}) = \beta + (X'X)^{-1}X'W\gamma. \] (10)

Hence, if (6) is estimated when (7) is the true model, the OLS estimator of \( \beta \) will be biased, unless one of two conditions holds, namely:

(i) \( \gamma \) is equal to 0; or

(ii) \( X \) and \( W \) are uncorrelated.

If (i) holds, then (7) is equivalent to (6), and the estimated model has no omitted variables. In practice, (ii) is unlikely to hold, as this condition requires that all the omitted variables be uncorrelated with all the included explanatory variables.

As the papers surveyed in this chapter involve the estimation of cross-sectional models, it is important to determine whether this is an appropriate approach. Quah (1993) suggests that it is not sensible to collapse decades of growth into a single summary statistic if permanent movements in income are not well-described by a smooth time trend. The methodology of cross-sectional analysis, in its simplified form, involves regressing average growth rates on a range of static conditioning variables. Quah (1993, p.426) states that "[i]mplicit in this empirical work, however, is a view that every country has a steady-state growth path, well-approximated by a time trend." The evidence presented involves OLS estimation of the coefficient of a linear time trend, regressed on the logarithm of per capita income for 118 countries over the period 1962 to 1985. As there appears to be a statistically significant break in this estimate after 1973/74 in virtually all cases, it is suggested that "assuming that each country has a stable growth path and then studying their cross-country
variation produces results that are difficult to interpret" (Quah (1993, p.428-9)).

The conclusion that a structural break in the time series behaviour of growth occurred due to the oil price shocks around 1973 is supported by Greasley and Oxley (1994a). In an analysis of the time series properties of the logarithm of U.S. industrial output, it is suggested that major trend discontinuities occurred at 1901 and 1973, coinciding with the closing of the frontier5 and the oil price shocks, respectively. Although this evidence relates solely to the U.S., it does emphasise the importance of testing for structural breaks over the period of estimation.

Some of the papers surveyed do, however, take the possibility of structural breaks into account. Dowrick and Nguyen (1989) test for temporal stability by splitting their full sample into three sub-periods: 1950-1960, 1960-1973 and 1973-1985. The first of these periods, it is suggested, relates to postwar reconstruction, the second to the "golden era" of economic growth, and the third to a period of productivity slowdown and stagflation. The sample includes all OECD countries except Japan6, and estimation is by Zellner's Seemingly Unrelated Regression method. It is found that the hypothesis that all slope coefficients are equal across the three sub-periods cannot be rejected by the data, suggesting that there are no structural breaks in this model.

Grier and Tullock (1989) test for temporal stability in OECD and

5 Greasley and Oxley (1994b, p.7) argue that "[t]he closing of the frontier imposed a physical constraint on resource intensive industrial development." Furthermore, Turner (1893) suggests that the disappearance of the frontier had a wide social and political significance.

6 This restricts the sample to 23 countries. See section 2 for the reasons presented by Dowrick and Nguyen (1989) for excluding Japan from the data set.
non-OECD countries separately. The stability of the OECD estimates is tested by splitting the sample in half, 1951-1965 and 1966-1980, and comparing the fit of this unrestricted model with that imposing the constraint that the slope coefficients are equal over the two sub-periods. It is found that the null hypothesis of equal slope coefficients cannot be rejected at the 5 percent level of significance. The stability of the estimates for non-OECD countries is tested by first estimating separate equations for Africa, the Americas, and Asia. Since the null hypothesis that the slope coefficients are constant across continents is rejected, the data set for each continent is divided in the same way as for the OECD data set, and its temporal stability tested in the same way. It is found that the null hypothesis of equal coefficients cannot be rejected for any of the three continents. Hence, the analysis by Grier and Tullock (1989) suggests that there is no structural change over the postwar period. There is, however, the question as to whether this is an appropriate way in which to divide the data set. While splitting a data set in half to test for temporal stability may be justified when there are no a priori beliefs as to where structural change has occurred, in this case a more thoughtful approach could have been taken, as in Dowrick and Nguyen (1989).

Since many of the empirical estimates using cross-sectional data involve over 100 country observations, it is also pertinent to test whether the estimated growth relationship is stable across various groupings. The most obvious question is whether the determinants of growth are the same for industrialised and less developed nations. This differential is generally tested by separating the data set into OECD and non-OECD countries, and testing whether there is a structural difference between the estimated

7 The data set used in Grier and Tullock (1989) comes from Summers and Heston (1984), and contains 24 OECD countries and 89 non-OECD countries over the period 1951 to 1980. Estimation is by OLS, based on pooled regressions on five-year averaged data, giving a total of 144 observations for OECD countries, and 356 observations for non-OECD countries.
relationships. This approach is taken in Grier and Tullock (1989). It was found that an F-test rejects the pooling of OECD and non-OECD data at the 1 percent level of significance. Thereafter the authors estimate separate relationships for the two data sets.

Dowrick (1992) estimates his model using a pooled data set, taking 5-year averages of variables for 111 countries, over the period 1955-59 to 1985-88. The test for cross-sectional stability is based on a separation of the data into three sub-groups, based on per capita GDP over 1970-74, giving a "poor" sub-group of 32 countries, a "middle" sub-group of 45 countries, and a "rich" sub-group of 34 countries. In all the models estimated, the Chow test for structural stability rejects the null hypothesis of equal coefficients; this evidence, as well as that in Grier and Tullock (1989), suggests that the determinants of growth are different between rich and poor countries.

3. The Convergence Hypothesis

As noted previously, the question as to whether poor countries tend to grow faster than rich ones is an important litmus test of the neoclassical model. However, it is possible to distinguish between two different concepts of convergence. The first results from the transitional dynamics of the neoclassical model, which suggests that "if economies are similar in respect to preferences and technology, then poor countries grow faster than rich ones" (Barro and Sala-i-Martin (1992, p.224)). The second idea behind the convergence argument is based upon the "catch-up" hypothesis. This argument suggests that countries with low initial income and productivity

---

8 The data set is taken from Summers and Heston (1991).

9 This type of convergence has been denoted β-convergence in Barro and Sala-i-Martin (1992), to distinguish it from σ-convergence, which can be defined as the reduction in cross-sectional dispersion over time.
levels will grow more rapidly as they are able to copy technology from the "leader" country without having to bear the costs of research and development. Arguing along these lines, Abramovitz (1986) suggests that, in the postwar period, the countries of the industrialised West were able to bring into production a large backlog of unexploited technology imported from the US.

It becomes important to distinguish between these two ideas when it is argued that empirical evidence for convergence supports the neoclassical model. Hence, while the first mechanism of convergence is based solely on the transitional dynamics of the neoclassical model, the second is not model-specific; that is, convergence due to technological transfer is consistent with both the neoclassical and endogenous specifications of growth. This is emphasised in Durlauf (1989), which analyses the extent to which technological advances in one country are associated with technological advances in another within an endogenous framework.

While this point will be pursued at a later stage, it is useful to develop further the neoclassical basis for convergence. Although the analysis in Chapter 2 described the equilibrium growth path for the neoclassical model, the implication of convergence is due to its transitional dynamics which have not, as yet, been adequately developed.

Consider the neoclassical model described in Chapter 2, in which production can be described by:

$$ y = f(k) $$

(11)

where $y$ and $k$ are output and capital per unit of effective labour, $L_{e}^{x}$, $L$ is labour, and $x$ is the rate of exogenous, labour-augmenting technological progress. This production function is assumed to exhibit diminishing returns to capital. The growth rate of capital per unit of effective labour is given by:客观
\[ \dot{k} = f(k) - c^* - (\delta + x + n)k \]  

(12)

where \( c^* \) is consumption per unit of effective labour, \( \delta \) is the depreciation rate, and \( n \) is the growth rate of the labour force. The consumption side of this economy is represented by an infinite-horizon household that seeks to maximise utility represented by:

\[
U = \int_0^\infty u(c) e^{nt} e^{-\rho t} dt
\]

(13)

where \( c \) is consumption per unit of labour, \( \rho \) is the (positive) rate of time preference, and \( u(c) = c^{1-\theta} - 1/(1-\theta) \), where \( 0<\theta<1 \). The first-order condition for maximising \( U \) is given by:

\[
\frac{\dot{c}}{c} = \frac{1}{\theta} [f'(k) - \theta - \rho].
\]

(14)

Hence, in the steady state, the effective quantities of output, capital and consumption do not change, while the per capita quantities grow at the rate \( x \). This is the conventional steady state result for the neoclassical model. However, in order to analyse the behaviour of economies off this steady state growth path, the transitional dynamics can be approximated by a log-linearisation around the steady state. Assuming that technology is Cobb-Douglas implies that:

\[
\log[y(t)] = \log[y(0)] e^{-\beta t} + \log(y^*) (1 - e^{-\beta t})
\]

(15)

where an asterisk indicates a steady state value and \( \beta \) determines the speed of adjustment, given by:
\[2\beta = \left[ \psi^2 + 4\left(1 - \frac{\alpha}{\theta}\right)(\rho + \delta + \theta \times x) \right] \times \left[ \frac{\rho + \delta + \theta x}{\alpha} \right]^{-\frac{1}{2}} - \psi \]  \tag{16}

where \( \psi = \rho - n - (1 - \theta)x > 0 \). This implies that the average growth rate over the period is given by:

\[
\frac{1}{T} \log\left[ \frac{y(T)}{y(0)} \right] = x + \frac{1 - e^{-\beta T}}{T} \log\left[ \frac{y^*}{y(0)} \right]. \tag{17}
\]

Hence, the higher is \( P \), the greater is the rate of convergence. Note that \( \alpha \), the share of capital in total income, influences \( \beta \). Barro and Sala-i-Martin (1992) provide an example assuming the following conventional parameter values: \( \rho=0.05, \delta=0.05, n=0.02, x=0.02, \) and \( \theta=1 \). If it is assumed that \( \alpha=0.35 \), the share of capital in total income suggested in Maddison (1987), then (16) implies that \( \beta=0.126 \); that is, the model implies that economies with identical steady state growth paths will converge at a rate of about 13 percent a year. However, if it is assumed that \( \alpha=0.80 \), a figure which Barro and Sala-i-Martin (1992) suggest may be more appropriate if the variable representing capital is interpreted to include human capital, then (16) implies that \( \beta=0.026 \) which is, as shown later in the chapter, far closer to the rates of convergence estimated in the literature.

The above analysis describes the neoclassical mechanism for convergence. However, it was noted that this notion of convergence depended upon the existence of identical steady states for all economies in the sample. On this basis, Barro and Sala-i-Martin (1992) and Mankiw et al. (1992) dispute the claim that the neoclassical model necessarily implies that poor countries will grow faster than rich ones. Instead, it is argued that the neoclassical model should properly be interpreted as implying that the growth rate of an economy is inversely related to the distance from its steady state, which gives rise to the distinction between "conditional" and "unconditional" convergence. While the notion of unconditional
convergence suggests that poor countries should always grow faster than rich ones, the idea of conditional convergence implies that only countries with similar preferences, technologies and institutional structures will tend to converge. The importance of this distinction has led to two different approaches to testing for convergence: the first uses a broad data set covering a range of seemingly disparate economies and attempts to condition the estimated equation for differences in steady states, while the second approach is to find economies which, it is argued, are approaching similar steady states.

The first approach has been dubbed the 'Barro approach' in Sala-i-Martin (1994), although similar lines of thinking were apparent prior to this in Kormendi and Meguire (1985) and Grier and Tullock (1989). Essentially, Barro (1991) estimates models, using data for about 100 countries, of the form:

$$\gamma_{t-T} = \alpha + \beta y_{t-T} + \delta X_{t-T} + \epsilon_{t}$$

(18)

where $\gamma_{t-T}$ is the average growth rate of per capita GDP of country $i$ over the period $t-T$ to $t$, $y_{t-T}$ is country $i$'s level of per capita GDP at time $t-T$, and $X_{t-T}$ is a vector of explanatory variables, which includes school enrolment rates, investment rates, measures of distortion and social unrest, and measures of government size. According to Sala-i-Martin (1994, p.741), "Barro's initial interpretation of regression [18] was that the variables $X_{i}$ were the determinants of long-run economic growth while the initial level of income was a proxy for some relative income variable that would capture the different levels of technological progress."

Using this approach, Barro (1991) estimated the coefficient of initial per capita GDP to be negative and significant, which is evidence of cross-country convergence over the period 1960 to 1985. Estimates over the sub-period 1970 to 1985 produced similar results, suggesting a speed of convergence of approximately 2 per cent per year. A similar approach is
adopted in Kormendi and Meguire (1985) and Grier and Tullock (1989). Kormendi and Meguire (1985) estimate, using a sample of 47 countries over the period 1950 to 1977, the coefficient of initial income to be negative and significant. Grier and Tullock (1989) support this result only for OECD countries. In the case of 89 non-OECD countries, the estimated coefficient of initial income is positive but insignificant at conventional levels. The notion that convergence has occurred only among the more developed countries, tending to reinforce the world's economies into rich and poor "clubs", is supported by Dowrick (1992).

Dowrick and Nguyen (1989) adopt a similar approach to test for convergence in OECD income levels over the period 1950 to 1985, regressing the trend growth rate of real GDP on the growth rate of employment, the average ratio of gross investment to GDP, and the logarithm of trend per capita GDP, relative to the U.S.. The use of this final variable to estimate convergence is significant, as it implies a different cause of the phenomenon. Instead of testing the neoclassical implication that convergence is caused by diminishing returns to capital, this measure reflects the notion that convergence is due to the effects of technological catch-up. However, the ability of this sort of cross-sectional analysis to distinguish between these two sources of convergence is minimal.

The use of a data set that includes only OECD countries is also significant, as it indicates the attempt by Dowrick and Nguyen (1989) to find a set of economies who are approaching similar steady states, rather than conditioning a disparate sample of economies for the differences mentioned above. This differs from the approach adopted in Barro (1991), but instead is similar to Barro and Sala-i-Martin (1992). The resulting estimates in Dowrick and Nguyen (1989) suggest that there is a statistically significant tendency for the growth rates of economies within the OECD to converge, at a rate of approximately 2 per cent a year in the full sample. However, it is suggested that the inclusion of Japan in the sample is
inappropriate, for two reasons. First, in the full sample, the test for heteroscedasticity is significant at 5 per cent whereas this is not the case when Japan is excluded. Second, the authors argue that Japan’s inclusion could result in _ex post_ selection bias, due to its becoming a member of the OECD as late as 1964. They suggest that it is reasonable to conclude that Japan was only invited to join the OECD on the basis that it was already growing at a relatively high rate. Although neither of these arguments fully justifies the exclusion of Japan from the sample, its post-war experience is enough to suggest that its treatment as an outlier is not entirely without basis. Note that, on the exclusion of Japan from the sample, the estimated rate of convergence falls to about 1.75 per cent.

Baumol (1986) tests for convergence over a much longer sample period, using Maddison’s (1982) 1870 to 1979 data set for 16 countries. These results have, however, been criticised in Romer (1986) and De Long (1988) on the basis of _ex post_ sample selection bias. It is argued that "by working with Maddison’s data set of nations that were industrialised _ex post_ (that is, by 1979), those nations that did not converge were excluded from the sample so convergence in Baumol’s study was all but guaranteed" (Sala-i-Martin (1994, p.740)).

The notion of conditioning is made explicit in Mankiw, et al. (1992), which develops a model with neoclassical assumptions, augmented by the inclusion of human capital as a productive factor, estimated across 98 countries over the period 1960 to 1985. Although the steady state growth path of model will not be derived here, it is based on a production function of the form:

\[
y(t) = K(t)^a H(t)^\delta (A(t) L(t))^{1-\alpha - \delta}
\]

where Y, K, L, H and A represent output, physical capital, labour, human capital and the level of technology, respectively, and t denotes time. If n and g represent the growth rates of labour and technology, respectively, \( \delta \)
represents the rate of depreciation of physical capital, and $s_k$ and $s_h$ denote the fractions of income invested in physical and human capital, respectively, then the steady state implied by this model is given by:

$$
\log \left( \frac{Y(t)}{L(t)} \right) = \log A(0) + \gamma t \left( \frac{\alpha + \beta}{1 - \alpha - \beta} \right) \log (n + g + \delta) \\
+ \frac{\alpha}{1 - \alpha - \beta} \log (s_k) + \frac{\beta}{1 - \alpha - \beta} \log (s_h). 
$$

This model, as in Barro and Sala-i-Martin (1992), suggests conditional convergence, in that a given country's income per capita is predicted to converge to that country's steady state. As such, in cross-country regressions, convergence only occurs after controlling for the determinants of that steady state.

The rate of convergence implied by this model can also be derived, as in Barro and Sala-i-Martin (1992), by a log-linear approximation around the steady state. Hence, the growth of output can be written as:

$$
\log (y(t)) - \log (y(0)) = (1 - e^{-\lambda t}) \left( \frac{\alpha}{1 - \alpha - \beta} \log (s_k) \\
+ (1 - e^{-\lambda t}) \frac{\beta}{1 - \alpha - \beta} \log (s_h) - (1 - e^{-\lambda t}) \right) \\
\times \frac{\alpha + \beta}{1 - \alpha - \beta} \log (n + g + \delta) - (1 - e^{-\lambda t}) \log (y(0)) 
$$

where $\lambda = (n + g + \delta) (1 - \alpha - 0)$, and $y$ denotes output per effective worker. This model is estimated to determine the implied rate of convergence using the log difference of GDP per working-age person between 1960 and 1985 as the dependent variable, controlling for investment rates, growth of the working age population, and human capital. In this case, human capital is measured by secondary school enrolment.
rates. The estimates over the entire 98-country sample, as well as a 75-country and 22 OECD country sub-samples, imply a convergence rate of between 1.4 and 2 percent, the highest figure being for the OECD sub-sample. Secondary school enrolment rates are estimated to be statistically significant in all samples except for OECD countries. However, with only 22 observations and much less variation in enrolment rates than the total sample, this is not startling.

Hence, Mankiw et al. (1992) find a rate of convergence of about 2 percent a year, similar to that in Barro (1991) and Barro and Sala-i-Martin (1992). Again, however, no diagnostic tests are reported, which leaves the reader unsure as to how much confidence should be placed in the reported results.

The conclusion that can be reached from this cross-country evidence is that, while large samples exhibit evidence of conditional convergence at a consistent rate of about 2 percent a year, it is important to test for structural differences in the sample, particularly differences between developed and less developed economies. This reinforces the idea that, while convergence may exist within "clubs" of nations, income levels between "clubs" may actually be diverging.

A different approach to testing for convergence is developed in Barro and Sala-i-Martin (1992). This paper uses data on 48 contiguous U.S. states, over the period 1840 to 1988. Behind this approach is, as mentioned previously, the idea that it can be assumed that all states in the U.S. are approaching the same steady-state growth path, and there is no need to condition the data for social or educational differences. As the theoretical framework of the model being estimated is neoclassical, the speed of

10 The problems involved in measuring human capital are considered in Section 4.
convergence, denoted $\beta$, is dependent on the size of the capital share coefficient.

Empirical estimation of this model uses data from 48 states of the U.S.. However, there are a number of problems with the interpretation of these results. First, no measures of price levels are available for individual states, so that nominal values for each state are deflated by a national index for consumer prices. This implies that, if relative purchasing power parity does not hold across states, the growth rates of income are mismeasured. Furthermore, if absolute purchasing power parity does not hold, then the levels of income are mismeasured. Second, no diagnostic tests are presented, leaving the reader unsure as to how much confidence can be placed in the results.

Nevertheless, the regression results are interesting. Estimated over the entire sample period, 1880 to 1988, the data on personal income suggest convergence occurred at a rate of 1.75 per cent a year. However, when the sample is split into 9 sub-periods, the joint estimate rejects the hypothesis that the coefficient for $\beta$ is the same for all sub-periods, which Barro and Sala-i-Martin (1992) suggest is partially due to aggregate disturbances having differential effects on state incomes. In order to account for this, a variable representing the proportion of income originating in agriculture is included in the model. With the addition of this variable, the joint estimate does not reject the hypothesis of equal $\beta$ coefficients, which implies that convergence has taken place at about 2.5 per cent a year.

Hence, despite the problems outlined above, Barro and Sala-i-Martin (1992) suggest that convergence in the U.S. has taken place at a rate of a little over 2 per cent a year, which is similar to the rate reported in Barro (1991). Although the finding of convergence is consistent with the neoclassical model, it should be noted that the estimated rate of convergence corresponds to a value of $\alpha$ of about 0.8., which does not
support the conventional interpretation of the neoclassical model.

This analysis has made a number of points in regard to evidence for the existence of convergence being used to support the neoclassical concept of growth. First, from an empirical perspective, there is considerable evidence of conditional convergence. Estimated rates of convergence are of the order of 2 percent a year, although it is not clear whether this convergence is universal or limited to rich and poor "clubs". Second, any cross-country evidence for convergence based on the cross-sectional regressions described above does not necessarily support the neoclassical concept of growth. This is due to the inability of simple, cross-country estimates to distinguish between mechanisms of causation of convergence, that is, whether convergence is due to the capital deepening implied by the neoclassical model or to technological catch-up, which is not model-specific.

4. Human Capital and Growth

The model in Mankiw et al. (1992) presented in the analysis of convergence suggests that human capital plays an important role in accounting for differences in economic growth. Although in Mankiw et al. (1992) differences in stocks of human capital were included to test for conditional convergence in a neoclassical model of growth, several other arguments have been suggested as to the role played by human capital. For example, Romer (1990) suggests that human capital may influence the growth rate of the economy by the rate at which it allows the development of new technologies. In this way, countries with greater initial stocks of human capital have a higher innovation rate of new capital goods, which leads to a greater rate of growth. Nelson and Phelps (1966) suggest that the ability of a given country to adopt new technology from abroad is a function of its domestic human capital stock. This explanation is a variant of the catch-up hypothesis described above in the exposition on
convergence. There is also the suggestion in Lucas (1990) that physical capital will only flow from rich to poor countries if these poor countries have sufficient human capital in order to complement this capital transfer. These models suggest different roles for human capital, namely in the capacity for innovation and increasing the rate of technical progress, and in the capacity to improvise technologies from abroad and to adapt them to local circumstances. It should be noted that this last role for human capital is inexorably linked to the catch-up hypothesis of convergence.

However, it is clear that evidence of the importance of human capital in understanding growth does not support either the neoclassical or endogenous concepts of growth. It has been shown that the effects of human capital can be incorporated into either perspective; Lucas (1988) provides an example of the effect of human capital within an endogenous framework, while Mankiw et al. (1992) build human capital into a model with neoclassical assumptions. It is not the importance of human capital that distinguishes between neoclassical and endogenous models, but whether investment in human capital exhibits decreasing, constant, or increasing returns to scale. However, estimates from cross-country regressions are unable to distinguish between these forms.

Despite these arguments, it is interesting to examine the problems involved in incorporating human capital into cross-sectional models of growth. The most obvious of these is the difficulty in finding an appropriate measure of human capital. From a theoretical perspective, models such as those in Lucas (1988), Romer (1990) and Mankiw et al. (1992), define human capital in slightly different ways. In Lucas (1988), the term "human capital" is taken to mean a given worker's general skill level, so that a worker with human capital of \( h \) units is twice as productive as one with human capital equal to \( 1/2 \) \( h \) units. Romer (1990) treats human capital as the number of years of education and training that are specific to a given worker, so that it is clear as to the units in which it is measured. Mankiw et
al. (1992) do not expand upon what is meant theoretically by their use of the term, although enrolment rates in secondary education are used in their empirical estimation. Ideally, a measure of human capital should incorporate several components; the general level of education of agents in the economy relevant to productive application, the quality of the education provided, and perhaps whether price signals are such that talented and educated individuals are attracted to productive enterprises, as suggested in Murphy et al. (1991).

As in Mankiw et al. (1992), many papers use school enrolment ratios to measure human capital stocks. Barro (1991) includes the initial school enrolment rates for both primary and secondary school in a cross-sectional model, for which the coefficients of both variables are estimated to be significantly positive. A similar inclusion of enrolment rates in Easterly and Rebelo (1993), and King and Levine (1993), supports this conclusion.

There are, however, several problems in the use of school enrolment rates to measure human capital stocks. First, enrolment ratios are flow variables, and it is the accumulation of these flows that creates future stocks. This implies that the significantly positive effects of the initial primary and secondary school enrolment rates on growth found by Barro (1991) could reflect instead a favourable situation that generates both increased investment in human capital and increased growth. Barro (1991) attempts to address this question as to the direction of causation by including the 1950 values of school enrolment rates. As neither of these two variables is statistically significant in this regression, and the 1960 values for enrolment rates remain significantly positive, it is concluded that the results cannot be attributed to the high correlation between the enrolment rate variables for 1950 and 1960. Second, Barro and Lee (1993) emphasise that these enrolment ratios do not account for human capital lost through migration, mortality, the repetition of grades or dropouts. It is noted that the latter two effects are generally high in developing countries. In the first
instance, Fredriksen (1983) estimated that for the total of developing countries in 1980, the average gross enrolment ratio at primary schools was 86 percent; when those students who were repeating grades were eliminated from the figures, this estimate was reduced to 73 percent. The problem posed by dropouts, which Barro and Lee (1993, p.367) suggest is "particularly serious for developing countries in which the government punishes parents that do not register their children at primary schools", is also not accounted for in figures for enrolment ratios. Third, enrolment ratios give no indication of the quality of education. Despite these criticisms, the fact that school enrolment rates do appear to be significant explanators of economic growth suggests that some measure of human capital must be incorporated into an estimated model.

Another measure for human capital stocks that is considered in Barro (1991) is adult literacy rates. This has the advantage that it is measuring human capital stocks. However, Barro and Lee (1993) note that the information required to construct these ratios comes from population censuses and surveys, which generally take place no more than once a decade. Benhabib and Spiegel (1992) also raise a number of problems involved with using adult literacy rates as a proxy for human capital, such as measurement differences across countries, biases introduced by the skewness of sampling towards urban areas, and the fact that developed countries typically have literacy rates which are close to unity. Indeed, when Barro (1991) augments his regression to include the adult literacy rate in the initial year of estimation, he finds that the coefficient of this variable is negative and significant, a result that he notes is difficult to interpret. However, if the school enrolment rates are excluded, the coefficient of the adult literacy rate is significant and positive. Finally, perhaps the most important objection to using literacy rates is given in Barro and Lee (1993, p.367), where it is noted that "literacy is only the first stage in the path of human capital formation." Hence, literacy rates, even if measured accurately, take no account of the other skills required for increases in
productivity, such as numeracy and technical knowledge.

Benhabib and Spiegel (1992) suggest the use of the human capital stock estimates constructed by Kyriacou (1991). These estimates are based on the data set provided by Psacharopoulos and Arriagada (1986). Kyriacou (1991) identifies 42 countries for which average years of schooling are available for the period 1974 to 1977. The relationship between average years of schooling and past enrolment ratios is estimated, and the fitted values from this regression are included as an explanatory variable in Benhabib and Spiegel's (1992) estimated growth model. This approach, however, suffers from problems due to generated regressors (GR). Essentially, this uncorrected 2-step estimation method is consistent, but produces inefficient estimates and also leads to invalid inferences, in general. Pagan (1984) shows that the estimated OLS standard errors are no greater than the true standard errors, which implies that the use of estimated human capital stocks in the growth equation will appear more significant than warranted because of the inherent bias.

The most comprehensive measure of human capital based on school enrolment rates found in the literature is in Barro and Lee (1993), which describes a data set on educational attainment of the total population aged 25 and over, for 129 countries over 5-year periods from 1960 to 1985. This data set recognises six levels of educational attainment: no schooling, entered primary, complete primary, entered lower secondary, entered higher secondary, and entered higher education. Although the method by which these data are derived is not presented here, it provides the most complete measure of human capital stocks in its measure of the average years of

\[ H_{75} = 0.0520 + 4.4390 \text{PRIM}_{60} + 2.6645 \text{SEC}_{70} + 8.0918 \text{HIGH}_{70}, \]

where \( H_{75} \) represents the average years of schooling in the labour force, \( \text{PRIM}_{60} \) is the 1960 primary school enrolment ratio, \( \text{SEC}_{70} \) is the 1970 secondary school enrolment ratio, and \( \text{HIGH}_{70} \) is the 1970 higher education enrolment ratio.
However, recent discussion has shifted attention from primary and secondary school enrolment rates. Instead, Nelson and Wright (1992) emphasises the importance of higher education in sustaining U.S. industrial leadership during the twentieth century. In this context, the "learning effects, which may be facilitated by basic education and predominated in the nineteenth century" can be distinguished from "research and development which rested on the twentieth century expansion of higher education" (Greasley and Oxley (1994a, p.14)).

Given the importance of higher education in supporting research and development, a further consideration in the measurement of human capital is whether those individuals in an economy who are most highly skilled are attracted to entering productive enterprises. Murphy et al. (1991) present both theoretical and empirical evidence to suggest that those economies with price signals such as to attract the most talented individuals into areas that are essentially involved in rent seeking, rather than entrepreneurship, will grow more slowly than if the reverse is the case. The empirical evidence comprises the basic regression in Barro (1991), augmented with two additional variables: college enrolments in law to total enrolments, and

12 The formula used by Barro and Lee (1993) to construct the measure of average years of schooling is given by:

$$DUR_p \left[ \frac{1}{2}h_p + h_{cp} \right] + (DUR_p + DUR_{sl})h_{is} + (DUR_p + DUR_{sl} + DUR_{s2})h_{cs} + (DUR_p + DUR_{sl} + DUR_{s2} + \frac{1}{2}DUR_{h})h_{ih} + (DUR_p + DUR_{sl} + DUR_{s2} + DUR_{h})h_{ch}$$

where $h$ refers to the fraction of the population for which the $j$th level of schooling is the highest attained, where $j = ip$ for incomplete primary, $cp$ for complete primary, $is$ for lower secondary, $cs$ for higher secondary, $ih$ for incomplete higher, and $ch$ for complete higher. $DUR_i$ is the duration in years of the $i$th level of schooling, such that $i = p$ for primary, $sl$ for lower secondary, $s2$ for upper secondary, and $h$ for higher.
the same ratio for engineering enrolments. Despite numerous problems in estimation, the results in Murphy et al. (1991) concur with those in Magee et al. (1989), namely that countries with higher incentives to enter areas more directed to rent seeking, such as law, grow more slowly that those economies which tend to draw their best and brightest to more productive professions. While this evidence borders on the anecdotal, it does emphasise that simply measuring enrolment ratios, or average years of schooling, is perhaps an inadequate way to differentiate between stocks of human capital over time and across countries.

However, the importance of higher education in understanding growth has been questioned in Wolff and Gittleman (1993), based on evidence from cross-country estimates. The data used in these 'Barro-type' estimates are from Summers and Heston (1988), and models are estimated across a number of different postwar periods and country groupings. In order to determine the effect of different types of human capital, 6 alternative measures are used; enrolment rates in primary, secondary and tertiary education, and educational attainment of the labour force at these three levels. Educational attainment is defined as the percentage of the active labour force who have attained a certain level of schooling.

Two models are estimated; in both, the dependent variable is the average growth rate of real GDP per capita over the sample period, while the explanatory variables are the starting values of real GDP per capita and the human capital measure. However, the second model includes average investment as an additional explanatory variable. The estimates from the first model, estimated over the periods 1950 to 1985 and 1960 to 1985, are taken by Wolff and Gittleman (1993, p.156) to imply that "primary school

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13 The 111 countries in Wolff and Gittleman's (1993) sample are separated into 4 sub-groups; industrial market economies, upper-middle income economies, lower-middle income economies and low income economies, based on the World Bank's 1986 definitions.
education appears to have a somewhat stronger effect than secondary school education (as indicated by the t-ratio and the $R^2$ statistics), and both are considerably stronger than higher education." However, the validity of these inferences can be questioned on the basis of omitted variable bias. Indeed, when the average investment rate is included as an explanatory variable, none of the educational attainment variables is significant, although primary and secondary school enrolment rates do remain so. Furthermore, no diagnostic tests are provided, and in particular, no attempt is made to examine the fragility of these estimates to model specification.

Wolff and Gittleman (1993) also estimate this model (including average investment as an explanatory variable) over the four sub-groups described in footnote 13. These estimates suggest that differences in higher education are important in explaining differences in growth rates between industrial and upper middle income economies, while differences in primary and secondary school education are important in explaining differences in lower-middle and low income economies. However, the criticisms regarding omitted variables and lack of diagnostic testing also apply to these models.

This analysis suggests that Wolff and Gittleman's (1993, p.149) claim, that there is an "apparent lack of importance of higher education in the convergence process", is unfounded. The models estimated are susceptible to numerous criticisms, and even their results point to the significance of higher education to the industrial market and upper-middle income economies.

5. Physical Investment and Growth

The role of physical investment and its influence on growth is an important issue. Papers in the growth accounting tradition, such as Solow (1957) and Denison (1967), have suggested that variations in physical investment account for little of the variation in measured growth rates.
Indeed, Solow (1957) suggests that only 12.5 per cent of the increase in gross output per man hour in the U.S. over the period 1909 to 1949 can be attributed to increased use of capital. According to Dowrick (1993, p.112), this "finding is puzzling in the face of the popular view amongst economic historians and others that it is the development of new physical means of production that impelled the first, and subsequent, industrial revolutions."

A simple examination of investment rates over the twentieth century is also instructive. Table 1.4 in Chapter 1 presents growth rates of fixed capital stocks for a number of countries, over the period 1965 to 1985. It is observed that those countries which have been economically successful over the postwar period, such as Taiwan and Republic of Korea, also have high growth rates of fixed capital stocks. While these figures are preliminary, they suggest that the role of capital investment should be investigated.

Much of the recent econometric evidence, however, suggests that differences in physical capital do significantly account for some of the variation in growth rates. In a cross-sectional model for 98 countries over the period 1960 to 1985, Barro (1991) finds that the estimate of the coefficient of the average ratio of real domestic investment (private plus public) to GDP is positive and significant. Kormendi and Meguire (1985) support this finding in a cross-sectional study of 47 countries over the period 1950 to 1977.

Levine and Renelt (1992), however, note problems involved with including the ratio of physical capital investment to GDP within growth regressions, suggesting that as the causal relationship between the economic growth rate and the investment share is ambiguous. "[T]he justification for including many variables in growth regressions is that they may explain INV [the investment ratio]. If we include INV, the only channel through which other explanatory variables can explain growth differentials is the efficiency of resource allocation" (Levine and Renelt (1992, pp.945-6)).
Despite these caveats, however, Levine and Renelt conclude that the correlation between growth rates and the average investment rate of the period is robust.\textsuperscript{14}

These results lead to two inferences. The first is that differences in the rate of physical capital accumulation appear to affect growth rates. From this, it is interesting to consider whether all types of physical capital seem to have the same effect. Indeed, De Long and Summers (1991, 1993) suggest that investment in equipment capital is more important than other forms. These arguments are analysed later in this section. The second inference regards Levine and Renelt's (1992) argument as to the direction of causation of investment on growth outlined above, and relates to the following section which examines the effect of government policy on growth. In essence, it can be argued that cross-country variations in many government policy variables influence the growth rate via their effect on the rate of investment. If this is the case, then the inclusion of these policy variables within a 'Barro-type' cross-country model, which also includes the investment rate as an explanatory variable, is unlikely to be significant. Therefore, it is necessary to examine whether the policy variables of interest not only appear to be significantly correlated with cross-country growth rates, but also significantly correlated with cross-country investment rates. This issue, however, is considered in the following section.

Before returning to the issue of the disaggregation of physical investment, it is important to emphasise that the absence of diagnostic testing of the results described in this survey detracts from their explanatory value. Indeed, it should be stressed that one of the primary reasons for many of the conflicting results reported in the literature is that published models are not subjected to adequate diagnostic testing.

\textsuperscript{14} Despite the criticisms of Levine and Renelt's (1992) approach presented later in this chapter, this conclusion is found to have much empirical support.
The possibility that not all forms of physical investment have the same effect on growth is explored in De Long and Summers (1991, 1993). It is suggested that investment should be disaggregated, as investment in equipment is of more relevance for explaining differences in rates of economic growth than are other forms of physical investment. These papers suggest that the accumulation of machinery and equipment is a major determinant of aggregate rates of productivity growth and, furthermore, argue that the private rate of return to equipment investment does not mirror its social product. Whether or not this assertion is valid, De Long and Summers (1991,1993) emphasise that the assumption that all components of investment have identical influences on economic growth is worth testing.

De Long and Summers (1991) present three reasons why equipment investment may have higher social returns than other types of investment. First, in historical accounts of economic growth, the driving force of growth has been increased mechanisation. Second, the new growth models, such as those of Romer (1990), have stressed the importance of externalities in economic growth. De Long and Summers (1991) suggest that, as manufacturing accounts for 95 percent of research and development in the U.S. and that, within manufacturing, the equipment sector accounts for more than one half of research and development spending (see Summers (1990)), it is reasonable to infer that equipment investment may lead to significant externalities. Finally, they observe that several countries have grown rapidly over the post-war period, while following a "developmental state" approach to development. This approach entails the government jump-starting a given economy by adopting the price structure of more affluent nations, thereby increasing the rate of transformation of the economy. De Long and Summers (1991) argue that this leads investment rates in equipment to rise and equipment prices to fall.

The data used in De Long and Summers (1991) are cross-sectional over the period 1960 to 1985, and come from Summers and Heston (1988,
1991), with additional benchmark estimates of price and quantity structures from the U.N. International Comparison Project (ICP), as described in Kravis et al. (1982). It is concluded that there is a significant positive correlation between the growth of real GDP per worker and the share of GDP devoted to machinery (or equipment) investment. The importance of finding appropriate deflators for equipment investment is noted, as the relative price of equipment varies greatly across countries. The data from the ICP provide disaggregated information on the relative prices of many components of GNP for a large sample of countries for individual years. However, as noted in De Long and Summers (1993, p.397), "the estimates of the share of equipment investment in GDP used were not very good, as they depended heavily on the ratio of equipment to total investment in benchmark years being good proxies for the average ratio of equipment to total investment on average over the sample." Furthermore, the sample analysed was restricted to those countries that had served as benchmarks for the ICP; notably, Singapore and Taiwan were omitted from the database.

The basic results in De Long and Summers (1991) are contained in two 'Barro-type' regressions; one using a high productivity sample of the 25 countries with levels of real GDP per worker in 1960 greater than 25 percent of the U.S., and the other using a larger 61-country sample. The dependent variable in both regressions is the rate of growth of real GDP per capita, with the other explanatory variables being the rate of growth of the labour force, the share of GDP devoted to non-equipment investment and the initial GDP per worker gap vis-à-vis the U.S.. The estimated coefficient for equipment investment in both these cases is positive and significant, whereas non-equipment investment is insignificant. However, as no diagnostics are provided, the inferences drawn are open to question.

15 The machinery investment variable comprises electrical and non-electrical machinery from the ICP data, and excludes producers' transportation equipment due to the inadequacy of data.
Further issues are considered in De Long and Summers (1991), such as whether the quantity of equipment is acting as a proxy for some other determinant of growth. To this end, De Long and Summers (1991) add variables to the basic regression described above, and examine whether the estimated coefficient of equipment investment is significantly affected. The variables included are the share of manufacturing in value added, the share of public investment, the real exchange rate, and the continent associated with a given country. However, the only additional variables that change the inferences for equipment investment are the continent dummy variables in the high productivity sample but, given the small sample of 25 observations, this is perhaps not surprising.

De Long and Summers (1993) extend the analysis with an improved database and, focusing on developing economies, reach the same conclusions as the earlier paper, namely that equipment investment has a significant positive influence on economic growth. While the results contained in De Long and Summers (1993) can also be criticised for their absence of diagnostic tests, they do suggest that the issue of the disaggregation of investment when estimating growth equations is one that must be considered.

6. Government Policy and its Influence on Growth

The final question considered in this chapter is whether cross-country differences in government policy lead to differences in growth rates. This issue is, however, somewhat broad, and so will be decomposed into two parts: first, the effect of differences in government size is examined; second, an analysis of whether measures of government policy are significantly correlated with growth rates.
6.1 Government size and growth

The issue as to whether differences in relative government size tend to correspond to differences in growth rates is contentious. Indeed, Appendix I presents a summary of results from 19 papers, which gives some indication of the range of conclusions reached, together with the variable used to measure government size, the methods of estimation and data sets used. Theoretical models such as Barro (1990) and Easterly (1993) have sought to formalise the effect of variations in government size on growth. Indeed, Barro (1990) suggests that increases in government spending can have two different effects on the growth rate of the economy; increases in public consumption expenditure unambiguously lead to a decrease in the growth rate, whereas increases in public productive expenditure are likely to have a non-linear effect on growth, depending on the initial relative size of the public sector. Easterly (1993) emphasised the distortionary effects of taxation in a model incorporating two types of capital goods, which implied that a subsidy to one type of capital that was financed by the taxation of another type of capital good would lower the growth rate of the economy. However, although these models are informative, they are unable to incorporate many of the subtleties suggested by less formal arguments.

Those that have argued that the public sector can have a positive effect on growth have suggested that governments provide growth-promoting public goods, distribute transfer payments, and impose taxes designed to harmonise the conflict between private and social interests. In addition, neo-Marxists such as Kalecki (1971) have argued that since taxes and transfers redistribute income from the rich, who tend to save a large proportion of it, to the poor, who tend to spend it, government expenditure and taxes increase the growth rate of output. On the other hand, it has been suggested that government operations are often performed inefficiently, and taxes and regulations distort price signals and incentives. Additionally,
Barro (1990, 1991) and Grossman (1988) emphasise the role of government in protecting the property rights of its citizens, while Grossman (1988, p.33) specifically endorses the "social contract" view of government, suggesting that "[d]efense, police services, and the judiciary define and enforce the 'constitutional contract' that permits society to escape the low productivity 'state of nature'." Grossman (1988) also draws attention to the theories of the public decision making process in Buchanan and Tullock (1962) and Downs (1957), and their implied effects on the efficiency of public resource allocation. This hypothesis suggests that with "participants in the political process motivated by rational self-interest, combined with the rational ignorance of the voters, decisions made in the political arena tend to favour the interests of small, cohesive and vocal minorities at the expense of the general public" (Grossman (1988, p.34)). A similar argument is made in Castles and Dowrick (1990, p.181), which suggests that "economic growth will be slowed by the competing activities of distributional coalitions of interest groups which wield economic and political influence to further narrow sectional interests at the expense of a more encompassing interest in greater aggregate levels of production."

It has been suggested, however, that as different components of government expenditure are likely to have different effects on growth, aggregate measures of government size are inadequate. As noted in Levine and Renelt (1992, p.95), "aggregate measures of government size will not capture the potentially important implications of how total government expenditures are allocated." However, the absence of broad, consistently-measured cross-country data disaggregating government expenditure implies that, while the problem is noted, very little can be done in cross-country estimation.

Many other measurement problems have also been suggested. If government expenditures are inefficiently allocated, aggregate measures of government size will not accurately measure the actual delivery of public
services. In addition, Carr (1989) argues that, as most government goods do not pass through an organised market, an imputation problem exists. In order to overcome this difficulty, national income accounts evaluate government goods at their cost of production, implying that any attempt to use national income accounting data to measure government efficiency is misguided. Carr (1989) also suggests that it is very difficult to distinguish final goods from intermediate goods in the government sector. Consequently, "the convention now accepted by SNA and by most market economies is to treat all government expenditure on goods and services as final products" (United Nations Technical Report, p.31). In order to quantify the magnitude of the problem, Carr (1989) points to the evidence presented in Reich (1986), who estimates that intermediate output represented 22.9 percent of government output for Canada. This double-counting phenomenon will only be of empirical relevance if this mislabelling varies across countries and over time. Unfortunately, information on this aspect is virtually non-existent.

However, Dowrick (1992) notes that, while the spurious correlation induced by the double counting is a problem in the estimation of the actual effect of government on growth, such arguments should not be used to discount totally the possibility that government provision of goods and services may promote real output. The example used in Carr (1989) to clarify the double-counting argument is the different treatment national accounting methods give to the provision of a road, depending upon whether it is provided by a government or privately. However, "in the absence of public provision, market failure might lead to no road being provided at all" (Dowrick (1992, p.5)).

Despite the problems outlined above, much evidence as to the effect of government size is found in the literature. There are, in general, two methods used in estimation. First, many papers use 'Barro-regressions', including some measure of government size among the explanatory
variables. As noted in the previous section, this approach may be two-pronged, alternatively using economic growth and the investment ratio as dependent variables. The justification for estimating the effect of government size on investment can be clarified with reference to the growth accounting model of Solow (1957). Within this paradigm, differences in growth are due to differences in the rate of accumulation of the factors of production or differences in total factor productivity. Hence, if labour and capital are the only factors of production, then government size can affect growth, either indirectly through its influence on investment or the labour supply, or directly through its influence on efficiency and productivity growth. The second approach involves developing an explicit theoretical model of government size. However, examples of this approach, such as Ram (1986), contain serious empirical flaws.

6.2 'Barro-regressions' of government size

The models described as 'Barro-regressions' estimate cross-country growth models, generally incorporating initial income levels to measure convergence rates, and conditioned by a number of other variables. Barro (1991) estimates a cross-country model using 98 countries, over the period 1960 to 1985. The variable used to measure government size in this model is the ratio of real government consumption expenditure to real GDP. Government consumption expenditure is an adaption of government consumption in the Summers and Heston (1988) data set; Barro (1991) subtracts from this figure the estimates of the ratio of nominal government spending on education and defence to nominal GDP.\textsuperscript{16} It is suggested that expenditures on defence and education are closer to public investment than to consumption, and are likely to influence private sector productivity and property rights. Hence, the government variable in this model attempts to

\textsuperscript{16} Nominal figures for education and defence were used because the relevant deflators were unavailable.
capture government consumption expenditure as it enters the endogenous growth model in Barro (1990),\textsuperscript{17} rather than actual government size. The coefficient of government size is estimated to be negative and significant\textsuperscript{18} in all models, from which Barro (1991) infers government size to have a negative effect on growth. However, the absence of any diagnostic tests leaves this inference open to question. Significantly, the stability of the estimated relationship over time or across sub-groups of countries is not tested.

Barro (1991) also estimates the effect of government size on both private and total investment ratios. It is noted that the values of these investment ratios reflect variations across countries in the ratio of the investment deflator to the GDP inflator; the importance of the relative price of capital goods is emphasised in De Long and Summers (1991, 1993). Barro (1991) calculates the private investment ratio by subtracting estimates of the ratio of real public investment to real GDP from the total investment ratio. As data on public investment at the consolidated general government level were only available for 76 countries over the period 1970 to 1985, the regression using the private investment ratio as the dependent variable contains only 76 observations over this period, whereas that using total investment as the dependent variable contains observations from 98 countries over the period 1960 to 1985. The explanatory variables in these regressions are the same as those in the basic Barro-regression for economic growth. The coefficient of government size is estimated to be negative, but is only significant at conventional levels when the private investment ratio is the dependent variable. Barro's (1991) conclusion is that government size appears to affect growth negatively, although this effect does not appear to be due to the effect of government size on investment.

\textsuperscript{17} The model in Barro (1990) is described in Chapter 2.

\textsuperscript{18} The magnitude of the coefficient varies between -0.094 and -0.178 in the reported regressions.
Kormendi and Meguire (1985) also estimate a cross-country model, using 47 countries over the period 1950 to 1977. In contrast to Barro (1991), however, the variable used to measure government size is the mean growth of government spending as a proportion of output over the period.\textsuperscript{19} This is a significant difference: while Barro (1991) is testing whether absolute variations in government size are conditionally correlated with growth, Kormendi and Meguire (1985) are testing whether it is changes in government size that are important. The result of this analysis is that the coefficient of the change in government size is estimated to be statistically insignificant when included as an explanatory variable.\textsuperscript{20} However, the model excludes any measure of investment as an influence on growth; additional models in Kormendi and Meguire (1985) include this variable, which has a positive and significant coefficient but, in these cases, the government size variable is omitted due to its insignificance in the base regression. This is unsatisfactory because its exclusion from the model will bias the estimate of the effect of government size if the investment ratio variable is correlated with government size. Furthermore, in common with most other papers in this area, no diagnostic tests are presented, leaving uncertainty as to how much faith should be placed in the reported estimates.

Grier and Tullock's (1989) analysis uses pooled cross-country/time series data for 113 countries over the period 1951 to 1980. Government size in this model is measured by the growth of the share of government

\textsuperscript{19} The data for government spending are from the IFS national income accounts, and exclude government fixed capital formation and transfer payments.

\textsuperscript{20} The dependent variable is the mean growth of real GDP, and the other explanatory variables are initial per capita income, mean population growth rate, standard deviation of real output growth, standard deviation of money supply shocks, mean of money supply growth, mean growth of exports as a proportion of output, and mean growth in the inflation rate. The variable representing the ratio of government spending to output is also included as a regressor, but this also yields an insignificant coefficient.
consumption in GDP, as was the case in Kormendi and Meguire (1985). This is justified by the argument that increased government activity will only temporarily affect growth, as production patterns, transaction requirements and investment procedures are altered. The data set used for estimation is pooled, containing six five-year averages for each of the 24 OECD countries, and four five-year averages for each of 89 other countries. Grier and Tullock (1989) present the results from an F-test of structural stability, which indicates that these two data sub-groups should not be combined. The government size effect is estimated to be negative and significant for OECD countries, but insignificant for non-OECD countries\(^{21}\) as a whole. However, when the non-OECD countries are separated on a continental basis, an F-test for structural stability rejects the null hypothesis of identical coefficients. When the model is estimated separately for each continent, the coefficient of government size is negative and significant for African and American countries, but positive\(^{22}\) for Asian countries. Again, no diagnostic tests are reported.

In a pooled cross-country/time series model for 65 lesser developed countries (LDCs) over the period 1960 to 1980, Landau (1986) includes a number of measures of government size as explanatory variables, categorised as either government expenditure, revenue raising, or regulatory. The dependent variable in this study is the rate of growth of real per capita GDP, and the notable feature of this paper is the number of explanatory

\(^{21}\) The dependent variable is the growth of real GDP, while the other explanatory variables are initial per capita real GDP, mean population growth, standard deviation of real GDP growth, mean inflation rate, mean change in inflation, and the standard deviation of inflation. Additionally, in the OECD regression, there are 5 dummy variables for each five-year period from 1956 to 1980; in the non-OECD regression, there are three dummy variables for each five-year period from 1966 to 1980, as well as a two dummy variables for African and American countries.

\(^{22}\) The coefficient is significant at the 10 percent level for Asian countries, with a t-ratio of 1.99.
variables included. These are separated into 10 categories: measures of
government expenditure and revenue raising, regulation and other
government impacts, the level of per capita product, international economic
conditions, human and physical capital variables, the structure of
production, historical-political factors, resources and geoclimatic factors,
population, and a time trend.

The government expenditure variables include both the federal
government, and state and local governments, and is divided into five types:
consumption other than defence or education, education, defence, transfers,
and capital expenditure. Revenue raising variables are current revenue, the
deficit, and a partial measure of foreign aid, official transfers from abroad.
All eight of these explanatory variables are averages of three lagged values,
in order to avoid contemporaneous correlation between these regressors and
the disturbance term. Landau (1986) suggests that consumption expenditure
has a significantly negative effect on economic growth, over all four sub-
samples. However, when the private investment share, current revenue
share, and budget deficit share are all included within the basic regression,
the coefficient of consumption expenditure is estimated to be insignificant
for the small annual, large annual, and four- year period sub-samples.
Landau argues that this result is due to the correlation between government
consumption spending and these three variables, and concludes that
government consumption expenditure has an unambiguously negative
influence on growth in LDCs. The coefficients of government expenditure
on education and defence are both insignificant, except within the seven
year sub-sample, in which defence expenditure has a negative and
significant influence on growth. In the case of transfer payments, the
estimated coefficient is only significant (and positive) in the small annual
sub-sample, and only if current revenue and budget deficits are excluded
from the regression. Finally, the estimated coefficient of government capital
expenditure is always insignificant.
There are two crucial problems in interpreting the results in Landau (1986). First, the estimation method is unsatisfactory: the technique of estimating the influence of a variable of interest within a base regression can lead to omitted variable bias; that is, if a given variable is statistically significant, it should be included in the base regression. Second, no diagnostics are provided.  

On the basis of these Barro-regressions, the conclusion reached is that government size appears to have a negative effect on growth. However, the robustness of these results is criticised in Levine and Renelt (1992), who conclude that the estimated sign of the government size variable is sensitive to model specification. Levine and Renelt (1992) base this conclusion on a version of Leamer’s (1983, 1985) extreme bounds analysis, which is described in the following section.

6.3 Extreme Bounds Analysis: How Robust is Robust?

One of the most serious problems involved in estimating the effect of government size on economic growth is the uncertainty as to what other explanatory variables should be included in the model. Indeed, Levine and Renelt (1992) note that over 50 different explanatory variables have been found to be significant in at least one published regression. One method of analysing this uncertainty is extreme bounds analysis (EBA) suggested by Leamer (1978,1983) and Leamer and Leonard (1983), which examines the sensitivity of inferences to a range of alternative assumptions regarding the selection of regressors. The claims of this methodology are broad; indeed, Leamer and Leonard (1983, p.306) suggest:

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23 Landau (1986) notes that heteroscedasticity is detected by Bartlett’s test and is corrected, although the specific method of correction is not mentioned.
"that researchers be given the task of identifying interesting families of alternative models and be expected to summarise the range of inferences which are implied by each of these families. When a range of inferences is small enough to be useful and when the corresponding family of models is broad enough to be believable, we may conclude that these data yield useful information. When the range of inferences is too wide to be useful, and when the corresponding family of models is so narrow that it cannot credibly be reduced, then we must conclude that inferences from these data are too fragile to be useful."

In order to give some idea of how EBA operates, suppose that a researcher wishes to examine the effect of government size on economic growth, but is uncertain as to which other variables should also be included in the model. For the purposes of the analysis, let \( y \) denote economic growth, \( x \) denote government size, and \( z_1 \) and \( z_2 \) denote the variables about which the researcher is doubtful. The model to be estimated can then be written as:

\[
y_t = \beta x_t + \gamma_1 z_{1t} + \gamma_2 z_{2t} + u_t
\]  

(22)

where \( u_t \) is assumed to be an independent normal random variable with zero mean and unknown variance \( \sigma^2 \). The procedure suggested by Leamer and Leonard (1983) is to find the largest and smallest estimates of \( \beta \) generated by varying the set of doubtful variables. A composite control variable is defined as:

\[
w_A(\theta) = z_{1t} + \theta z_{2t}
\]  

(23)

where \( \theta \) is to be determined. The model to be estimated now becomes:

\[
y_t = \beta x_t + \eta w_A(\theta) + v_t
\]  

(24)

where each value of \( \theta \) imposes a different linear combination of the doubtful variables on the model. Hence, for each value of \( \theta \), there corresponds an estimate of \( \beta, b(\theta) \). It is then possible to find the maximum and minimum values of \( b(\theta), b_{\text{min}} \) and \( b_{\text{max}} \), which form the extreme bounds of the estimate of \( \beta \).
The ideas behind EBA are, however, essentially Bayesian. Leamer (1985, p.309) states that the extreme bounds:

"are applicable when the prior distribution for a subset of coefficients is located at the origin but is otherwise unspecified, and the prior distribution for the other coefficients is "diffuse". A sensitivity analysis is then performed to determine if features of the posterior distribution depend importantly on the way this partially defined prior distribution is fully specified. It is particularly easy to search over the set of alternative posterior distributions to find the extreme posterior modes of linear combinations of coefficients, ergo "extreme bounds"."

An important point to note is that these extreme bounds are themselves random variables and, hence, have probability distributions associated with them. McAleer and Veall (1989) suggest that the analytic calculation of these standard errors is very difficult, and instead use the bootstrap method to calculate the standard errors numerically. McAleer and Veall (1989) do, however, provide formulae useful for constructing the standard errors of the extreme bounds generated by the implicit restrictions imposed in EBA analysis. Consider the linear regression model given by:

\[ y = X\beta + u \]  

(25)

where \( u \) is assumed to be distributed as \( N(0,\sigma^2) \). Given the uncertainty in specification, the explanatory variables are partitioned into two subsets: a set of "free" variables that are always included in the regression, and a set of "doubtful" variables whose coefficients can be constrained by linear restrictions of the form \( R\beta = r \). This set of doubtful variables corresponds to the variables \( z_1 \) and \( z_2 \) presented above. Furthermore, as the model is being used to investigate the effect of a particular "focus" variable (corresponding to the variable \( x \) in Leamer and Leonard’s (1983) model), "the extreme bounds are intended to give the largest and smallest values of the estimated focus coefficient consistent with the doubtful aspect of the specification" (McAleer and Veall (1989, p.99)). This focus variable can be treated as
either free or doubtful. However, if it is treated as doubtful, McAleer, Pagan and Volker (1985) show that the extreme bounds generated necessarily span zero.

The formulae for the generation of these extreme bounds is presented in McAleer and Veall (1989 p.101), using the following notation:

(i) The doubtful variables are assigned values by a subset of $\beta$ being set equal to zero, i.e. $R = (1:0)$ and $r = 0$.

(ii) The focus coefficient is given in the form $\beta_F = \psi \beta$, which involves a linear combination of the elements of $\beta$.

Given the constraints $R\beta = r$, the restricted least squares estimator of $\beta$ is given by:

$$\hat{\beta} = \hat{\beta} - (X'X)^{-1}R'(R(X'X)^{-1}R')^{-1}(R\hat{\beta} - r)$$  \hspace{1cm} (26)

where

$$\hat{\beta} = (X'X)^{-1}X'y$$  \hspace{1cm} (27)

is the unrestricted least squares estimator of $\beta$. The extreme bounds of $\hat{\beta}_F$ are the maximum and minimum values of $\hat{\beta}_F$ as $M$ ranges over all full row rank matrices, where $M(R\beta-r)=0$. The extreme bounds of $\hat{\beta}_F$, subject to $M(R\beta-r)=0$, are given by:

$$\nu(\hat{\beta}_F + \hat{\beta}_F) \pm \nu(\text{Var}(\hat{\beta}_F) - \text{Var}(\hat{\beta}_F))^{1/2}$$  \hspace{1cm} (28)

in which $\chi^2_D$ is the chi-squared statistic for testing the prior restrictions when $\sigma^2$ is known. However, in practice the bounds could be calculated as:

$$\nu(\hat{\beta}_F + \hat{\beta}_F) \pm \nu(SE^2(\hat{\beta}_F) - SE^2(\hat{\beta}_F) \cdot (\hat{s}^2/\hat{s}^2)qF_d)^{1/2}$$  \hspace{1cm} (29)

where $SE$ denotes the standard error of the estimated coefficient, $\hat{s}^2$ ($\hat{s}^2$) is the estimated error variance from the unrestricted (restricted) model, $q$ is the
number of linear restrictions, and \( F_D \) is the F-statistic for testing the restrictions on the doubtful coefficients.

Given the analysis described above, Learner and Leonard (1983) informally suggest two measures of fragility. Inferences regarding a focus coefficient are said to be Type A fragile if the difference in the bounds is greater than a constant, \( k \), times \( SE(\hat{b}_{F0}) \), the "sampling uncertainty".\(^{24}\) The second measure, Type B fragility, occurs if the extreme bounds span zero. McAleer et al. (1985, pp.296-7) show that these two measures can be expressed in terms of classical statistical theory in two important propositions:

**PROPOSITION 1:**
(a) When the focus variable is doubtful, the necessary and sufficient condition for Type A fragility to exist is that the chi-square statistic of the doubtful variable coefficients to equal their prior means \( (\chi_D^2) \) exceeds \( k^2 \).
(b) When the focus variable is free, the necessary condition for Type A fragility is that \( XD > \chi_D^2 > k^2 \).

**PROPOSITION 2:**
(a) When the focus variable is doubtful the necessary and sufficient condition for Type B fragility to exist is that \( \chi_D^2 > \chi_{FO}^2 \), where \( \chi_{FO}^2 \) is the \( \chi^2 \) statistic for testing if the focus coefficient is zero.
(b) When the focus coefficient is free, the necessary condition for Type B fragility is \( \chi_D^2 > \chi_{FO}^2 \).

Essentially, Proposition 1 shows that inferences regarding the focus coefficient will only be fragile if the doubtful variables are informative, and as such can hardly be treated as useful measures. Much the same is the case for Type B fragility; however, instead of an arbitrarily chosen \( k \) determining the benchmark against which the significance of the doubtful variables is compared, it is the significance of the focus variable. It should be noted that

\(^{24}\) McAleer et al. (1985, p.296) note that a common value for \( k \) in empirical studies is 2.
if the focus variable is treated as doubtful, it will always be the case that $\chi^2_D$ is greater than $\chi^2_{FO}$. Hence, these two propositions show that the conclusions of fragility that can be derived from EBA are highly dependent on which variables are classified as free and doubtful.

The above exposition provides a brief summary of the theory underlying EBA. In essence, it is a technique purported to alleviate much of the uncertainty involved in model specification. The explanatory variables are separated into three subgroups: the focus variable whose influence is being estimated, a set of free variables which are always included in the model, and a set of doubtful variables which can be combined linearly in an arbitrary manner. By varying the linear restrictions imposed on these doubtful variables, the maximum and minimum values of the estimate of the focus coefficient can be generated, from which an analysis of sensitivity can be conducted.

A number of papers have employed this sort of analysis of specification uncertainty in a variety of contexts. Learner (1983) provides, as an example of the practical use of EBA, an investigation as to whether capital punishment influences the murder rate. The data examined are a cross-section of the 44 states of the U.S., with the murder rate in 1950 as the dependent variable. The explanatory variables are divided into three subsets: deterrent variables, economic variables, and social variables. It

25 The four deterrent variables are the probability of conviction, the probability of execution given conviction, the median time served in prison for murder, and a dummy variable indicating those states that had at least one execution over the period 1946 to 1950.

26 Economic variables are the median income of families, the percentage of families with less than one half of the median income, the unemployment rate, and the labour force participation rate.

27 Social variables are the percentage non-white population, the percentage of the population aged between 15 and 24, the percentage of the population living in urban areas, the percentage of males in
is found that, if all these variables are included in a linear regression model, then the estimate of the coefficient of the probability of execution variable implies that every additional execution deters, on average, thirteen murders, with a standard error of seven. In order to examine the fragility of this inference, Leamer suggests that there are a number of prior beliefs which treat different subsets of variables as doubtful. Each of these priors can be used to generate extreme bounds for the estimate of the effect of executions on the murder rate. The results of estimation are summarised in Table 3.2. The columns headed "minimum estimate" and "maximum estimate" represent the extreme bounds obtained for the estimated coefficient of the probability of execution variable by imposing the appropriate linear constraints on the variables considered doubtful by the particular prior belief. Both the Right Winger and Rational Maximiser find that their conclusions are insensitive to the choice of doubtful variables whereas, for the other three priors, inferences regarding the probability of execution are sensitive to the choice of explanatory variables. Hence, Leamer (1983) suggests that inferences regarding the deterrent effect of capital punishment are, in general, too fragile to be believed.

Cooley and LeRoy (1981) provide another example of EBA in practice. This paper uses EBA to determine the fragility of inferences regarding the effects of interest rates on the demand for money. Seasonally adjusted quarterly data are used, from 1952(2) to 1978(4), and the equation is estimated in log-linear form. The dependent variable is the logarithm of the demand for real money (M1), under the assumption that the long-run income elasticity of the demand for money is unity, and the focus variables are the logarithms of the savings and loans passbook rate, and the ninety-day Treasury bill rate. Cooley and LeRoy (1981) wish to determine whether inferences regarding the coefficients of the interest rate variables are

the population, the percentage of families that have both husband and wife present, and a dummy variable for southern states.
Table 3.2 Summary of the EBA in Learner (1983)

<table>
<thead>
<tr>
<th>Prior</th>
<th>Deterrent</th>
<th>Economic</th>
<th>Social</th>
<th>Min estimate</th>
<th>Max estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Winger</td>
<td>F</td>
<td>D</td>
<td>D</td>
<td>-22.56</td>
<td>-.86</td>
</tr>
<tr>
<td>Rational Max</td>
<td>F</td>
<td>F</td>
<td>D</td>
<td>-15.91</td>
<td>-10.24</td>
</tr>
<tr>
<td>Eye-for-an-eye</td>
<td>F(^a)</td>
<td>D</td>
<td>D</td>
<td>-28.66</td>
<td>1.91</td>
</tr>
<tr>
<td>Bleeding Heart</td>
<td>D</td>
<td>F</td>
<td>D</td>
<td>-25.59</td>
<td>12.37</td>
</tr>
<tr>
<td>Crime of Passion</td>
<td>D</td>
<td>F</td>
<td>F</td>
<td>-17.32</td>
<td>4.10</td>
</tr>
</tbody>
</table>

Notes: F indicates that the variables are not restricted, that is, they are treated as free. D indicates that the variables are considered to be doubtful by the researcher, and are combined in an arbitrary linear manner to generate the extreme bounds for the estimate of the effect of capital punishment.

\(^a\) The eye-for-an-eye prior treats the time spent in prison variable as doubtful.

sensitive to the inclusion of other explanatory variables in the model. Consequently, several doubtful variables are considered: real GNP, current inflation rate, real value of credit card transactions, and real wealth. It is noted that if all these variables are included in the model, the sum of the interest rate coefficients is equal to -0.165, with a standard error of 0.080. However, Cooley and LeRoy generate extreme bounds for this estimate, which are found to span zero. Furthermore, extreme bounds are also generated for the case in which only one interest variable is included in the model (the ninety-day Treasury bill rate), and these bounds are also found to span zero. Consequently, Cooley and LeRoy (1981) conclude that the negative interest rate elasticities reported in much of the literature are sensitive to alternative specifications, and hence should remain contentious.

These examples illustrate how EBA is used in practice. However, McAleer et al. (1985) and McAleer and Veall (1989) argue that there are
serious reservations as to its value as an indicator of specification uncertainty. First, it may be the case that the restrictions imposed on the doubtful variables to generate the extreme bounds are theoretically unacceptable. McAleer et al. (1985, p.295) use the example of the money demand function from Cooley and LeRoy (1981):

"Suppose that \( \gamma_1 \) and \( \gamma_2 \) are the parameters associated with the income and lagged dependent variable terms in a money demand function, and both variables are treated as doubtful. Then a restriction of the form \( \gamma_2 - \theta \gamma_1 = 0 \), with \( \theta \) negative, would offend against theoretical conceptions. An extreme bound generated with \( \theta < 0 \) in a money demand example would be of little interest and, yet, there is nothing to safeguard against such a possibility."

Second, EBA assumes that the error term in all models is an independently and identically distributed normal random variable, with mean zero and an unknown variance \( \sigma^2 \). Furthermore, it assumes that all regressors are exogenous or predetermined, and that the sample size is large. Hence, if it were the case that one or more of these conditions were not to hold in a model generating an extreme bound, then that bound would be affected accordingly. This suggests that any model generating an extreme bound should be subjected to a range of diagnostic tests before that bound is taken seriously. Indeed, McAleer et al. (1989, p.295) state that "[w]ithout knowing the full set of characteristics of the models generating the extremes, it is impossible to know what weight should be placed on the latter."

Further problems are also evident in the application of EBA. Although the purpose of EBA is to account for specification uncertainty, it says nothing about whether variables should be expressed in linear or log-linear form, or how the dynamics of time series models should be incorporated. In addition, EBA can presently only be determined for single-equation models. The combination of all of these problems suggests that, while the fragility of inferences to alternative specifications needs to be accommodated in any reasonable research methodology, EBA is too flawed
to be taken seriously.

This leads us to the variant of EBA used in Levine and Renelt (1992), which attempts to ascertain the linkages between long-run growth rates and a variety of economic, political, and institutional indicators. This version of EBA is based on equations of the form:

\[ Y = \beta_{FO}X + Z_1\beta_F + Z_2\beta_D + u \tag{30} \]

where \( Y \) is either the rate of growth of per capita GDP or the share of investment in GDP, \( X \) is the focus variable, \( Z_1 \) is the set of free variables, and \( Z_2 \) is a set of doubtful variables, comprising three variables chosen from seven that previous studies have identified as being significant. Upper and lower bounds, \( \hat{\beta}_{FO\text{,min}} \) and \( \hat{\beta}_{FO\text{,max}} \), for the estimate of \( \beta_{FO} \) are generated by examining the regression results for all linear combinations of the variables in \( Z_2 \), identifying the highest and lowest values of \( \hat{\beta}_{FO} \), then adding or subtracting two standard deviations, respectively. For example, the upper bound \( \hat{\beta}_{FO\text{,max}} \) is given by the group of \( Z_2 \) variables that produces the maximum value of \( \hat{\beta}_{FO} \), plus two standard deviations. Thus, if \( \hat{\beta}_{FO} \) is statistically significant and of the same sign at both the upper and lower bounds, then it is termed robust; otherwise, the inference is regarded as fragile. This is an uncomfortable marriage of Bayesian and classical ideas, although it attempts to accommodate the stochastic nature of the extreme bounds.

The four variables treated as free are as follows: the investment share of GDP, the initial level of real GDP per capita in 1960, the initial secondary school enrolment rate in 1960, and the average annual rate of population growth. The pool of seven doubtful variables consists of the average ratio of government consumption expenditure to GDP, the ratio of exports to GDP, the average inflation rate, the average growth rate of domestic credit, the standard deviation of inflation, the standard deviation of domestic credit growth, and an index for the number of revolutions and
coup. Levine and Renelt (1992) include only three variables in \( Z_2 \), which restricts the number of variables in any one regression to eight or fewer. Surprisingly, other than pointing out that this total is similar to that in Kormendi and Meguire (1985) and Barro (1991), no reason is given for this restriction.

According to the propositions established in McAleer et al. (1985), the classification of inferences as either robust or fragile is dependent on the classification of variables as free or doubtful.\(^{28}\) Even if the extreme bounds were to be treated simply as point estimates, inferences would be regarded as fragile if the estimates of the doubtful variables were more significant than the estimate of the focus variable (that is, if \( \chi^2_D > \chi^2_{FO} \)). Furthermore, the characteristics of the models that generated these extreme bounds are not given. Consequently, the restrictions imposed on the doubtful variables in the model producing an extreme bound might be theoretically unreasonable. Moreover, the error term might not have the desirable properties required for a sensible application of EBA. Either scenario should lead the reader to discount the meaning attached to the generated extreme bounds. Unfortunately, however, this information is not provided by the authors.

Levine and Renelt (1992) conclude that only the average share of investment in GDP, the level of real GDP in 1960, and the initial secondary school enrolment rate are robustly correlated with the growth rate of GDP; the inferences regarding the other 16 variables are reported to be fragile. Note that, in this sense, fragility is taken to mean that the extreme bounds generated for a given variable are of opposite signs, and robustness the

---

\(^{28}\) Levine and Renelt (1992, p.958) note that the EBA was also conducted with two different sets of free variables. The first set included the original free variables plus sub-Saharan African and Latin American dummy variables. The second set treated only the investment share as free. It is noted that these alternative specifications did not significantly alter the results.
converse. Of particular relevance for this thesis is the fact that the four measures of government size\textsuperscript{29} used are all found to be fragile. However, for the reasons outlined above, it is concluded here that Levine and Renelt’s (1992) use of the term fragile is itself fragile, and the extreme bounds generated are "essentially a measure of the significance of the doubtful variables as contributors to the explanatory power of the regression model" (McAleer and Veall (1989, p.99)). Consequently, while Levine and Renelt’s (1992) emphasis on testing the fragility of estimates is welcomed, the variant of EBA used to account for this specification uncertainty is inadequate.

6.4 Alternative methods used to estimate the effect of government size on growth

A number of other estimates of the effect of government size are based on the two-sector production function framework suggested in Feder (1983). Ram (1986) bases empirical estimation on a model in which the government output has an externality effect on the non-government sector. The production functions for the two sectors are written as:

\[ C = C(L_c, K_c, G) \]  

\[ G = G(L_g, K_g) \]

where G denotes the government sector, C denotes the non-government sector, L and K denote units of labour and capital, respectively, and

\textsuperscript{29} These measures are the ratio of government consumption expenditures to GDP, the ratio of total government expenditures to GDP, government consumption less defence and education share of GDP, and the ratio of central government deficit to GDP. Levine and Renelt (1992) also note that the ratios of government capital formation, government education, and government defence expenditures to GDP were also included, but were found not to be robustly correlated with the rate of growth of real per capita GDP.
subscripts denote sectoral inputs. Total inputs of labour and capital are given as:

\[ L_c + L_g = L \] (33)

\[ K_c + K_g = K \] (34)

and total output, \( Y \), is simply the sum of the government and non-government sector outputs.

It is assumed that relative factor productivity in the two sectors differs, such that:

\[ \frac{G_L}{C_L} = \frac{G_K}{C_K} = 1 + \delta \] (35)

where the subscripts denote partial derivatives. This assumption allows marginal productivities of the two inputs to differ systematically across the two sectors. These assumptions can be manipulated to provide an expression for the growth of aggregate output of the form:

\[ \dot{Y} = \alpha(\dot{L}/L) + \beta \dot{L} + [(\delta/(1 + \delta)) - \theta] \dot{G}(G/Y) + \theta \dot{G} \] (36)

where a dot over a variable indicates a rate of growth, \( \beta \) is the elasticity of non-government output with respect to labour, \( \alpha \) is the marginal product of capital in the non-government sector, \( \theta \) is the elasticity of non-government output with respect to \( G \), and \( I (=dK) \) represents investment.

Since \( \theta \) is constant, equation (36) can be used to estimate \( \delta \) and \( \theta \). Ram (1986) notes that if \( C_G \), the partial derivative of non-government output with respect to government output, rather than \( \theta \) is assumed to be constant, (36) can be rewritten as:

\[ \dot{Y} = \alpha(\dot{L}/L) + \beta \dot{L} + (\delta_1 + C_G) \dot{G}(G/Y) \] (37)

where \( \delta_1 = \delta/(1+\delta) \).
As the focus of Ram (1986) is to determine the overall effect of government size on growth, (37) is estimated to assess the sign and significance of \((\delta + C_g)\). It is clear that the effects of the externality parameter \((\theta)\) and the intersectoral productivity differential \((\delta)\) cannot be separated, i.e. there is an identification problem. However, since most models of the effects of government size on economic growth use \((G/Y)\) as an explanatory variable, Ram (1986) also estimates the equation:

\[
\dot{Y} = \alpha_k(L/Y) + \beta_L \dot{L} + \gamma(G/Y).
\] (38)

The data used for OLS estimation are from Summers and Heston (1984), and include 115 market economies over the period 1960 to 1980. Ram (1986, p.195) notes that "a random stochastic disturbance term with the usual nice (sic!) properties is assumed." This assumption is unnecessary because the residuals of the estimated equation can be tested for these "usual nice properties". As no diagnostic tests are presented, Ram's results must be viewed with caution.

While Ram (1986) suggests that the results indicate that both the externality effect of government and the factor productivity differential are positive and significant, any inferences from these results must be regarded as inconclusive, due to the econometric problems involved. The most obvious drawback of such estimation is the likelihood of bias due to omitted variables. Significantly, Ram (1986) does not include any measure of convergence or human capital within the model estimated. Such an omission may seriously bias the estimates, so that any inferences about the effect of government size are questionable.

In addition to the cross-country estimates described above, Ram
(1986) estimates (37) and a variant of (36)\(^{30}\) with time series data over the period 1960 to 1980 for each of the 115 countries in Summers and Heston's (1984) data set. These equations are estimated by OLS, as well as under the assumption of a first-order autoregressive (AR(1)) error term. Again, this can be criticised on the basis of the likelihood of omitted variable bias and the absence of diagnostic testing. Moreover, no reason is given for using an AR(1) process over a higher-order AR or moving average process.

Rao (1989) specifically draws attention to some of the above problems in Ram (1986). The explanatory variables in Ram (1986) are compared with those in Landau (1986), which include "the level of per capita product, indicators of international economic conditions, human and physical capital variables, the structure of production, historical-political factors, geo-climatic factors, and others" (Rao (1989, p.272)). In comparing Ram (1986) and Landau (1986), Rao (1989) suggests that Ram's model has a better theoretical foundation. This statement, however, is open to question: simply because Ram's model is based on an explicit theoretical framework does not imply that it is based on a better theoretical foundation. Indeed, it could be argued that Ram has taken his theoretical model out of context, as Feder's (1983) model was not intended to provide the basis for estimating the effect of government size on economic growth.

Rao (1989) also notes a number of other problems with Ram (1986). First, the assumption that each factor input in the government sector bears an identical proportional relationship to that in the non-government sector is not tested. However, if this assumption is invalid, Ram's theoretical

\(^{30}\) This equation excludes the variable \(dG/Y(G/Y)\), because it was found to be statistically insignificant at conventional levels. Such an exclusion implies that \(\delta_i = 0\), and hence the estimated equation is given by:

\[ \dot{Y} = \alpha(I/Y) + \beta L + \theta G. \]
foundation is without basis. Rao (1989) presents the results of RESET specification tests for Ram's cross-sectional regressions, and these indicate problems over the period 1960 to 1970. Rao (1989, pp 275-6) suggests that this is not the case for 1970 to 1980 "because the variation in economic growth across countries in this period has been greatly influenced by economic shocks and the effectiveness of government responses to deal with them."

This approach of Ram (1986) is further developed in Dowrick (1992), which presents the estimates from two models of economic growth. The first is based on Ram's (1986) growth accounting approach, and the second is based on Barro's (1990) endogenous growth model. The data set used in Dowrick's estimation is from Summers and Heston (1991); these time series data are averaged over five-year periods in order to remove the effects of business cycle variation, so that the pooled data set from 111 countries contains 691 observations over the period 1955-59 to 1985-88.

The first model of Dowrick (1992) is an extension of Ram (1986) in that it allows for different rates of technical progress between the government and non-government sectors. Again, the model is based on separable production functions. However, in this case, a time index enters each production function, so that:

\[ C = C(L_c, K_c, G, t) \]  \hfill (39) 

\[ G = G(L_g, K_g, t) \]  \hfill (40)

where the definitions of the variables are the same as for (31) and (32). The marginal productivity differential assumed by this model is also identical to (35) in Ram (1986), together with the assumption of constant elasticity of non-government sector output with respect to government input, so that
It is assumed that technical progress in the government sector, $\lambda^G$, is related to that in the non-government sector, $\lambda^C$, by:

$$
\lambda^G = (1 + \delta)(\gamma + \lambda^C)
$$

(41)

where $\gamma$ is a constant. Additionally, following Dowrick and Nguyen (1989), it is assumed that the rate of technical progress in the non-government sector consists of a time-specific component, $\lambda^t$, a technological catch-up factor, $\lambda \log(y/y^*)$, and a randomly distributed error term, $\epsilon$:

$$
\frac{C_t}{C} = \lambda^t + \lambda \log(y/y^*) + \epsilon.
$$

(42)

Algebraic manipulation of these equations gives the following expression for the growth rate of aggregate output:

$$
\dot{Y} = \alpha \dot{L} + \beta \frac{dK}{Y} + \lambda^t + \lambda \log(y/y^*)
$$

$$
+ \frac{\delta}{1+\delta} \frac{G}{Y} + \theta \frac{C}{Y} + \left[\frac{\lambda^G}{1+\delta} - \lambda^C\right] \frac{G}{Y} + \epsilon
$$

(43)

where $\alpha = L, \theta = C_k$. Dowrick (1992) suggests that Ram’s (1986) criticism of the inclusion of the variable $G/Y$ in Landau’s (1983) specification is unjustified as it is simply due to Ram’s omission of technological growth.

Dowrick (1992) also considers the possibility that the labour and investment variables may be endogenous. He specifies employment and investment functions of the form:

---

31 Again, as in Ram (1986), whether or not the data support the imposition of this constraint is not tested.

32 The variable $y$ denotes per capita GDP, and the asterisk denotes that country with the highest level of per capita GDP.
\[ I/Y = a_0 + a_1(p^G/G/Y) + a_2(p^G/G/Y)^2 \]
\[ + a_3 \log(p^I) + a_4 y + a_5 y^2 + \epsilon \]  
\[ (44) \]

\[ L/P = b_0 + b_1(p^G/G/Y) + b_2(p^G/G/Y)^2 \]
\[ + b_3(A/P) + b_4 \dot{P} + b_5 y + b_6 y^2 + \mu \]
\[ (45) \]

where \( p^G \) is the price of government services relative to the price of GDP, \( p^I \) is the relative price of investment goods, \( L/P \) is the employment ratio, and \( A/P \) is the ratio of adults to total population.

This model is estimated by OLS, 2SLS and the Least Squares Dummy Variable (LSDV)\(^{33}\) approach; this last method is used as, with a pooled data set, there may be country-specific effects that are not captured by the explanatory variables. The dependent variable in these regressions is the rate of growth of real GDP. Initial estimation by OLS gives estimates of the effect of government size that are similar to those in Ram (1986). However, the Hausman test\(^{34}\) for exogeneity suggests that the variables denoting the factor productivity effect and the production externality effect are endogenous. The equation is re-estimated by 2SLS, which gives insignificant estimates at conventional levels of significance. This estimation procedure is repeated using the LSDV approach, and again the test for endogeneity is significant; re-estimation using 2SLS provides insignificant estimates.

It is difficult to draw any firm conclusions from these results. There is no diagnostic testing, and the omission of measures of convergence and

\(^{33}\) These LSDV estimates are obtained by adding a dummy variable for each country, and then estimating by OLS. Dowrick (1992) notes that this is equivalent to using first differences.

\(^{34}\) The instruments used in the Hausman test are the first and second lags of the government variables.
human capital may seriously bias the estimates. However, Dowrick (1992) suggests that Ram's (1986) reporting of a positive relationship between government size and economic growth is probably due to the impact of government on development, rather than the reverse. Furthermore, he states that there is some evidence of a negative impact of government size on economic growth.

The estimates from the investment and labour force equations are also difficult to interpret. In the investment equation, the coefficient of \( p^G/Y \) is positive and significant when estimated by OLS across the entire sample, but negative and significant when estimated by LSDV. When the data set is separated into "poor", "middle" and "rich" countries, parameter stability across the three sub-groups is rejected by the Chow test. Re-estimation of the three equations separately indicates a negative and significant relationship between nominal government size and investment for rich countries, but either positive or insignificant for middle and poor countries, depending upon whether the estimation method is by OLS or LSDV, respectively. The results for the labour force equation are similar; parameter stability across the three sub-groups is rejected, and the sign and significance of nominal government size when the three data sets are estimated separately is dependent upon whether OLS or LSDV is used. Again, no diagnostic tests are provided, but the ambiguity mentioned above would indicate inadequate specification of the estimated equations.

Dowrick (1992) also estimates a version of Barro's (1990) model. However, this adaptation omits the effect of government consumption expenditure. In addition, this model differs from Barro (1990) since the price of government services relative to the price of output, \( p^G \), is included as an exogenous variable. This implies that the government budget equality

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35 This separation is based on 1970-74 real GDP per capita; there are 32 countries in the "poor" sample, 45 in the "middle" sample, and 34 in the "rich" sample.
is now $\tau = p\frac{g}{y}$, where $\tau$ is a flat rate tax. The equation estimated by Dowrick (1992) is of the form:

$$\gamma = \psi_1(p\frac{g}{y}) + \psi_2\log_e(g/y) + \epsilon$$  \hspace{1cm} (46)

where $\gamma$ is the growth of real GDP, $\epsilon$ is an error term whose properties are not mentioned, and estimation is by LSDV. When the data set is split into the three sub-groups outlined above, parameter stability is rejected, so that separate models should be used for each sub-group. It is found that only those estimates for the "rich" countries are statistically significant; in this case, the coefficient of $p\frac{g}{y}$ is negative and significant, and the coefficient of $\log_e(g/y)$ is positive and significant. However, due to the absence of diagnostic testing and the likelihood of bias due to omitted variables, these results cannot be interpreted with confidence.

Finally, Grossman (1988) presents an estimate of the effect of government size for Australia using time series data over the period 1949-50 to 1983-84. The theoretical model upon which this is based is nominally derived from that used in Feder (1983) and Ram (1986). However, a simple three-sector growth accounting model is estimated, augmented by two additional variables representing government transfers and a vector of proxy variables for the extent of government created misallocation of resources. Furthermore, it is assumed that productivity in the government sector is $(1+\delta)$ times that in the non-government sector, for both capital and labour, so that the estimated model is of the form:

$$\frac{dY}{Y} = C_L\frac{dL}{Y} + C_K\frac{dK}{Y} + C_T\frac{dG}{Y} + C_{TR}\frac{dTR}{Y} + C_D\frac{dD}{Y} + \epsilon$$  \hspace{1cm} (47)

where $Y$ is total output, $L$, $K$ and $G$ represent labour, capital, and government output, respectively, $TR$ is government transfer payments, $D$ is the vector of proxy variables already mentioned, $C_L$, $C_K$, $C_{TR}$ and $C_D$ are the marginal productivities, $c$ is equal to $\frac{\delta}{1+\delta} + C_{G1}$, where $\delta$ is the productivity differential, and $\epsilon$ is a random error term whose properties are
not discussed. The vector D consists of four variables: the square of the ratio of total government revenue to GDP (TX), the ratio of the number of recipients and government transfer payments to population (R), the ratio of government employment to total employment (LG), and the total number of pages of Acts passed in Parliament (A).

Estimation of this model is by OLS, in which the dependent variable is the rate of growth of real GDP. Diagnostic testing of the reported model includes only the Durbin-Watson statistic, which suggests that the error terms are not first-order serially correlated. Both the relative size of government, dG/Y, and the relative size of transfer payments, dTR/Y, have positive and significant coefficients, implying that increases in the size of the public sector increase the growth rate of the economy. However, this is offset by the variable dTX/Y, which has a negative and significant coefficient. As an example of this effect, Grossman (1988) argues that, if government expenditure (G) in 1984-85 increased by 10 percent over its 1983-84 level, the economic growth rate would be about 5 percent. However, this would require an increase in taxes and, therefore, an increase

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36 This variable aims to measure the aggregate average tax rate as an indicator of the effect of the burden of government expenditure.

37 Grossman (1988) intends this variable to measure the welfare losses from government distortions, on the assumption that increases in welfare recipients represent increases in the disincentive to work. Furthermore, he suggests that this variable will act as a proxy for the influence of special interest groups receiving transfer payments.

38 This variable is intended to measure the misallocation of resources generated by the bureaucracy.

39 This variable is intended to measure the effect of distortionary special interest legislation. However, the degree to which the number of pages of Acts passed in Parliament actually measures this effect is open to question.

40 Grossman (1988) states that the estimated coefficient for the variable dR/Y is also statistically significant at the 1 percent level. However, the reported t-statistic of 1.43 does not support this inference.
in the size of the government (TX). These increased taxes would offset the
increase in G, reducing the growth rate to 2.4 percent.

There are a number of difficulties with estimation of the effect of
government size on economic growth. First, the variable representing
investment\textsuperscript{41} is insignificant in both of these regressions, suggesting that
investment in physical capital has no effect on growth. This result could be
due to the endogeneity of investment, which would bias estimation;
Grossman (1988) does not test this hypothesis. Second, measures of
convergence and human capital are not included in estimation. Finally, the
absence of diagnostic testing is notable.

From the survey presented above, a tentative conclusion can be
reached. First, government size, that is, the size of government consumption
expenditures, \textit{appears} to be negatively correlated with growth rates over the
postwar period. However, the strength of this conclusion is unclear for a
number of reasons. First, it is not clear if this correlation is robust across
sub-periods and country groupings. Indeed, Grier and Tullock (1989)
suggest that this is not the case. Second, it is not clear that it is possible to
distinguish the effect of government size from a number of other variables.
Levine and Renelt (1992) found that the estimated sign on the government
size variable could be made insignificant by the inclusion of such variables
measuring the relative size of exports and the average inflation rate.
However, Sala-i-Martin (1994) notes that Levine and Renelt always find
some group of policy variables that matter, and suggests that, as these
variables are so highly correlated with each other, the data have difficulty
distinguishing the separate effects. Hence, it is informative to examine the
literature focusing on the effects of government policy on growth.

\textsuperscript{41} Note that this variable is defined as gross fixed investment, for both
the private and public sectors.
6.5 Government policy and growth

The effect of fiscal policy on economic growth is explicitly considered in Easterly and Rebelo (1993a), which looks at the effect of marginal tax rates and levels of public investment. Evidence for the effect of these variables comes from two sources: cross-country data for 100 countries over the period 1970 to 1988, and historical data for 28 countries over the period 1870 to 1988. The initial cross-country estimation is in the form of a 'Barro-regression'. However, Easterly and Rebelo (1993a, p.418) "find that the high correlation between many fiscal variables and the level of income in the beginning of the period makes it difficult to isolate the effect of fiscal policy in the context of the Barro regression."

It has been suggested that theoretical evidence for the importance of fiscal policy in determining growth behaviour is consistent with the predictions of endogenous growth models. Basically, as the neoclassical model is driven by exogenous population and technological change, fiscal policy can only affect the growth rate in the transition to the steady state. However, endogenous growth models "tend to transform the temporary growth effects of fiscal policy implied by the neoclassical model into permanent growth effects" (Easterly and Rebelo (1993a, p.420)). Despite these claims, evidence for the importance of fiscal policy for growth cannot be regarded as definitive for either the neoclassical or endogenous paradigm. Hence, although fiscal policy does not affect the steady state in the neoclassical model, Barro and Sala-i-Martin (1992) and Sala-i-Martin (1994) have suggested that the transition to the steady state takes place at a rate of about 2 per cent a year. This implies that fiscal policy can affect an economy over a significant period of time and still be consistent with the neoclassical model.

The measurement of fiscal policy variables is a major problem. Statutory tax rates tend to overestimate the distortions associated with
income taxation due to the prevalence of evasion, especially within LDCs.\footnote{By way of anecdotal evidence, Easterly and Rebelo (1993) note the case of Colombia. In 1984, marginal tax rates ranged between 7\% and 49\%, while revenue collected represented only 1.75\% of personal income.} However, the three other types of tax rate measures used, namely revenue from different types of taxes as a proportion of GDP, income-weighted marginal tax rates computed in Easterly and Rebelo (1993b), and the marginal tax rates computed by regressing the revenue from each type of tax on its tax base, all tend to underestimate the distortionary effects of taxation.

The cross-country analysis involves estimating a basic 'Barro-regression',\footnote{The dependent variable is the average growth rate of per capita GDP, while the explanatory variables are per capita income in 1960, primary and secondary school enrolment rates in 1960, and assassinations per million population, the number revolutions and coups per year, and war casualties per capita, all averaged over the period of estimation.} then testing for the inclusion of the fiscal policy variables individually. It is found that these included variables tend to be statistically insignificant, often causing the coefficient on initial income to be insignificant as well. However, Easterly and Rebelo (1993a) conclude that, as there is a strong correlation between the fiscal variables and the logarithm of initial income, it is difficult to separate the different effects.

Easterly and Rebelo (1993a) also report the results from including additional variables to their basic regression.\footnote{The results from three 'basic' regressions are reported: one as described above, another including the ratio of M2/GDP in 1970 as an additional regressor, and a third including both M2/GDP in 1970 and the trade share in 1970.} It is suggested that the correlations between growth and the ratios of central government surplus to GDP, and the standard deviation of the ratio of domestic taxes to

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consumption plus investment, are the most robust, as they are consistently estimated to be significant in models of both growth and investment. Fischer (1993) and Easterly and Rebelo (1993a) suggest that these variables can be interpreted as measuring macroeconomic instability.

Finally, evidence for the effect of public investment on growth is reported, using data compiled by Easterly and Rebelo (1993a) on aggregate and sectoral consolidated public investment. Again, these various measures of public investment are added to a Barro-regression conditioned on the variables already described. It is concluded that transport and communication investment appears to be consistently and significantly positively correlated with growth, and total public investment and public enterprise investment are consistently and significantly negatively correlated with growth and investment. However, general government investment appears to be consistently and significantly positively correlated with both growth and investment.

These results are informative despite the absence of diagnostic testing, measurement problems of the taxation variables, and the fact that these estimated correlations appear not to be robust to the inclusion of additional fiscal policy variables. They suggest that government policy does influence cross-country growth behaviour, although it is not clear how best to measure the effects of government policy. However, it should be concluded that, due to the correlation between many fiscal variables, cross-country evidence is insufficient to distinguish between the effects of these variables, and additional evidence is required.

These conclusions are supported in Fischer (1991, 1993), who explicitly considers the role of macroeconomic factors in determining growth rates, and concludes that a stable macroeconomic framework is
required for sustainable economic growth. Fischer (1993, p.487) defines\textsuperscript{45} stability as follows: "inflation is low and predictable, fiscal policy is stable and sustainable, the real exchange rate is competitive and predictable, and the balance of payments situation is perceived as viable." However, of these variables, only low and stable inflation is directly measurable. Hence, three indicators of macroeconomic policy are used: the inflation rate, the budget deficit, and the black market exchange rate premium, which are taken to indicate "the overall ability of the government to manage the economy" (Fischer (1993, p.487)). Furthermore, changes in the terms of trade are included as an explanatory variable, as in Easterly et al. (1993).

It is suggested that macroeconomic factors affect growth primarily through their effect upon uncertainty, either through reducing the efficiency of the price mechanism or by reducing the investment rate. It is for this reason that Fischer (1993) estimates the effect of these macroeconomic factors on both the economic growth rate and the investment rate. Estimation is by OLS for cross-sectional data for 101 countries, and by GLS for pooled cross-section/time series data, both taken from Summers and Heston (1991) over the period 1960 to 1989. In order to determine the effects of macroeconomic indicators on growth and investment, Fischer initially regresses each of five indicators (inflation rate, ratio of budget surplus to GDP, change in the terms of trade, black market exchange premium, and the standard deviation of the inflation rate) \textit{individually} on the dependent variable. However, despite the fact that all variables except the change in the terms of trade in the growth regression are statistically significant, these rank correlations are biased due to omitted variables. Fischer (1993) also estimates models of economic growth and capital accumulation which include all indicators except the standard deviation of

\textsuperscript{45} This definition is based on World Bank (1990, p.4).
inflation. Several problems exist in the interpretation of these estimates. First, in the growth model using cross-country data, there are only 22 countries for which data on all these variables are available. This small sample size suggests that any inferences are questionable. Second, both of these regressions exclude variables measuring convergence rates and differences in human capital, which suggests that the reported estimates are biased. Third, in the models using the pooled data set, no attempt is made to test or control for the endogeneity of the explanatory variables. Fischer (1993) notes this problem, stating that this is due to the difficulty in choosing instruments for endogenous variables. However, it is suggested that, as adverse supply shocks possibly cause both inflation and slower economic growth, including the terms of trade variable should accommodate this problem. Although this hypothesis could easily be tested with a Hausman test, Fischer does not do so. Finally, no diagnostic tests are reported.

Despite these problems, the pooled data results suggest that increases in inflation and the black market exchange rate premium have a significantly negative effect on both economic growth and capital accumulation. However, budget surpluses and increases in the terms of trade have significantly positive effects only on economic growth, suggesting differing avenues of causation.

The effect of inflation on economic growth has been debated in the theoretical literature. The growth models of Stockman (1981) and De Gregorio (1993) suggest that increases in the inflation rate will lead to decreases in the rate of growth of output by reducing capital accumulation. In contrast, the opposite result is implied by the Tobin-Mundell effect,

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46 As the inflation rate and its standard deviation are highly correlated, this precludes the accurate estimation of individual effects. Accordingly, Fischer excludes the standard deviation from his full regression.
which involves a shift away from real money balances toward real capital as a consequence of increases in anticipated inflation. This increase in real investment in capital goods results in higher economic growth.

The level, first difference, and standard deviation of the inflation rate have been included as explanatory variables in Grier and Tullock (1989), and the rate of change in inflation has been included in Kormendi and Meguire (1985). Grier and Tullock (1989) report separate estimates for OECD and non-OECD countries; in the case of the OECD sub-sample, only the coefficient for the standard deviation of inflation, which is negative, is significant. The non-OECD sub-sample is further separated into continental sub-groups. In the African sub-sample, only the mean inflation rate is a significant regressor; in the American sub-sample, both the rate of change and standard deviation of inflation are significant; in the Asian sub-sample, none of the three is significant. Note that, in all these cases, the variable is estimated to have a negative effect.

In Kormendi and Meguire (1985), the mean growth in the inflation rate enters the regression with a negative and significant coefficient, except when the investment to income ratio is included as a regressor. However, Kormendi and Meguire (1985) also estimate a model with this investment ratio as the dependent variable, using the same explanatory variables as in the growth regression. In this model, the mean growth of inflation has a negative and significant coefficient, suggesting that the effect of growth in the inflation rate acts predominantly to decrease physical investment, and through this channel to decrease growth.

However, the same criticisms of Kormendi and Meguire (1985) and Grier and Tullock (1989) outlined in the previous section apply. Potential omitted variable bias and the absence of diagnostic testing suggest that the conclusions reached are not necessarily supported by the data.
The role of financial systems in influencing economic growth is studied in King and Levine (1993a,b). King and Levine (1993b, p.513) construct

"an endogenous growth model in which financial systems evaluate prospective entrepreneurs, mobilise savings to finance the most promising productivity-enhancing activities, diversify the risks associated with these innovative activities, and reveal the expected profits from engaging in innovation rather than the production of existing goods using existing methods."

King and Levine (1993a) present an empirical analysis of the hypothesis that the level of financial development is correlated with the growth of real per capita GDP, using cross-country data for 80 countries over the period 1960 to 1989. They note (p.717) the argument of Joseph Schumpeter, namely that "the services provided by financial intermediaries - mobilising savings, evaluating projects, managing risk, monitoring managers, and facilitating transactions - are essential for technological innovation and economic development." Four indicators of financial development are used to evaluate this hypothesis: the ratio of liquid liabilities to GDP, the importance of deposit banks relative to the central bank in allocating domestic credit, credit issued to non-financial private firms divided by total credit, and credit issued to non-financial private firms relative to GDP. The first variable is the traditional measure of financial depth, the

47 Liquid liabilities consist of currency held outside the banking system, plus demand and interest-bearing liabilities of banks and non-bank financial intermediaries (this measure is equal to M3). However, when data on M3 are not available for a given country, M2 is used instead. While this inconsistency is regrettable, the large number of countries in the database makes it unavoidable.

48 This is measured by the ratio of deposit money bank domestic assets to deposit money bank domestic assets plus central bank domestic assets.

49 These variables are measured by the ratio of claims on the non-financial private sector relative to total domestic credit and GDP.
second distinguishes between the financial institutions conducting intermediation, and the final two differentiate between where the financial system distributes assets.

King and Levine's (1993a) methodology is based on that of Kormendi and Meguire (1985), and Levine and Renelt (1992); there is both a cross-country analysis using data averaged over the 1960 to 1989 period, and a pooled data analysis using data averaged over the 1960s, the 1970s, and the 1980s. The database contains 119 countries, but a lack of financial data and the elimination of the major oil exporters{50} restricts the analysis to 80 countries. The dependent variable in this model is the rate of growth of real per capita GDP, and the other explanatory variables are the logarithm of initial income, the logarithm of initial secondary school enrolment rate, the ratio of trade to GDP, the ratio of government spending to GDP, and the average inflation rate. It is found that the influences of all four financial indicators are positive and significant at the 1 percent level, when they are included individually in the base regression. However, the absence of any reported diagnostics is notable.

A regression is estimated using the initial value of financial development, in particular, the ratio of liquid liabilities to GDP in 1960, to provide some evidence as to the direction of causation. This is important, as it can be argued that economic growth leads to financial development, rather than the reverse. Indeed, Joan Robinson (1952, p.86) argued that "[b]y and large, it seems to be the case that where enterprise leads finance follows." Therefore, the dependent variable of the regression estimated remains the average of real per capita GDP growth over the period 1960 to respectively.

{50} King and Levine (1993a) do not give reasons for this exclusion; it must be presumed that it is based on the belief that the growth experience of major oil exporters is markedly different from that of other countries. However, this proposition is testable.
1989. However, the government, inflation and trade variables now enter as initial values. Furthermore, an index of civil liberties, the number of revolutions, the number of assassinations, a sub-Saharan Africa dummy, and a Latin America dummy, are also included. While the estimated coefficient for the financial variable is positive and significant, the reasons for using initial values of government, inflation and trade is open to question. As these reasons are not explained in the paper, and there are no reported diagnostics, the conclusions to be reached are unclear. The methodology employed here is also used with the pooled data set; in this case, the three observations of each financial indicator for any given country are the initial values for each decade. Again, the dependent variable is the rate of growth of real per capita GDP, and the other explanatory variables are the initial values for government, inflation, trade, income, and the secondary school enrolment rate, as well as dummy variables for each decade. When included in this base regression individually, all the financial variables have positive estimated coefficients, although the coefficient for the initial ratio of credit issued to non-financial private firms to total credit is now insignificant at conventional levels. This is taken to be evidence that the direction of causation is, in fact, from increases in financial development to increases in economic growth. However, the same problems as those mentioned above still apply.

There are alternative measures of the effect of government policy that can be found in the literature. For example, Barro (1991) includes measures of political instability\(^51\) and market distortions,\(^52\) which are estimated to significantly effect the growth rate. However, what can be

\(^{51}\) There are two variables representing political instability; the number of revolutions and coups per year, and the number of political assassinations per million population per year.

\(^{52}\) Two variables are used to measure market distortions; the initial year PPP value for the investment deflator, and the magnitude of the deviation of this initial PPP value from the sample mean.
concluded from the evidence outlined above is that government policy does appear to affect growth rates. This is the conclusion that Sala-i-Martin (1994, p.743) takes from the study by Levine and Renelt (1992): it "is not that nothing matters, but that policy matters. The data, however, cannot really tell exactly which policy is bad."

Although there are many other questions about the determinants of growth that can be examined, such as the influence of openness to trade, a number of conclusions can be reached from the above analysis. First, there is substantial evidence of convergence over the postwar period, although it appears to be slow (approximately 2 percent per year). Furthermore, it is unclear whether this evidence is universal or limited to within rich and poor "clubs". However, this does not necessarily support the neoclassical model, as cross-country estimates cannot distinguish the source of this convergence. Moreover, the apparently slow pace of convergence poses another difficulty in using postwar data to distinguish between exogenous and endogenous concepts of growth. The exogenous, neoclassical model suggests that factors such as government policy can only have an effect in the short-run, that is, they can only affect the transition to the steady state, rather than the steady state itself. Hence, if the rate of convergence is as slow as has been suggested, then evidence of importance of government policy variables does not constitute evidence against the basic neoclassical model.

Second, although differences in human capital appear to be important in understanding differences in growth rates, cross-country evidence cannot be used to distinguish between neoclassical and endogenous growth, as the significance of human capital is not specific either conception of growth. Instead, what is required is some way in which to determine whether the returns from investment in human capital are decreasing. Additionally, it is unclear which aspect of human capital is of most relevance in the determination of a given country's ability to innovate and imitate, and whether the effect of different levels of education are
constant across country sub-groups.

Third, while differences in physical investment rates appear to be important in understanding differences in growth rates, this again cannot be used in support of either the neoclassical or endogenous model due to the slow estimated convergence rate. Furthermore, it appears that specific areas of investment, particularly in equipment capital, have a significantly stronger capacity to explain differences in growth rates.

Fourth, while it is clear that government policy does affect growth, the high degree of correlation between policy variables makes it difficult to distinguish between different effects in cross-country regressions.
CHAPTER 4 EXOGENOUS OR ENDOGENOUS GROWTH: TESTS USING TIME SERIES DATA

1. Introduction

The previous chapter surveyed the cross-country evidence on economic growth, focusing on four principal questions: convergence, human capital, physical capital, and government policy. However, it is argued that cross-country estimates using postwar data are unable to distinguish between the neoclassical and endogenous specifications. In essence, if convergence rates are slow, as has been suggested in Barro and Sala-i-Martin (1992) and Mankiw et al. (1992), then the fact that differences in macroeconomic aggregates are estimated to be significantly correlated with growth rates is still consistent with the neoclassical specification, due to the length of the period of analysis. Since the available cross-country data cannot differentiate between exogenous and endogenous concepts of growth, this chapter examines whether the estimated properties of time series data suggest that one model may be preferred over the other.

The motivation for this approach is as follows. First, the stochastic versions of the neoclassical and Rebelo's (1991) endogenous growth model developed in Lau (1994) are presented. The comparison of these models formalises the argument that, unless it is assumed that shocks are I(1), the neoclassical model implies that output will be trend stationary (TS), while the Rebelo-type endogenous growth model implies output will be difference stationary (DS). Hence, long-run output data for 8 industrialised countries is examined for evidence of nonstationarity. On this basis, it is argued that evidence for the nonstationarity of output supports the Rebelo-type endogenous specification of growth over the neoclassical model.

This approach to distinguish between the exogenous and endogenous
concepts of growth has previously been applied in Greasley and Oxley (1994a) to US data. To complement these results, this thesis examines a larger sample of countries and identifies the formal arguments behind these ideas. Informally, however, this argument is summarised in Durlauf (1989, p.87) as follows:

"If the marginal product of capital diminishes to zero as the capital-labour ratio becomes unbounded, then a given technological configuration implies a bounded production set for the economy. Unit roots in output imply that the production set is asymptotically unbounded. Random and persistent shocks to the production possibilities frontier can be explained only as technical change."

This is intuitively reasonable. The neoclassical model, which assumes that the index of labour augmenting technical conditions grows at a constant proportional rate, suggests that all quantity variables will possess a common deterministic trend; that is, "the basic neoclassical model implies that consumption, investment and output time series are trend stationary" (King et al. (1988b, p.313)). Indeed, this result is formalised in Lau (1994b), who demonstrates that output, consumption and capital in the neoclassical model will only be nonstationary if it is assumed that there is at least one source of random shocks that is I(1).

However, Lau (1994) demonstrates that, for the class of endogenous growth models that possess a steady state growth path, there will be a unit root in the autoregressive polynomial of the observed variables, even though the exogenous shocks are stationary. In order to demonstrate this property, let \(X_t=(X_{1t},...,X_{nt})'\) be a vector of \(n\) variables expressed in logarithmic form. Along a steady state growth path, the structural relationships among these

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1 In order for neoclassical models to generate non-stationarity and cointegration, it is required that shocks to the system be I(1).

2 King et al. (1991) and Neusser (1991) assume that the technological shocks are I(1).
variables can be represented by:

$$\sum_{j=0}^{b} \sum_{i=1}^{n} \phi_{k}^{j}X_{t-i-j} = \mu_{k} + e_{it}$$  \hspace{1cm} (1)$$

where $k \in (1, n)$ and $b$ is the maximum number of included lags. Furthermore, the random shocks, $e_{it}$, are assumed to be stationary with mean zero. This system of structural relationships can be represented in vector form by:

$$\Phi(L)X_{t} = \mu + e_{t}$$ \hspace{1cm} (2)$$

where $L$ is the lag operator, $\mu=(\mu_{1},...,\mu_{n})'$, $e_{t}=(e_{1t},...,e_{nt})'$, and:

$$\Phi(L) = \sum_{j=0}^{b} \Phi_{j}L^{j}$$ \hspace{1cm} (3)$$

where $\Phi_{j}$ is an $n \times n$ matrix. These $n$ equations can be solved simultaneously to give the univariate time series representation:

$$\text{det}[\Phi(L)]X_{it} = g_{i} + u_{it}$$ \hspace{1cm} (4)$$

where $\text{adj}[\Phi(L)](\mu+e_{t}) = g + u_{t}$, $g_{i}$ and $u_{it}$ are the $i$-th components of $g$ and $u_{t}$, respectively, and $\text{det}[\Phi(L)]$ and $\text{adj}[\Phi(L)]$ are the determinant and adjoint of the matrix polynomial $\Phi(L)$, respectively.

As the assumption of a steady state growth path excludes the possibility of explosive growth, $\text{det}[\Phi(L)]$ must contain roots on or outside the unit circle. This finite-order polynomial can be represented as:

$$\text{det}[\Phi(L)] = (1-L)^{m}P(L)$$ \hspace{1cm} (5)$$

where $m$ is a positive integer or zero, and $P(L)$ contains roots strictly outside the unit circle. In order to derive the properties of this univariate representation, (4) can be rewritten as:

$$(1-L)X_{it} = (1-L)^{1-m}P^{-1}(1)g_{i} + (1-L)^{1-m}P^{-1}(L)u_{it}$$ \hspace{1cm} (6)$$

so that the left-hand side of (6) is the growth rate of the variable. Lau (1994) demonstrates that in order to exhibit positive but non-explosive
growth, the expected value of the right-hand side of (6) should be a positive constant, which requires that there be exactly one factor of (1-L) in the autoregressive polynomial of the variable, that is:

$$\text{det}[\Phi(L)] = (1-L)P(L)$$

which implies that (6) becomes:

$$X_{it} = P^{-1}(1)\xi_t + X_{i,t-1} + P^{-1}(1)\epsilon_{t'}$$

Hence, as $u_{it}$ is a convolution of the impulses, $e_{it}$ affecting the system, its order of integration is at most that of $e_{it}$, which is stationary. This implies that $X_{it}$ is difference stationary.

This analysis shows that endogenous growth models that possess a steady state growth path will generate trend stationary variables. Lau (1994, p.7) suggests that "[t]he intuition is that since there is no trend growth in the impulse, there has to be some conditions on the propagation mechanism (e.g. production is homogenous of degree one in accumulable factors or the extent of the externality is strong enough) that generate growth." In addition to this property, Lau (1994) also shows that there will be exactly $n-1$ cointegrating vectors among $n$ variables generated by an endogenous growth model.3 This can be demonstrated with reference to the stochastic variant of the 'AK' model of Rebelo (1991), as developed in Lau (1994).

Consider the representative agent in an economy populated by a constant number of identical agents, allocating consumption in order to maximise expected lifetime utility, given by:

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3 However, as a caveat to this result, Lau (1994, p.17) notes that it is based on the assumption that the system of $n$ variables is generated by one endogenous growth model with no dichotomous sub-systems.
\[ E_0 \left[ \sum_{t=0}^{\infty} \rho^t \ln C_t \right] \]

where \( E \) is the conditional expectations operator, \( \rho \) is the discount factor \((0 < \rho < 1)\) and \( C_t \) is consumption at time \( t \). Output is generated by a single factor, constant returns production function of the form:

\[ Y_t = AK_t \theta_t \]  

(10)

where \( A \) is positive, and \( Y_t, K_t \) and \( \theta_t \) are output, capital and technological shock at time \( t \), respectively. Note that capital in this economy, as in the model described in Lucas (1988), can be interpreted broadly, including both physical and human capital. Additionally, \( \ln(\theta) \) is assumed to have white noise properties, that is, the technological shocks are \( \mathcal{I}(0) \). Since the capital stock is assumed to depreciate at a fixed rate, \( \delta \), its evolution is described by:

\[ K_{t+1} = Y_t - C_t + (1-\delta)K_t \]  

(11)

To determine the equilibrium of this economy, it is first assumed that \( \theta_t \) is deterministic and exogenous, which implies that the Lagrangian can be written as:

\[ \mathcal{L} = \sum_{t=0}^{\infty} \rho^t (\ln C_t + \nu_s (1-\delta + A\theta_t)K_t - C_t - K_{t+1}) \]  

(12)

where \( \nu_s \) is interpreted as the shadow price of the capital stock. The first-order conditions of (12) are given by:

\[ \frac{\partial \mathcal{L}}{\partial C_t} = \rho^t\left( \frac{1}{C_t} - \nu_s \right) = 0 \]  

(13)

and

\[ \frac{\partial \mathcal{L}}{\partial K_t} = \rho^t\nu_s (1-\delta + A\theta_t) - \rho^{t-1}\nu_{t-1} = 0 \]  

(14)

while the transversality condition is given by:
Solving for $C_t$ from (13) and (14) yields:

$$C_t = \rho(1-\delta+A\theta_t)C_{t-1}. \quad (16)$$

If the steady state paths of the variables, with $\theta_t$ at its mean value of 1, are denoted by an asterisk, and the steady state growth path of a given variable $X$ is denoted $\gamma_X$, then (10) and (12) imply that $\gamma_C=\gamma_k$ and $\gamma_c=-\gamma_r$. Furthermore, (16) and (11) can be used to solve for the steady state paths of consumption and capital, yielding:

$$K_{t-1}^* = (1-\delta+A)K_t^*-C_t^* \quad (17)$$

and

$$c_t^* = \rho(1-\delta+A)c_t^*-\rho c_{t-1}^*. \quad (18)$$

These equations can be linearised near the steady state path to give:

$$\ln C_t = \ln[\rho(1-\delta+A)] + \ln C_{t-1} + \frac{A}{1-\delta+A}\ln \theta_t \quad (19)$$

and

$$\ln K_{t+1} = \frac{1-\rho}{\rho} \ln(1-\rho) + \ln \rho + \frac{1}{\rho} \ln(1-\delta+A) \ln K_t - \frac{1-\rho}{\rho} \ln C_t + \frac{A}{\rho(1-\delta+A)} \ln \theta_t \quad (20)$$

Hence, the evolution of consumption and capital depends upon past values and the technological shock. Lau (1994) solves (19) and (20) to express consumption and capital in terms of their own lagged values and the random disturbance term, so that:
\[(1-L)\ln C_t = \ln[\rho(1-\delta+A)] + \frac{A}{1-\delta+A}\ln \theta_t \quad (21)\]

and

\[(1-L)\ln K_t = \ln[\rho(1-\delta+A)] + \frac{A}{1-\delta+A}B\ln \theta_t \quad (22)\]

where \(L\) is the lag operator. It is observed that \(\ln C_t\) and \(\ln K_t\) depend upon the common autoregressive polynomial, which has exactly one unit root, implying that both series are difference stationary. Hence, Lau (1994) shows that, under the condition for sustained growth (that is, constant returns to scale with respect to reproducible inputs), consumption and capital will each contain a unit root even though the exogenous shocks are stationary. Moreover, the two variables will be cointegrated with cointegrating vector \((1,-1)'\), since \(\ln C_t-\ln K_t\) is stationary.

These properties suggest several approaches in differentiating between neoclassical and Rebelo-type endogenous growth models. The first involves the analysis of the time series properties of output, as Lau (1994) shows that the variables of an endogenous growth model will be difference stationary (DS) even though the shocks to the system are stationary. Hence, this analysis involves testing for the existence of unit roots and determining the degree of persistence evident in the data. The second approach involves examining the cointegration properties of the data.

2. Stationarity in Output Series

Before describing the procedures used to test for non-stationarity, it is useful to develop the properties of unit roots. From Campbell and Perron (1991), consider the decomposition of the univariate series, \(y_t\), into:

\[y_t = TD_t + Z_t \quad (23)\]

where \(TD_t\) is the deterministic trend in \(y_t\), and \(Z_t\) is the stochastic
component of $y_t$. For the purposes of this analysis, it is assumed that the
deterministic trend is a linear function of time, so that:

$$TD_t = \kappa + \delta t.$$  \hfill (24)

Furthermore, it is assumed that $Z_t$ can be described by an autoregressive-
moving average process:

$$A(L)Z_t = B(L)e_t$$  \hfill (25)

where $A(L)$ and $B(L)$ are polynomials in the lag operator $L$ of orders $p$ and
$q$, respectively, and $e_t$ is a series of identically and independently distributed
innovations. Finally, it is also assumed that $B(L)$ has roots strictly outside
the unit circle. It is now possible to distinguish $y_t$ as either trend-stationary
(TS) or difference-stationary (DS). In the TS specification the roots of $A(L)$
are strictly outside the unit circle, while in the DS model $Z_t$ has one unit
autoregressive root while all other roots are strictly outside the unit circle.

The noise function, $Z_t$, can be further decomposed into a cyclical
component, $C_t$, and a stochastic trend, $TSt$, where $C_t$ is assumed to be a
stationary process with zero mean. Hence, $TS_t$ includes all random shocks
that have permanent effects on the level of $y_t$. It is this component that is of
interest in the comparison of exogenous and endogenous models of growth.
In the exogenous concept of growth, random shocks to the economy have
only a transitory effect on output, which suggests that the stochastic trend is
zero and the series are stationary.

The DS model is more complicated. If $A(L)$ in (25) has a unit root,
then it can be written as:

$$A(L) = (1-L)A^\ast(L)$$  \hfill (26)

where $A^\ast(L)$ has roots strictly outside the unit circle. This implies that $\Delta Z_t$
follows the stationary ARMA process:
Hence, from Beveridge and Nelson (1981), the noise component of $y_t$ can be rewritten as:

$$Z_t = TS_t + C_t = \psi(1)S_t + \psi^*(L)e_t$$  \hspace{1cm} (28)

where $\psi(L) = A^*(L)^{-1}B(L)$, $\psi(1)$ is the sum of these moving average coefficients, $\psi^*(L) = (1-L)^{-1}[\psi(L)-\psi(1)]$, and:

$$S_t = \sum_{j=1}^{t} e_j$$  \hspace{1cm} (29)

is a random walk with zero mean. This implies that the stochastic trend, which is the sum of the moving average coefficients of $\Delta Z_t$, can be interpreted as the long-run effect of a shock, $e_t$, on the level of the noise component. In the measurement of the persistence of shocks, Campbell and Mankiw (1987) suggest that the coefficient $\psi(1)$ is an appropriate measure of persistence, given the interpretation outlined above. In a similar vein, Cochrane (1988) suggests that persistence can be measured by the ratio of the variance of innovations in $TS_t$ to the variance of innovations in $y_t$, where the ratio can be written as $\psi(1)^2 \sigma_e^2 / \sigma_{\Delta y}^2$. Cochrane (1988) shows that this conception of persistence is equivalent to examining the spectral density function at frequency zero of the first difference of output. The difference between these two measures is clearer in a simplified representation. Consider the variable $y_t$, the log of GDP, as a moving average process given by:

$$\Delta y_t = A(L)e_t$$  \hspace{1cm} (30)

where $A(L)$ is an infinite polynomial lag operator and $e_t$ is white noise. In this case, the effect of a shock in period $t$ on the growth rate in period $t+k$ is $A_k$, whereas the effect of the shock on the level of GDP is $1+A_1+...+A_k$. This implies that the ultimate impact of the shock is the infinite sum of these moving average coefficients, $A(1)$, and corresponds to Campbell and
Mankiw's (1987) measure of persistence. If $y_t$ follows a random walk, then $A(1)$ is equal to one; however, if $y_t$ is stationary, then $A(1)$ is equal to zero. In contrast, Cochrane (1988) suggests the alternative measure of persistence, $V^k$, which can be written as a ratio of variances or as a function of autocorrelations:

$$V^k = \frac{1}{k+1} \frac{\text{var}(y_{t+k+1} - y_t)}{\text{var}(y_{t+1} - y_t)} = 1 + 2 \sum_{j=1}^{k} \left(1 - \frac{j}{k+1}\right) \rho_j \quad (31)$$

where $\rho_j$ is the jth autocorrelation of $\Delta y_t$. If $y_t$ is nonstationary, then the variance of the $(k+1)$-lagged difference is $(k+1)$ times the variance of the once-lagged difference, so that $V^k$ is equal to one. However, if $y_t$ is stationary, the variance of the $(k+1)$-lagged difference approaches twice the variance of the series, which is a finite constant. In the limit, given by:

$$V = \lim_{k \to \infty} V^k = 1 + 2 \sum_{j=1}^{\infty} \rho_j \quad (32)$$

$V^k$ approaches zero for large $k$. The persistence measure in Cochrane (1988) can be estimated by replacing the population autocorrelations in (31) with the sample autocorrelations, so that:

$$\hat{V}^k = 1 + 2 \sum_{j=1}^{k} \left(1 - \frac{j}{k+1}\right) \hat{\rho}_j \quad (33)$$

If $k$ increases with sample size, then this estimator consistently estimates $V$. Furthermore, it is demonstrated in Priestly (1982, p.463) that this estimate of persistence is an estimate of the normalised spectral density at frequency zero that uses a Bartlett window.

Despite the fact that these measures of persistence are directly related, they lead to different perspectives on persistence. Durlauf (1989, p.75) argues that "Cochrane employs an estimation strategy that is sensitive to long-run mean reversion, whereas Campbell and Mankiw choose a strategy better suited to uncovering short-run movements." This view is
reinforced by Monte Carlo evidence presented in Cochrane (1988), which shows that low order ARMA representations tend to over-estimate the random walk element. By comparison, Cochrane (1988, p.905) argues that the "spectral density at frequency zero of first differences captures all the effects of a unit root of the behaviour of a series in a finite sample."

This exposition describes the analysis of the time series properties of output considered in this thesis. First, output is tested for nonstationarity, where the null hypothesis is that the series contains a unit root and the alternative is that the series is TS. However, as argued in Greasley and Oxley (1994b, p.1), "interpreting time series as either TS or DS, and by implication output innovations as either transitory or infinitely persistent, may be extreme." To this end, the measure of persistence suggested by Cochrane (1988) is examined.

The measure of output examined in this section is real GDP over the period 1860 to 1989 for 8 industrialised countries, as compiled by Maddison (1993). Plots of these series can be found in Appendix II of this thesis, and a detailed description of the method of compilation of this data set can be found in Maddison (1993, Appendix A, pp. 195-222).

Progressing to the issue of testing, the conventional way in which to distinguish a univariate series, $y_t$, as either trend stationary (TS) or difference stationary (DS) has been the Dickey-Fuller (1981) test for unit roots. This test estimates an equation of the form:

$$\Delta y_t = \mu + (\beta - 1)y_{t-1} + \delta t + \varepsilon_t \tag{34}$$

However, there are often problems with the test in that it makes no allowance for possible serial correlation of the error term. In order to

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4 These countries are Australia, Canada, France, Germany, Italy, Japan, the UK, and the US.
accommodate this potential inadequacy, Dickey and Fuller proposed a correction of the test, described as the Augmented Dickey-Fuller test, by including k lags of $\Delta y_t$ in the estimated equation, as follows:

$$\Delta y_t = \mu + (\beta - 1)y_{t-1} + \delta t + \sum_{i=1}^{k} \gamma_i \Delta y_{t-i} + u_t$$  (35)

As noted in Campbell and Perron (1991), the choice of the truncation lag parameter k is an important issue, as too few lags may adversely affect the size of the test, while too many may reduce power. In order to overcome this problem, Campbell and Perron (1991, p.155) suggest a procedure to select k:

"Start with some upper bound on k, say $k_{\text{max}}$, chosen a priori. Estimate an autoregression of order $k_{\text{max}}$. If the last included lag is significant (using the standard normal asymptotic distribution), select $k=k_{\text{max}}$. If not reduce the order of the estimated autoregression by one until the coefficient on the last included lag is significant. If none is significant, select k=0."

The null hypothesis of this test is that the series contains a unit root, while the alternative is that it is stationary. However, the critical values for the t-statistic are non-conventional, as the non-stationarity of $y_t$ under the null causes the distribution to be non-standard. As such, the t-statistic for the OLS estimate of $\beta$ must be compared with the critical values tabulated in Dickey and Fuller (1981).

This approach would appear to be a straightforward way of distinguishing between neoclassical and Rebelo-type endogenous growth models. If output is non-stationary then shocks have permanent effects, which supports the endogenous specification. In contrast, if output is stationary then shocks have only a transitory effect on the series, which supports the neoclassical model.

However, Perron (1989) demonstrates that breaks in the series can
lead to biased results in favour of the null hypothesis. Instead, the test presented in Perron (1989) allows for the possibility of a one-time change in the level or in the slope of the trend function, and calculates appropriate critical values. With the introduction of the possibility of crash or trend breakpoints in the series, the model to be estimated becomes:

$$\Delta y_t = \mu + (\beta - 1)y_{t-1} + \delta t + \rho DT + \theta DU + \sum_{i=1}^{n} \gamma_i \Delta y_{t-i} + \epsilon_t \ (36)$$

where $DU=1$ for each period after the break, and zero otherwise, while $DT=t$ for each period after the break, and zero otherwise. It is shown that the size of these critical values depends upon the time of the break relative to total sample size, which is denoted as $\lambda$. As an example, Perron (1989) applies this technique to the variables analysed in Nelson and Plosser (1982).\(^5\) It is found that, for those series ending in 1970, if a break at the 1929 crash is postulated then, for 11 of the 14 series\(^6\) analysed in Nelson and Plosser (1982), the unit root hypothesis can be rejected. Furthermore, if an exogenous break in the trend function at the time of the oil price shock (1973) is postulated, then the null hypothesis of a unit root is also rejected for postwar quarterly real GNP.

It should be noted that Perron (1989, p.1361) assumes that the breaks in the series are exogenous, concluding that "[i]f one is ready to postulate that the 1929 crash and the slowdown in growth after 1973 are not realizations of an underlying time-invariant stochastic process but can be modelled as exogenous, then the conclusion is that most macroeconomic time series are not characterised by the presence of a unit root." Zivot and

\(^5\) Nelson and Plosser (1982) suggested that, based on an analysis of US data, most macroeconomic variables have a univariate time series structure with a unit root.

\(^6\) These series include real GNP, nominal GNP, real per capita GNP, industrial production, employment, GNP deflator, consumer prices, wages, real wages, the money stock, velocity, the interest rate, common stock prices, and postwar quarterly GNP.

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Andrews (1992) take issue with this assumption of exogeneity, and instead present a variation of Perron's (1989) test in which the breakpoint is estimated rather than fixed. It is argued that Perron's (1989) "choices of breakpoints are based on prior observation of the data and hence problems associated with "pre-testing" are applicable to his methodology" (Zivot and Andrews (1992, p.251)). In an application of this technique, Zivot and Andrews (1992) find that the unit root hypothesis cannot be rejected for 4 of the 10 series of Nelson and Plosser (1982) which were rejected by Perron (1989). However, Zivot and Andrews (1992, p.266) argue that:

"The reversals of some of Perron's results should not be construed as providing evidence for the unit-root null hypothesis, because the power of our test against Perron's trend-stationary alternatives is probably low for small to moderate changes in the trend functions. Rather, the reversals should be viewed as establishing that there is less evidence against the unit-root hypothesis for many of the series than the results of Perron indicate."

Testing for the non-stationarity of GDP in this thesis initially uses Dickey and Fuller's (1981) techniques, before allowing for the possibility of breaks in the series. However, a problem arises in that the techniques outlined in Perron (1989) and Zivot and Andrews (1992) only allow for the possibility of a single break in the series whereas, to take the US as an example, Perron (1989) found two structural breaks in the period considered.

Table 4.1 presents the estimated t-ratios and critical values for the augmented Dickey-Fuller (1981) tests. This table contains the estimated t-ratios for $y_{t-1}$ in (1), where the value of $k$ has been determined by the rule outlined in Campbell and Perron (1991). The results of these tests suggest that all variables except US output contain a unit root, which supports the endogenous concept of growth.

However, as already noted, Perron (1989) demonstrates that these Dickey-Fuller (1981) tests will be biased towards the null hypothesis if the
Table 4.1 Augmented Dickey-Fuller tests (ADF(k)) for non-stationarity

<table>
<thead>
<tr>
<th>Country</th>
<th>Period of estimation</th>
<th>Estimated t-value and order of ADF (k)</th>
<th>Critical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>1860-1989</td>
<td>-2.09 (2)</td>
<td>-3.4455</td>
</tr>
<tr>
<td>Canada</td>
<td>1870-1989</td>
<td>-3.14 (2)</td>
<td>-3.4484</td>
</tr>
<tr>
<td>France</td>
<td>1860-1989</td>
<td>-1.21 (3)</td>
<td>-3.4458</td>
</tr>
<tr>
<td>Germany</td>
<td>1860-1989</td>
<td>-2.93 (1)</td>
<td>-3.4455</td>
</tr>
<tr>
<td>Italy</td>
<td>1861-1989</td>
<td>-1.75 (1)</td>
<td>-3.4555</td>
</tr>
<tr>
<td>Japan</td>
<td>1885-1989</td>
<td>-1.44 (1)</td>
<td>-3.4535</td>
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<td>UK</td>
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<td>-2.37 (1)</td>
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<tr>
<td>US</td>
<td>1869-1989</td>
<td>-3.90** (1)</td>
<td>-3.4478</td>
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</table>

** indicates significant at the 0.05 level.

series contain an exogenous structural break. Table 4.2 contains the results of Perron-type unit root tests for those series that appear non-stationary using the Dickey-Fuller techniques, allowing for the possibility of a one-time change in intercept (crash), a one-time change in slope (trend), or a combination (crash and trend). The choice of possible break-points is, however, problematic. Zivot and Andrews (1992) specifically highlight the problems associated with pre-testing applicable to this technique. Despite these arguments, possible exogenous breaks can be postulated. Perron (1989) suggested that, for US data, there is a structural break (crash) due to the crash in 1929, and a slowdown in 1973 (trend-break) due to the oil price shock. For the UK, Greasley and Oxley (1994b) found trend discontinuities at 1914, 1920, 1973 and 1979. Hence, although any choice of break points is open to argument, this thesis suggests that the two World Wars, the 1929 crash and the 1973 oil price shocks can be treated as exogenous shocks. Table II contains the results of these tests for these...
possible breaks. However, since the two World Wars were of considerable length, it is difficult to determine at which point to test for a break. With this in mind, although the results from the conventional starting and ending dates are reported, some degree of searching occurred in the cases of Japan and Italy during WWII.

On the evidence presented, it appears that GDP in Canada, Germany, Japan, and the UK can be modelled as TS processes if a structural break is allowed. In the case of Canada, this break takes place in 1929, presumably due to the 1929 Crash; in Germany, WWI, the 1929 crash and WWII all appear to be significant breaks; in Japan, a break occurred around WWII; for the UK, only the shocks associated with WWI appear to have had a permanent effect on output. These inferences are made at the 0.05 level; tests at the 10 percent level suggest that Italian GDP can also be modelled as a TS process, with suitable break-points.
<table>
<thead>
<tr>
<th>Year</th>
<th>Crash</th>
<th>Trend</th>
<th>Crash and trend</th>
</tr>
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<td></td>
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Notes: \textsuperscript{w} denotes t-ratio determined using White’s adjusted covariance matrix. \textsuperscript{**} denotes significant at the 0.05 level. \textsuperscript{*} denotes significant at the 0.10 level.
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Notes: ^w: denotes t-ratio determined using White's-adjusted covariance matrix
**: denotes significant at the 0.05 level
*: denotes significant at the 0.10 level
Table 4.2 (continued)

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Notes: **: denotes significant at the 0.05 level  
*: denotes significant at the 0.10 level

This evidence is suggestive; the effect of shocks appears to be transitory for Canada, Germany, Japan, the UK and the US,\(^7\) which can be taken as evidence against the Rebelo-type endogenous specification. In contrast, the specified break points cannot overturn the unit root hypothesis for Australia, France, and Italy, which supports the endogenous specification.

It is also useful to examine postwar data on annual GDP per capita for the eight countries discussed above, as in Durlauf (1989), for several reasons. First, the quality of historical data is questionable. Maddison (1993) emphasises that, for data series prior to 1950, the estimates are nearly all made retrospectively, while Jaeger (1990) argues that before WWII "the method of linear trend interpolation was common and may induce a bias in favour of rejecting the unit root hypothesis" (Campbell and Perron (1991, p.153)). Second, the use of long sample periods increases the possibility that

\(^7\) This inference is based on the assumption that WWI, WWII and the 1929 Crash can be treated as exogenous shocks to the economy.
the series are affected by a major structural change. This limited data set does, however, give rise to problems in terms of the power of the tests.

**Table 4.3** Augmented Dickey-Fuller tests for real GDP per capita, 1950 to 1990

<table>
<thead>
<tr>
<th>Country</th>
<th>Estimated t-ratio</th>
<th>Critical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>-2.53</td>
<td>-3.53</td>
</tr>
<tr>
<td>Canada</td>
<td>-2.37</td>
<td>-3.53</td>
</tr>
<tr>
<td>France</td>
<td>-2.57</td>
<td>-3.53</td>
</tr>
<tr>
<td>Germany</td>
<td>-2.01</td>
<td>-3.53</td>
</tr>
<tr>
<td>Italy</td>
<td>-2.80*</td>
<td>-3.53</td>
</tr>
<tr>
<td>Japan</td>
<td>-1.15</td>
<td>-3.53</td>
</tr>
<tr>
<td>UK</td>
<td>-2.11</td>
<td>-3.53</td>
</tr>
<tr>
<td>US</td>
<td>-2.84</td>
<td>-3.53</td>
</tr>
</tbody>
</table>

Notes: *w*: denotes t-ratio determined using White's-adjusted covariance matrix

Despite these difficulties, data on real GDP per capita from Summers and Heston (1991) are analysed to distinguish between exogenous and endogenous models of growth. Table 4.3 contains results from the initial Augmented Dickey-Fuller tests for the 8 industrialised countries considered previously. These estimates suggest that, without allowance for the possibility of a structural break, all series are nonstationary.

As with the long-run analysis of output data, it is also possible to use the techniques outlined in Perron (1989) to test for unit roots while allowing for the possibility of an exogenous structural break. In this case, only one possible break point was included, relating to the 1973 oil price shocks. Table 4.4 contains estimates from tests incorporating the possibility of a crash, trend-break, or a combination of crash and trend-break in 1973.
The results from these tests suggest that, given the low power of the tests due to the small sample size, not all series should be modelled as DS. At conventional levels of significance, the inclusion of a crash dummy variable in 1973 implies that Canada, Italy and the US can be modelled as TS processes. This can be compared with the results obtained from the long-run analysis of GDP series considered earlier, in which the inclusion of suitable dummy variables suggested that Canada, Germany, Japan, the UK and the US could be modelled as TS processes.

Hence, despite differences in sample size and output measure, these tests are suggestive. In the case of Canada and the US, both analyses with long-run GDP data and shorter-term GDP per capita data suggest that output in these countries can be modelled as TS processes with suitable break points, which can be considered to be evidence against the Rebelo-type endogenous specification. A second group comprises Germany, Japan, and the UK, for which the long-run data imply that these series can be described by TS processes, although this is not supported by the shorter sample analysis. Third, in the case of Italy, the shorter term data imply that output is TS, while the long-run data suggest it is DS. Finally, both the long-run and shorter-term data suggest that output in Australia and France should be modelled as a DS process.

To complement the tests for non-stationarity, the results from the Cochrane-type (1988) estimates of persistence are presented in Table 4.5 for all 8 countries. Three different window lengths of the Bartlett estimator are estimated; for k=5, k=30, and k given by the Chatfield (1989) criterion. Furthermore, the Cochrane (1988) measure of persistence is determined over prewar and postwar subsamples, in addition to the entire sample period. These sub-sample estimates are important, as Cochrane (1988) demonstrates

---

8 The Chatfield (1989) criterion for the choice of window length sets the window size at \(2T^{1/2}\), where \(T\) is the effective sample size.
### Table 4.4

Tests for nonstationarity of postwar GDP per capita using Perron's (1989) technique

<table>
<thead>
<tr>
<th>Year of break</th>
<th>Crash</th>
<th>Trend</th>
<th>Crash and trend</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Australia</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1973</td>
<td>-3.41</td>
<td>-3.00</td>
<td>-0.99</td>
</tr>
<tr>
<td><strong>Canada</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1973</td>
<td>-3.75**</td>
<td>-3.48</td>
<td>-1.18</td>
</tr>
<tr>
<td><strong>France</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1973</td>
<td>-3.56*</td>
<td>-2.52</td>
<td>-1.99</td>
</tr>
<tr>
<td><strong>Germany</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1973</td>
<td>-2.96</td>
<td>-2.94</td>
<td>-2.69</td>
</tr>
<tr>
<td><strong>Italy</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Japan</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1973</td>
<td>-0.41W</td>
<td>-0.52W</td>
<td>-2.41</td>
</tr>
<tr>
<td><strong>UK</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1973</td>
<td>-2.44</td>
<td>-2.17</td>
<td>-0.02</td>
</tr>
<tr>
<td><strong>US</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1973</td>
<td>-4.03**</td>
<td>-3.57</td>
<td>-0.20</td>
</tr>
</tbody>
</table>

Notes:  
- **W**: denotes t-ratio determined using White's-adjusted covariance matrix  
- ****: denotes significant at the 0.05 level  
- *: denotes significant at the 0.10 level

that measures of persistence constructed for periods of different growth rates will be biased towards finding too much persistence.
Table 4.5 Cochrane (1988) measures of persistence

<table>
<thead>
<tr>
<th>Sample Period</th>
<th>k=5</th>
<th>k=30</th>
<th>k=Chatfield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1860-1989</td>
<td>1.1710</td>
<td>0.9797</td>
<td>1.0574</td>
</tr>
<tr>
<td></td>
<td>(0.2662)</td>
<td>(0.5455)</td>
<td>(0.5042)</td>
</tr>
<tr>
<td>1860-1939</td>
<td>1.0787</td>
<td>0.8333</td>
<td>0.9760</td>
</tr>
<tr>
<td></td>
<td>(0.3133)</td>
<td>(0.5929)</td>
<td>(0.5380)</td>
</tr>
<tr>
<td>1945-1989</td>
<td>1.6587</td>
<td>0.8400</td>
<td>1.7020</td>
</tr>
<tr>
<td></td>
<td>(0.6384)</td>
<td>(0.7919)</td>
<td>(1.0962)</td>
</tr>
<tr>
<td>Canada</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1870-1989</td>
<td>1.4962</td>
<td>0.6074</td>
<td>0.8225</td>
</tr>
<tr>
<td></td>
<td>(0.3541)</td>
<td>(0.3521)</td>
<td>(0.4084)</td>
</tr>
<tr>
<td>1870-1939</td>
<td>1.3532</td>
<td>0.5455</td>
<td>0.7775</td>
</tr>
<tr>
<td></td>
<td>(0.4206)</td>
<td>(0.4153)</td>
<td>(0.4323)</td>
</tr>
<tr>
<td>1945-1989</td>
<td>1.3214</td>
<td>0.6778</td>
<td>1.1494</td>
</tr>
<tr>
<td></td>
<td>(0.5086)</td>
<td>(0.6390)</td>
<td>(0.7403)</td>
</tr>
<tr>
<td>France</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1860-1989</td>
<td>1.4759</td>
<td>1.2129</td>
<td>1.1649</td>
</tr>
<tr>
<td></td>
<td>(0.3355)</td>
<td>(0.6754)</td>
<td>(0.5555)</td>
</tr>
<tr>
<td>1860-1939</td>
<td>0.7881</td>
<td>0.1511</td>
<td>0.2072</td>
</tr>
<tr>
<td></td>
<td>(0.2289)</td>
<td>(0.1075)</td>
<td>(0.1142)</td>
</tr>
<tr>
<td>1945-1989</td>
<td>1.7717</td>
<td>2.5630</td>
<td>2.3306</td>
</tr>
<tr>
<td></td>
<td>(0.6819)</td>
<td>(2.4164)</td>
<td>(1.5011)</td>
</tr>
</tbody>
</table>

Notes: k denotes the window size for the Bartlett estimator. Figures in parentheses are asymptotic standard errors.
<table>
<thead>
<tr>
<th>Sample period</th>
<th>k=5</th>
<th>k=30</th>
<th>k=Chatfield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Germany</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1860-1989</td>
<td>1.2372 (0.2812)</td>
<td>0.4435 (0.2470)</td>
<td>0.5811 (0.2771)</td>
</tr>
<tr>
<td>1860-1939</td>
<td>1.1124 (0.3232)</td>
<td>0.4705 (0.3348)</td>
<td>0.7307 (0.4027)</td>
</tr>
<tr>
<td>1945-1989</td>
<td>1.2480 (0.4803)</td>
<td>0.4171 (0.3933)</td>
<td>0.8344 (0.5374)</td>
</tr>
<tr>
<td><strong>Italy</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1860-1989</td>
<td>1.3085 (0.2986)</td>
<td>1.4936 (0.8349)</td>
<td>1.4384 (0.6886)</td>
</tr>
<tr>
<td>1860-1939</td>
<td>0.9358 (0.2736)</td>
<td>0.4852 (0.3475)</td>
<td>0.7141 (0.3961)</td>
</tr>
<tr>
<td>1945-1989</td>
<td>0.6393 (0.2460)</td>
<td>0.7864 (0.7414)</td>
<td>0.7847 (0.5054)</td>
</tr>
<tr>
<td><strong>Japan</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1885-1989</td>
<td>1.2133 (0.3072)</td>
<td>1.1501 (0.7133)</td>
<td>1.2442 (0.6300)</td>
</tr>
<tr>
<td>1885-1939</td>
<td>0.4654 (0.1635)</td>
<td>0.2587 (0.2226)</td>
<td>0.3764 (0.2213)</td>
</tr>
<tr>
<td>1945-1989</td>
<td>1.0480 (0.4034)</td>
<td>0.5696 (0.5370)</td>
<td>0.9877 (0.6362)</td>
</tr>
</tbody>
</table>

Notes: k denotes the window size for the Bartlett estimator. Figures in parentheses are asymptotic standard errors.
The first point to be noted about these results is that the standard errors are large. Indeed, in most cases it is not possible to distinguish between the stationary and nonstationary hypotheses. However, as argued in Cochrane (1988, p.916), the "standard errors of univariate estimates of random walk components will remain large in century-long macroeconomic data and larger still in postwar macroeconomic data because there are inherently few nonoverlapping long runs available."

Second, looking at \( k=30 \) and the Chatfield window sizes, when estimated over the entire sample period only the results for Germany and the US support the hypothesis that output is stationary. Thus, only for Germany and the US can the null of a zero value be accepted and the null of a unitary value be rejected. By comparison, the estimates and standard
errors for the other output series are high, which suggests a greater degree of persistence. For example, the point estimates of persistence for Australia, France, Italy, and Japan are 0.9797, 1.2129, 1.4936 and 1.1501, respectively.

Third, when the Cochrane (1988) measure is estimated over the subsamples, allowing for a break at WWII, the estimates of the degree of persistence are generally substantially reduced, especially for the prewar period. For example, while the point estimate of persistence for Italy over the entire sample period is 1.4936, the estimates for prewar and postwar persistence are 0.4852 and 0.7864, respectively. In the case of Japan, while the estimate over the whole sample period is 1.1501, prewar and postwar persistence are estimated at 0.2587 and 0.5696, respectively. Greasley and Oxley (1994b) suggest that the existence of structural breaks in output led Leung (1992) to overstate Twentieth Century levels of persistence. Indeed, the estimates presented in Table 5.5 support this interpretation.

Fourth, although the standard errors are large, it appears that there is evidence of a greater degree of postwar persistence compared with prewar, except in the case of Germany. The most pronounced instance of this is for France, where the prewar estimate of persistence is 0.1511, while the postwar estimate is 2.5630. However, it should be noted that the standard errors for the postwar measures are large, due to the small sample size available for estimation.

Fifth, the k=5 window size, which is similar to the low-order ARMA measure of persistence suggested in Campbell and Mankiw (1987), indicates a much higher degree of persistence than that suggested by the larger window sizes. However, Greasley and Oxley (1994b, p.11) suggest "that results based upon low valued k are spurious."

Despite the combination of evidence from unit root tests and
Cochrane's (1988) measure of persistence, it is difficult to describe the results as anything but inconclusive. The Perron-type (1989) tests for nonstationarity suggest that, in the long run, only output in Australia, France and Italy can reasonably be characterised as a DS process. In contrast, tests for nonstationarity that allow for a suitable structural break reject the null hypothesis of a unit root for Canada, Germany, Japan, the UK and the US. However, as already noted, testing for unit roots against the TS alternative may be an extreme way of characterising the persistence of output shocks. To this end, estimates of Cochrane's (1988) measure of persistence were presented. These results also tended to be inconclusive due to large standard errors. However, it could be argued that countries such as Australia, France and Italy exhibit greater persistence of output shocks, particularly in the postwar period.

Despite these results, it is important to bear in mind the underlying problems involved in testing for unit roots. First, as emphasised in Campbell and Perron (1991), Cochrane (1991) and Miron (1991), unit roots and stationary processes cannot easily be distinguished in finite samples. Indeed, "any trend stationary process can be arbitrarily well approximated by a unit root process (and vice versa) in a sample of a given size" (Miron (1991, p.211)). On the basis of this theoretical criticism, Cochrane (1991, p.202) suggests that "the search for tests that will sharply distinguish the two classes in finite samples is hopeless." This point is taken further by Miron (1991) where it is argued that, if it is impossible to distinguish between DS and TS, then any result that relies on such a distinction is inherently uninteresting.

This criticism directly subverts the idea that unit root tests can be used to distinguish between the neoclassical and Rebelo-type endogenous models of economic growth. Indeed, King et al. (1988b) and Neusser (1991) develop variants of the neoclassical model under uncertainty, which also
generate nonstationarity in output. Furthermore, Miron (1991) also argues that, if it is impossible to distinguish between TS and DS processes, then it is uninteresting to test for cointegration since, "at a general level, cointegration presumes integration" (Miron (1991, p.213)). Nevertheless, testing for cointegration in the context of the model described in Lau (1994) is useful, since a rejection of the hypothesis that there will be \( n-1 \) cointegrating vectors in an \( n \)-variable system can be regarded as evidence against the Rebelo-type endogenous growth specification.

The conclusion that can be reached from the available evidence is that, although it is difficult to confidently describe the output in the 8 industrialised countries considered in this paper as DS, there is much less evidence for nonstationarity of output than is suggested in Nelson and Plosser (1982) and Campbell and Mankiw (1987). Furthermore, evidence based on the results of Cochrane's (1988) test for persistence suggests that the smaller nations in the sample, in particular Australia, exhibit a greater degree of persistence than the larger nations. Indeed, the unit root tests of Perron (1989) could not reject the null hypothesis of nonstationarity for Australia, France and Italy.

3. Endogenous Growth and Cointegration

The 'generic' endogenous growth model presented in Lau (1994) implied that there should be \( n-1 \) cointegrating vectors in a system of \( n \) variables. This result suggests an important test of the Rebelo-type endogenous growth model. First, however, it is useful to outline the concept of cointegration and the methods whereby it may be tested. Following Engle and Granger (1987), suppose there exists a vector \( x_t \), containing \( n \) variables, all of which are non-stationary. These variables can be described as

\[ x_t = \begin{bmatrix} x_{1t} \\ x_{2t} \\ \vdots \\ x_{nt} \end{bmatrix} \]

These variants of the neoclassical model will generate nonstationary growth if technological shocks are specified as stochastic processes of order one.
cointegrated if there exists a linear combination of the form:

\[ z_t = \alpha' x_t \]  \hspace{1cm} (37)

such that \( z_t \) is stationary. In this case, \( \alpha \) is known as the cointegrating vector.

Two methods for testing for cointegration will be outlined here. The first is based on the analysis of the residuals of a static regression. If the vector \( x_t \) is partitioned into \( (x_{1t}, x_{2t}) \), where \( x_{1t} \) is a scalar nonstationary variable and \( x_{2t} \) is an \( m \)-element vector of nonstationary variables, then the following regression can estimated:

\[ x_{1t} = \alpha' x_{2t} + u_t \]  \hspace{1cm} (38)

Hence, the hypothesis that \( x_{1t} \) and \( x_{2t} \) are not cointegrated can be understood as the hypothesis that there does not exist any vector of coefficients \( \alpha \) such that \( u_t = x_{1t} - \alpha x_{2t} \) is stationary. Campbell and Perron (1991, p.175) suggest that a "straightforward approach is to apply OLS to [38] and conduct a unit root test on the estimated residuals, \( e_t \), as a proxy for the true residuals." However, the critical values for these tests are not the same as those applied to raw data, as they depend on the number of integrated regressors in (38) and whether these regressors contain a trend. Phillips and Ouliaris (1990) tabulate the critical values for this test of cointegration, based on asymptotic theory.

A second technique for testing for cointegration has been developed in Johansen (1988, 1989). Again, consider the vector \( x_t \) which contains \( n \) variables, all of which are nonstationary. This vector can be given the autoregressive representation:

\[ x_t = c + \sum_{i=1}^{k} \pi_i x_{t-i} + e_t \]  \hspace{1cm} (39)

where \( c \) is a constant and \( k \) is chosen such that the residuals exhibit white
noise properties. This system can then be rearranged as follows:

\[ \Delta x_t = c + \sum_{i=1}^{k-1} \Gamma_i \Delta x_{t-i} + \Pi x_{t-k} + e_t \]  

(40)

\[ \Gamma_j = -(I - \sum_{i=1}^{j} \pi_i) \]  

(41)

\[ \Pi = -(I - \sum_{i=1}^{k} \pi_i) \]  

(42)

where I is the identity matrix. As described in Muscatelli and Hurn (1992), this system will only be balanced\(^{10}\) if \(\Pi = 0\), in which case the variables in the vector \(x_t\) are not cointegrated, or if the parameters of \(\Pi\) are such that \(\Pi x_{t-k}\) is also stationary. In this second case, the rank of the matrix \(\Pi\), \(r\), is known as the order of cointegration.

The matrix \(\Pi\) can be further decomposed into:

\[ \Pi = \alpha \beta' \]  

(43)

where \(\beta\) is the matrix containing the \(r\) cointegrating vectors, and \(\alpha\) is the matrix of (adjustment) weights associated with each cointegrating vector. Johansen’s (1988) maximum likelihood procedure to estimate these matrices is described in Muscatelli and Hurn (1992) as follows. The first step is to estimate the following regressions:

\[ \Delta x_t = c + B_{01} \Delta x_{t-1} + \ldots + B_{0k-1} \Delta x_{t-k+1} + R_{01} \]  

(44)

\[ x_{t-k} = d + B_{k1} \Delta x_{t-1} + \ldots + B_{kk-1} \Delta x_{t-k+1} + R_{kz} \]  

(45)

where \(d\) is a constant. The fitted residuals from (44) and (45) are then used to construct the product moment matrices given by:

\(10\) In this sense, the term "balanced" refers to a system in which the degree of integration is the same on both sides of the equations.
These matrices are used to find the cointegrating vectors by solving:

$$\lambda S_{kk} - S_{kk}^{-1}S_{0k} = 0.$$  (47)

This gives rise to $n$ estimated eigenvalues $(\lambda_1, \ldots, \lambda_n)$ and $n$ estimated eigenvectors $(v_1, \ldots, v_n)$, which are then normalised, such that:

$$V'S_{kk}V = I$$  (48)

where $V$ is the matrix of estimated eigenvectors. Hence, the $r$ cointegrating vectors are given by the $r$ most significant eigenvectors, so that:

$$\hat{\beta} = (v_1, \ldots, v_r).$$  (49)

Johansen (1988) suggests two statistics that can be used to determine $r$, given by:

$$\Lambda_1(q, n) = -T \sum_{i=q+1}^{n} \log(1 - l_i)$$  (50)

and

$$\Lambda_2(q, q+1) = -T \log(1 - l_{q+1}).$$  (51)

The statistic described in (50) tests the null hypothesis that $r \leq q$ against the alternative $r > q$, while the second statistic in (51) tests the null hypothesis $r = q$ against the alternative $r = q + 1$.

Before a set of variables can be tested for cointegration, it is necessary to determine whether they are nonstationary. Table 4.6 contains the results from Augmented Dickey-Fuller tests for unit roots from the output, consumption and capital stock series for 7 countries.

The data used to construct these series come from OECD estimates, and is
Table 4.6 Tests for nonstationarity on output, consumption and capital stock series

<table>
<thead>
<tr>
<th></th>
<th>Output</th>
<th>Consumption</th>
<th>Capital stock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>-0.971</td>
<td>-0.797</td>
<td>-1.556</td>
</tr>
<tr>
<td>France</td>
<td>-1.509</td>
<td>-1.413</td>
<td>-1.198</td>
</tr>
<tr>
<td>Germany</td>
<td>-2.149*</td>
<td>-0.923</td>
<td>-1.891*</td>
</tr>
<tr>
<td>Italy</td>
<td>-0.986</td>
<td>-0.496</td>
<td>-2.330</td>
</tr>
<tr>
<td>Japan</td>
<td>-1.347</td>
<td>-1.260</td>
<td>-1.039*</td>
</tr>
<tr>
<td>UK</td>
<td>-2.576</td>
<td>-3.410</td>
<td>-0.239</td>
</tr>
<tr>
<td>US</td>
<td>-2.962</td>
<td>-2.732</td>
<td>0.163</td>
</tr>
</tbody>
</table>

Notes: *w:* denotes t-ratio determined using White's-adjusted covariance matrix.
None of the estimated t-ratios rejects the null hypothesis of a unit root at conventional levels.
All three variables, output, consumption and capital stock, are expressed as logarithms.

The results in Table 4.6 suggest that all 21 series are nonstationary, although no effort is made to determine whether the data series contain structural breaks. Despite the criticisms outlined in Cochrane (1991) and Miron (1991) as to the possibility that these tests can differentiate between TS and DS processes, the data on consumption and the capital stock can be used to test the Rebelo-type endogenous specification of growth.
Specifically, Lau (1994) shows that within a Rebelo-type growth model, consumption and the capital stock are cointegrated and, furthermore, that the cointegrating vector is $(1, -1)'$.

However, the results from this data set do not support this type of steady state endogenous growth model. Testing for cointegration involved the use of both the residual based tests and Johansen’s (1988) maximum likelihood procedures. Table 4.7 contains the results from the residual based tests, which involve regressing consumption on the capital stock and an intercept, then testing whether the residuals from this regression are stationary. These results suggest that consumption and the capital stock are cointegrated for only one country in the sample, namely Italy.

Table 4.7  Residual-based tests for cointegration on consumption and capital stock series over the period 1960 to 1994

<table>
<thead>
<tr>
<th>Country</th>
<th>Estimated coefficient on capital stock</th>
<th>Test statistic from ADF(1) test on residuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>0.8392</td>
<td>-1.0673</td>
</tr>
<tr>
<td>France</td>
<td>0.8501</td>
<td>-2.5541</td>
</tr>
<tr>
<td>Germany</td>
<td>0.7878</td>
<td>-2.2896</td>
</tr>
<tr>
<td>Italy</td>
<td>1.0570</td>
<td>-3.5193*</td>
</tr>
<tr>
<td>Japan</td>
<td>0.5960</td>
<td>-2.2320</td>
</tr>
<tr>
<td>UK</td>
<td>0.7708</td>
<td>-1.4295</td>
</tr>
<tr>
<td>US</td>
<td>0.7805</td>
<td>-2.9590</td>
</tr>
</tbody>
</table>

Note: * denotes the test statistic is significant at the 0.05 level.

The second procedure for testing for cointegration uses the techniques outlined in Johansen (1988). However, the results from these tests are similar to those suggested by the residual based tests. These tests
were performed assuming the existence of a trend in the data generating process, and considered alternative numbers of lags in the vector autoregressive (VAR) process. Only in three cases did these procedures suggest that there was exactly one cointegrating vector between consumption and the capital stock, and this result was sensitive to the number of lags in the VAR process.

When the lag of the VAR was two, the data series for Canada appeared to contain exactly one cointegrating vector, which was estimated to be \((-1, 1.2815)\)'. In addition, a test restricting this vector to equal \((-1, 1)\) could not be rejected at conventional levels of significance, with \(\chi^2(1)=1.9799\). The second case involved the series for Germany, for which tests suggested the existence of exactly one cointegrating vector when the lag of the VAR was four. The cointegrating vector was estimated to be \((-1, 0.56513)\), and a test restricting this vector to that suggested in Lau (1994) was rejected at conventional levels, with \(\chi^2(1)=14.184\). Finally, the series for the UK were estimated to have exactly one cointegrating vector when the lag of the VAR was four. This vector was estimated to be \((-1, -1.8640)\), and a test imposing the restriction suggested in Lau (1994) was again rejected at conventional levels, with \(\chi^2(1)=12.4150\).

However, as already noted, these results are sensitive to the number of lags included in the VAR process. Hence, these results do not support the Rebelo-type endogenous growth model, in which Lau (1994) demonstrates consumption and the capital stock are cointegrated. However, the tests presented in this thesis are based on a relatively small data set (68 observations), and a measure of capital stock that does not include human capital.

Further tests of the endogenous specification based on the existence of cointegrating vectors are suggested in Durlauf (1989, p.88), who argues:
"If technological shocks represent the basis of persistence in output innovations, then one would expect that long-run growth rates of industrialised countries would be related at least with lags. One test of the technology interpretation of persistence is the tendency of permanent innovations in one country to migrate eventually to another."

This argument suggests that output in advanced countries should be cointegrated, as technological advances in one country should be associated with technological advances in another. Durlauf (1989) tests this hypothesis using the techniques outlined in Engle and Granger (1987), based on the analysis of the residuals of a static regression. Essentially, if output in two countries, GDP_{it} and GDP_{jt}, both contain a unit root, then a test of cointegration of these series is based on the analysis of the estimates of the residuals, e_t, from the following regression:

\[ GDP_{it} = c + \gamma GDP_{jt} + e_t \]  \hspace{1cm} (52)

If the series e_t do not contain a unit root, this suggests that the two output series are cointegrated. Based on these tests, Durlauf (1989) finds that, in an analysis of 5 industrialised economies, the null hypothesis of no cointegration is not rejected at conventional levels of significance in all 15 tests for possible cointegration between two series.

In contrast with this analysis, alternative methods to test for cointegration between series are available, notably that described in Johansen (1988). Table 4.8 contains the results of tests for cointegration using Johansen's (1988) procedures on the long-run GDP data, while Table 4.9 contains the results for GDP per capita over the shorter sample period. Note that Table 4.8 does not consider the possibility of cointegration between the US and other countries. This is because the results of

11 These countries are Japan, France, West Germany, the UK and the US, while the data used in the analysis are the logarithms of real GDP per capita from 1950 to 1985, as reported in Summers and Heston (1988).
Augmented Dickey-Fuller tests suggested that US GDP was TS, without the necessity of including a break point. These results suggest that, in contrast to those reported by Durlauf (1989), output for many pairs of countries are cointegrated. In the case of the long-run GDP data, the tests for cointegration suggest that output in France is cointegrated with that in Germany, Italy and Japan; output in Germany is additionally cointegrated with that in Italy and the UK; while output in Italy is additionally cointegrated with that in Japan.

Tests on the shorter-run GDP per capita data suggest an even greater incidence of cointegration between output series. Output in Australia is cointegrated with that in France, Germany, Italy, Japan, the UK and the US. Canadian GDP is cointegrated with that in Germany, Japan, the UK and the US. In addition, output in France is cointegrated with output in Germany and the UK; output in Germany is cointegrated with that in Italy, the UK and the US; output in Japan is cointegrated with that in the UK and the US; and output in the UK is cointegrated with output in the US.

As noted previously, these results differ from those reported in Durlauf (1989), who found no evidence of cointegration between output in 6 industrialised economies over the period 1950 to 1985. Durlauf (1989, p.90) concluded that "[t]he collective results of this table strongly suggest the importance of domestic conditions and institutions in determining the long-run characteristics of economic growth." In contrast, the results reported in this section support the technological shock interpretation of unit roots, and hence the Rebelo-type endogenous specification of growth.

4. Conclusions

This chapter has examined the time series properties of data to differentiate between the neoclassical and Rebelo-type endogenous concepts of growth. First, long-run output was tested for stationarity, as the analysis
in Lau (1994) demonstrated that endogenous growth models that possess steady state growth paths will contain a unit root, even though shocks to the system are stationary. The results from the Augmented Dickey-Fuller tests for unit roots suggested that only US output could be regarded as stationary, while tests for the other seven countries could not reject the null hypothesis of nonstationarity. However, Perron (1989) argues that the existence of structural breaks in a given series can lead to biased results in favour of the null hypothesis. When the possibility of exogenous structural breaks was considered, it was found that unit root tests on output in Canada, Germany, Japan and the UK also rejected the null hypothesis of nonstationarity. Hence, of the eight industrialised nations considered, only output in Australia, France and Italy appeared to be nonstationary.

However, Greasley and Oxley (1994b, p.1) argue that "interpreting time series as either TS or DS, and by implication output innovations as either transitory or infinitely persistent, may be extreme." In order to examine the degree of persistence in evidence in long-run output, Cochrane's (1988) measure of persistence is estimated. These results suggest that, despite large standard errors, there is less evidence for the nonstationarity of output than is suggested in Nelson and Plosser (1982) and Campbell and Mankiw (1987).

Hence, when the results from these tests are combined with the criticisms of unit root testing, in general, outlined in Cochrane (1991) and Miron (1991), it is difficult to find evidence in time series data to strongly support either the neoclassical or Rebelo-type endogenous specifications of growth. However, there does appear to be a greater degree of persistence in output shocks in small countries such as Australia.

The tests for cointegration presented in Section 3 examined two separate aspects of endogenous growth models. The first set of tests was based on Lau's (1994) analysis of endogenous growth models that possess
steady state growth paths, which demonstrated that, within a Rebelo-type (1991) model, consumption and the capital stock will be cointegrated with cointegrating vector \((1, -1)\)' \(179\). The evidence from these tests is, in general, unsupportive of Lau's (1994) hypothesis, that is, there is little evidence to suggest that consumption and the capital stock are cointegrated. There are, however, some caveats that must be observed. First, the size of the sample was not large, due to the problems in obtaining consistent estimates of stocks of physical capital. Second, the estimates of capital stock did not include human capital.

The second set of tests examined the evidence for the cointegration of output between countries. This was motivated by the analysis in Durlauf (1989, p.88), who suggested that "[i]f technological shocks represent the basis of persistence in output innovations, then one would expect that long-run growth rates of industrialised countries would be related at least with lags." The results from these Johansen (1988) tests suggest that there is considerable evidence of cointegration of output between countries, especially in postwar GDP per capita data.

However, this evidence cannot necessarily be taken to support the endogenous specification, as it is simply indicative of the importance of technological shocks in forming the basis of persistence. An alternative interpretation of these results is that they support the catch-up hypothesis of convergence, that is, these results may be taken to indicate the degree to which follower countries adopt the technological innovations developed in leader countries.

Hence, while it was argued in Chapter 3 that estimates from cross-country postwar data are unable to distinguish between neoclassical and endogenous specifications of growth, the time series evidence presented in this chapter is also ambiguous. Indeed, in reference to tests for nonstationarity, Cochrane (1991, p.202) argues that "the search for tests that
will sharply distinguish the two classes in finite samples is hopeless." On this basis, this thesis argues that the attempt to differentiate between these alternative modelling specifications using aggregate level data is inconclusive.
<table>
<thead>
<tr>
<th>Country</th>
<th>Australia</th>
<th>Canada</th>
<th>France</th>
<th>Germany</th>
<th>Italy</th>
<th>Japan</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>9.1 9.5</td>
<td>6.9 8.4</td>
<td>9.5 9.6</td>
<td>11.6</td>
<td>5.6 8.5</td>
<td>6.4 9.1</td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>3.4 4.4</td>
<td>10.3 10.5</td>
<td>5.4 6.2</td>
<td>3.5 4.4</td>
<td></td>
<td>7.3 7.8</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>18.7* 20.2* (-1, 0.692)</td>
<td>21.5* 22.3* (-1, 0.729)</td>
<td>26.4* 26.8* (-1, 0.544)</td>
<td></td>
<td>11.9 14.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td></td>
<td>17.8* 20.1* (-1, 1.090)</td>
<td></td>
<td>10.1 11.1</td>
<td>17.2* 17.5* (-1, 1.501)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td></td>
<td></td>
<td>32.8* 32.8* (-1, 0.691)</td>
<td></td>
<td>6.9 9.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.7 8.4</td>
<td></td>
</tr>
</tbody>
</table>

Notes: The first number in each box is the statistic based on the maximal eigenvalue of the stochastic matrix, while the second is based on the trace of the stochastic matrix. If either of these tests is significant at the 0.05 level, the estimated cointegrating vector is presented below. These tests are determined using one lag in the VAR process.

*: indicates that the statistic is significant at the 0.05 level.
Table 4.9  Tests for cointegration on postwar GDP per capita using Johansen’s (1988) techniques

<table>
<thead>
<tr>
<th>Country</th>
<th>Australia</th>
<th>Canada</th>
<th>France</th>
<th>Germany</th>
<th>Japan</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>12.8</td>
<td>15.1</td>
<td>10.7</td>
<td>12.4</td>
<td>15.0</td>
<td>13.2</td>
</tr>
<tr>
<td>Canada</td>
<td>(1.0312)</td>
<td>(1.169)</td>
<td>(1.149)</td>
<td>(1.096)</td>
<td>(1.0930)</td>
<td>(1.068)</td>
</tr>
<tr>
<td>France</td>
<td>21.0†</td>
<td>21.1†</td>
<td>20.5†</td>
<td>22.9†</td>
<td>22.5†</td>
<td>18.8†</td>
</tr>
<tr>
<td>Germany</td>
<td>26.9†</td>
<td>27.2†</td>
<td>27.3†</td>
<td>20.4†</td>
<td>21.2†</td>
<td>18.8†</td>
</tr>
<tr>
<td>Japan</td>
<td>17.0†</td>
<td>21.1†</td>
<td>17.3†</td>
<td>17.8†</td>
<td>17.1†</td>
<td>21.0†</td>
</tr>
<tr>
<td>UK</td>
<td>23.9†</td>
<td>26.8†</td>
<td>5.8</td>
<td>11.4</td>
<td>9.4</td>
<td>9.4</td>
</tr>
</tbody>
</table>

Notes: The first number in each box is the statistic based on the maximal eigenvalue of the stochastic matrix, while the second is based on the trace of the stochastic matrix. If either of these tests is significant at the 0.05 level, the estimated cointegrating vector is presented below. * indicates that the statistic is significant at the 0.05 level.

These tests are determined using one lag in the VAR process.
CHAPTER 5  CONCLUSIONS

The previous chapter argued that, on the basis of the time series evidence presented, there is little support for the Rebelo-type endogenous specification of growth. This result supports the conclusion of Greasley and Oxley (1994a), which also found little support in US data for Rebelo-type growth. Although this thesis employed unit root and cointegration tests in an attempt to distinguish between the two alternative classes of growth models, the criticisms of Cochrane (1991) and Miron (1991) were recognised. These authors argued that, as it is impossible to distinguish between DS and TS processes in finite samples, any result that relies on such a distinction is inherently uninteresting. It can be argued that this criticism appears to subvert the approach adopted in Greasley and Oxley (1994a,b) and in this thesis. However, evidence based on Cochrane's (1988) measure of persistence is also presented in this thesis. On this basis, it is argued that Rebelo's (1991) assumption of constant returns to scale in production finds little support empirically.

Although this thesis has concluded that cross-country and time series data cannot differentiate between the exogenous and Rebelo-type endogenous growth models, the evidence on persistence from these two sources suggests that policy is able to influence growth rates over long periods of time. Hence, from a policy perspective, Dowrick (1992, p.114-5) argues that:

"the focus of economic policy analysis on static inefficiencies in resource allocation may be misplaced. If the new growth theories are correct - and is it is possible accurately to target policies to exploit opportunities for stimulating endogenous growth - the gains from policy intervention are potentially much larger than those gains identified by static analysis of market failure and externalities."
It must be observed, however, that the time series evidence presented in this thesis only considers a particular class of endogenous growth models. Although the evidence presented rejects Rebelo's (1991) specification of endogenous growth, this should not be taken to imply that the neoclassical model is supported. Indeed, the lack of support for a Rebelo-type specification of growth suggests that the endogenous growth models based on externalities and monopoly power, of the sort suggested in Lucas (1988) and Romer (1990), appear to be a more fruitful approach, although this conclusion is subject to greater effort in empirical verification. This last point is important; Pack (1994, p.69) argues that, although the "major contribution of endogenous growth theory has been to reinvigorate the investigation of the determinants of long-term growth ... endogenous growth theory has led to little tested empirical knowledge."
# APPENDIX 1

## SUMMARY OF THE EMPIRICAL LITERATURE ESTIMATING THE EFFECT OF GOVERNMENT SIZE ON ECONOMIC GROWTH

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Data</th>
<th>Dependent variable</th>
<th>Method of estimation</th>
<th>Measure of government size</th>
<th>Estimated sign of government size variable(s)</th>
<th>Diagnostic tests used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alexander (1990)</td>
<td>1959-84; 17 OECD countries; time series and pooled data</td>
<td>Growth rate of real per capita GDP</td>
<td>OLS</td>
<td>Growth rate of ratio of government consumption to GDP</td>
<td>Negative</td>
<td>DW</td>
</tr>
<tr>
<td>Barro (1990)</td>
<td>1960-85; 98 countries; cross-sectional</td>
<td>Growth rate of real GDP per capita</td>
<td>OLS</td>
<td>Ratio of real government consumption to GDP, minus ratios of government spending on defence and education to GDP</td>
<td>Negative</td>
<td>None</td>
</tr>
<tr>
<td>Barro (1991)</td>
<td>1960-85; 98 countries; cross-sectional</td>
<td>Growth rate of real GDP per capita</td>
<td>OLS</td>
<td>Ratio of real government consumption to GDP, minus ratios of government spending on defence and education to GDP</td>
<td>Negative</td>
<td>LM(H)</td>
</tr>
<tr>
<td>Castles and Dowrick (1990)</td>
<td>1960-85; 18 OECD countries; cross-sectional and pooled data</td>
<td>Trend growth rate of real GDP per capita</td>
<td>OLS, 2SLS</td>
<td>Total government revenues, real government consumption expenditure, non-consumption expenditure, social expenditure and non-social expenditure</td>
<td>Unclear, but concluded to be slightly positive</td>
<td>RESET, LM(H), exogeneity, Chow 1, Chow 2</td>
</tr>
<tr>
<td>De Long and Summers (1991)</td>
<td>1960-85; 23 and 52 countries; cross-sectional</td>
<td>Growth rate of real GDP per worker</td>
<td>OLS</td>
<td>Ratio of real public domestic investment to real domestic investment</td>
<td>Insignificant</td>
<td>LM(H), spatial correlation</td>
</tr>
</tbody>
</table>
### APPENDIX 1

**SUMMARY OF THE EMPIRICAL LITERATURE ESTIMATING THE EFFECT OF GOVERNMENT SIZE ON ECONOMIC GROWTH**

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Data</th>
<th>Dependent variable</th>
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<th>Measure of government size</th>
<th>Estimated sign of government size variable(s)</th>
<th>Diagnostic tests used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dowrick (1992)</td>
<td>1950-88; 111 countries; pooled data</td>
<td>Growth rate of real GDP</td>
<td>OLS, 2SLS, LSDV</td>
<td>Real government size as proportion of GDP, nominal government size as proportion of GDP</td>
<td>Insignificant or negative</td>
<td>Chow 1, exogeneity</td>
</tr>
<tr>
<td>Easterly (1993)</td>
<td>1970-85; 38 and 51 countries; cross-sectional</td>
<td>Growth rate of real GDP per capita</td>
<td>OLS</td>
<td>Ratio of real government consumption to GDP</td>
<td>Insignificant or negative</td>
<td>LM(H)</td>
</tr>
<tr>
<td>Easterly and Rebelo (1993a)</td>
<td>1970-88; 103 countries; cross-sectional</td>
<td>Growth rate of real GDP per capita</td>
<td>OLS</td>
<td>Ratio of real government consumption to GDP, minus ratios of government spending on defence and education to GDP, ratio of expenditure on general public services to GDP</td>
<td>Negative</td>
<td>LM(H)</td>
</tr>
<tr>
<td>Fischer (1993)</td>
<td>1960-89; 101 countries; cross-sectional and pooled data</td>
<td>Growth rate of real GDP per capita</td>
<td>OLS, GLS</td>
<td>Ratio of the budget surplus to GDP</td>
<td>Positive</td>
<td>Exogeneity, Chow 1</td>
</tr>
<tr>
<td>Grier and Tullock (1989)</td>
<td>1951-80; 113 countries; pooled data</td>
<td>Growth rate of real GDP</td>
<td>OLS</td>
<td>Growth of ratio of government consumption to GDP</td>
<td>Negative</td>
<td>Chow 1</td>
</tr>
</tbody>
</table>
**APPENDIX 1**

**SUMMARY OF THE EMPIRICAL LITERATURE ESTIMATING THE EFFECT OF GOVERNMENT SIZE ON ECONOMIC GROWTH**

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Data</th>
<th>Dependent variable</th>
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<th>Measure of government size</th>
<th>Estimated sign of government size variable(s)</th>
<th>Diagnostic tests used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grossman (1988)</td>
<td>1949-84; Australia; time series</td>
<td>Growth rate of real GDP</td>
<td>OLS, 2SLS</td>
<td>Change in government component of GDP</td>
<td>Positive</td>
<td>DW</td>
</tr>
<tr>
<td>Gupta (1988)</td>
<td>1950-77; 47 countries; cross-sectional</td>
<td>Not stated</td>
<td>OLS</td>
<td>Growth of ratio of government spending to output</td>
<td>Insignificant</td>
<td>LM(H), Chow 1</td>
</tr>
<tr>
<td>Kornendi and Meguire (1985)</td>
<td>1950-77; 47 countries; cross-sectional</td>
<td>Growth rate of real GDP</td>
<td>OLS</td>
<td>Growth of ratio of government spending to output</td>
<td>Insignificant</td>
<td>None</td>
</tr>
<tr>
<td>Landau (1983)</td>
<td>1961-76; 96 countries; cross-sectional</td>
<td>Growth rate of real GDP per capita</td>
<td>OLS, 2SLS</td>
<td>Share of government consumption in GDP</td>
<td>Negative</td>
<td>LM(H), exogeneity, Chow 1</td>
</tr>
<tr>
<td>Landau (1986)</td>
<td>1960-80; 65 LDCs; pooled data</td>
<td>Growth rate of real GDP per capita</td>
<td>OLS</td>
<td>Government consumption other than on defence and education, government expenditure on defence, education, transfers, and capital, current government revenue, budget deficit, all expressed as shares of GDP</td>
<td>Negative</td>
<td>LM(H), Chow 1</td>
</tr>
</tbody>
</table>
APPENDIX I

SUMMARY OF THE EMPIRICAL LITERATURE ESTIMATING THE EFFECT OF GOVERNMENT SIZE ON ECONOMIC GROWTH

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Data</th>
<th>Dependent variable</th>
<th>Method of estimation</th>
<th>Measure of government size</th>
<th>Estimated sign of government size variable(s)</th>
<th>Diagnostic tests used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levine and Renelt (1992)</td>
<td>1960-89; 103 countries; cross-sectional</td>
<td>Growth rate of real GDP per capita</td>
<td>OLS</td>
<td>Ratios of government consumption, total government expenditure, government consumption net of expenditure on defence and education, and the central government budget deficit, all relative to GDP</td>
<td>Insignificant</td>
<td>None</td>
</tr>
<tr>
<td>Murphy et al. (1991)</td>
<td>1960-85; 98 countries; cross-sectional</td>
<td>Growth rate of real GDP per capita</td>
<td>OLS</td>
<td>Ratio of real government consumption to GDP, minus ratios of government spending on defence and education to GDP</td>
<td>Negative</td>
<td>None</td>
</tr>
<tr>
<td>Ram (1986)</td>
<td>1960-80; 115 countries; cross-sectional and time series</td>
<td>Growth rate of real GDP</td>
<td>OLS, AR(1)</td>
<td>Growth rate of government, growth rate of government multiplied by government share in GDP, government share in GDP</td>
<td>Positive</td>
<td>Non-nested J</td>
</tr>
<tr>
<td>Rao (1989)</td>
<td>1960-80; 115 countries; cross-sectional and time series</td>
<td>Growth rate of real GDP</td>
<td>OLS</td>
<td>Growth of government share of GDP</td>
<td>Unclear</td>
<td>RESET, exogeneity</td>
</tr>
</tbody>
</table>
Appendix II: The logarithm of GDP for 8 industrialised countries

Figure 1 Logarithm of GDP for Australia, 1860 to 1989

Figure 2 Logarithm of GDP for Canada, 1880 to 1989
Figure 3 Logarithm of GDP for France, 1860 to 1989

Figure 4 Logarithm of GDP for Germany, 1860 to 1989
Figure 5 Logarithm of GDP for Italy, 1860 to 1989

Figure 6 Logarithm of GDP for Japan, 1900 to 1989
Figure 7 Logarithm of GDP for the U.K., 1860 to 1989

Figure 8 Logarithm of GDP for the U.S., 1880 to 1989
REFERENCES


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