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ENDOGENOUS GROWTH: LESSONS FOR AND FROM ECONOMIC HISTORY

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ABSTRACT

Endogenous Growth: Lessons for and from Economic History*

The paper surveys both the usefulness of endogenous innovation models of growth in economic history and the implications of historical research for new growth theorists. It is suggested that economic historians should take endogenous innovation models seriously and that this will help them to integrate traditional historians' emphasis on the impact of institutions and policy with cliometric research. A review of historical research suggests that growth economists should pay more attention to learning effects and technological shocks. Further research into measurement issues is shown to be seriously needed, notably, into establishing the magnitude and sources of total factor productivity growth.

JEL Classification: N10, O47, O52
Keywords: economic growth, endogenous innovation, total factor productivity

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NON-TECHNICAL SUMMARY

This paper reviews research on endogenous growth in terms of its applicability to economic history and with a view to influencing further work in the area. A distinction is drawn between models of endogenous growth that have capital accumulation as the engine of growth and those that emphasize technological change. The latter class of models in which growth is the result of the allocation of resources to innovative activity in pursuit of profits seems much more fruitful.

The first part of the paper presents some descriptive data on growth in relatively rich economies since 1870. Evidence is also presented to suggest that the trend rate of growth has tended to vary substantially in most countries for which there is long-run data and to highlight the unusually fast growth of the early post-war years. Using traditional methods of growth accounting, it is noticeable that total factor productivity (TFP) growth looms large as a source of growth and varies substantially over time. A comparison of the nineteenth and twentieth centuries reveals that an acceleration in TFP growth between the two periods would be predicted by endogenous innovation models on the grounds of wider markets, greater availability of human capital and more R&D and that these factors are indeed stressed by traditional economic historians. At the same time, it is clear that TFP growth involved technological advance based on learning and also resulted from other aspects of economic development such as structural change. The implications are both that existing empirical research in economic history is broadly supportive of endogenous innovation type growth models and that the view of growth that they embody is somewhat lopsided seen in an historical context.

This initial overview is then followed by two rather more detailed sections. The first of these considers three controversies in the history of British economic growth: the interpretation of productivity change during the industrial revolution; the alleged failure of the late Victorian/Edwardian economy; and relative economic decline during the Golden Age of the 1950s and 1960s. In each of these cases it is suggested that an analysis based on insights from endogenous innovation growth models provides important new arguments – in the first case to explain why TFP growth was low, in the second case to explain the overtaking of the United Kingdom by the United States without recourse to irrational entrepreneurial failure and in the third case to provide firmer support for institutional idiosyncrasy as a reason for relatively slow growth. At the same time, there are important aspects of the historical experience that are not well captured by these models, notably localized learning and technological shocks, and in each case there are serious measurement problems to contend with.

The second more detailed section of the paper concentrates on the post-war period, looking both at cross-section and time-series studies. In particular, the experience of Europe during the early post-war years is closely reviewed. This scrutiny of recent historical research strongly suggests that policy choices and institutional arrangements were central to the Golden Age and that these aspects are not well captured by most regression analyses of international cross-sections. Economists need to take the 'social capability' aspects of growth more seriously. The slowdown in productivity growth since the early 1970s is also considered, particularly with regard to suggestions that, since this has coincided with further expansion in R&D, this episode is a refutation of endogenous growth models. It is argued that this is not necessarily so since TFP growth is not synonymous with technological change, it is not clear that the potency of R&D has actually declined and that it is possible that what is observed is better thought of as a Schumpeterian long-wave.

Overall, the survey points to an exciting agenda for further research and important possibilities of fruitful interaction between economists and economic historians. Endogenizing TFP growth has always been implicit in historical research and recent progress in economic theory formalizes some of these ideas and may make them more testable. At the same time, historical research emphasizes that it is crucial to obtain better measures of key variables such as human capital accumulation which are typically crudely proxied in empirical growth economics at present. Better measurement and analysis of TFP growth also stands out as a key requirement for adequately evaluating the contribution of endogenous growth models.

1. Introduction

In a survey of economic history written in the mid-1980s, I wrote that "economic history has had little influence upon and has been relatively little affected by growth theory of the postwar variety" (Crafts 1987, p. 40). Clearly, growth accounting had been highly influential for measurement purposes but, at that point, for economic historians keen to understand productivity growth in terms of induced innovation or endogenous technological change, economic theory had little to offer, as the review of the well-known Habakkuk debate in David (1975) had made painfully obvious.

Since the mid-1980s, endogenous growth theory has developed very rapidly and has produced a large volume of theoretical research. At the core of these models is the proposition that investment in a broad sense, including human as well as physical capital and the production of new processes and products through research, is central to growth which can be driven on without being halted by diminishing returns.

One branch of endogenous growth theory obtains results by arguing for constant returns to routine investment in broad capital with the production function, $Y = A\tilde{K}$, as in Rebelo (1991). The key to rapid long-run growth is to be found in cultures, institutions and tax policies which make a high rate of saving optimal. In this 'capital-fundamentalist' approach there is no explicit role for total factor productivity (TFP) growth or technological change. Despite the initial appeal of ideas of this kind, they are not persuasive as models of long-run growth. For example, cross-sectional regression evidence on the growth of GDP across countries (Mankiw et al., 1992; Islam, 1995) and on output across British manufacturing sectors (Oulton and O'Mahony, 1994) suggests that the sum of the exponents on physical and human capital in the production function is less than one and that there are diminishing returns to routine investment in the long-run.

Perhaps more importantly, as Romer has recently written, "our knowledge of economic history, of what production looked like 100 years ago, and of current events convinces us beyond any doubt that discovery, invention and innovation are of overwhelming importance in economic growth and that the economic goods that come from these activities are different in a fundamental way from ordinary objects. We could produce statistical evidence suggesting that all growth came from capital accumulation with no room for anything called technological change. But we would not believe it" (Romer 1993, p. 562).

The second strand of modern growth theory seeks to explain rather than to abolish TFP growth. In doing so it emphasizes the role of profit-motivated investments in discovering new products and/or processes. This has involved the development of growth models of an aggregate economy in which at the micro level production takes place under conditions of imperfect competition which allows the appropriation of profits to cover the fixed costs of R and D. The key feature of these models is that growth depends on the incentives to invest in improving technology. This can be seen to some extent as formalizing ideas long familiar in economic history and is likely to be found much more congenial by economic historians than capital fundamentalism.

Grossman and Helpman (1991) developed the paradigmatic model of this kind. Production is assumed to be a function of capital, labour and differentiated products used as intermediate inputs and growth of output is proportional to the rate of innovation. The endogenous steady improvement in intermediate inputs is analogous to growth in TFP in the traditional neoclassical model and, as might be expected, the rate of capital formation adjusts to the rate of innovation rather than vice versa. Growth depends on the allocation of resources to innovation and is promoted by larger markets, more productive labour in research and greater market power in exploiting discoveries.

A central concern of this paper is to assess both the potential of this approach for research in economic history and the implications of historical experience for further development of endogenous innovation models of growth. Here there seems to be an important opportunity for the two-way flow of ideas and information which ought to characterize the relationship between economics and economic history.

Thus the new growth economics offers new and/or better specified models with which to investigate why growth rates have differed while economic history provides a much richer array of experience with which to test and refine growth models than is comprised in the much used Heston-Summers data set relating to the world since 1960. Beyond this, however, endogenous growth theory allows institutions and government policy to play a central role in long-run growth outcomes. This may open the door to a deeper understanding of the growth process and connects with central concerns of the historical growth and development literature. Here the intellectual arbitrage possibilities may be particularly promising.

2. Overview of the Historical Experience of Economic Growth

A major part of the quantitative economic historian's task is the construction of datasets. Over the last forty years a massive effort has gone into historical national accounting together with the collection of information on prices to permit the calculation of purchasing power parity adjusted estimates of income levels. The 16 rich countries dataset compiled by Maddison (1991) which contains annual data on real GDP since 1860 in most cases is well-known and has already been widely used in econometric exercises. Maddison (1995) gives information on a much larger sample of countries and will permit further testing. Table 1 presents some of Maddison's most recent estimates.

Table 1. International Cross-Sections of Real Output Levels and Growth Rates Per Capita, 1870-1992.

(a) 1870-1913.

	Y/P 1870	Y/P 1913	Growth Rate	(Rank)
1. Portugal	1085	1354	0.53	(20)
2. Finland	1107	2050	1.45	(9=)
3. Norway	1303	2275	1.31	(11)
4. Argentina	1311	3797	2.50	(2)
5. Spain	1376	2255	1.16	(14)
6. Italy	1467	2507	1.26	(12)
7. Canada	1620	4213	3.28	(1)
8. Sweden	1664	3096	1.46	(7=)
9. Ireland	1773	2733	1.10	(16=)
10. France	1858	3452	1.45	(9=)
11. Austria	1875	3488	1.46	(7=)
12. Germany	1913	3833	1.64	(4)
13. Denmark	1927	3764	1.58	(5)
14. Switzerland	2172	4207	1.56	(6)
15. USA	2457	5307	1.82	(3)
16. Belgium	2640	4130	1.05	(15)
17. Netherlands	2640	3950	0.95	(18)
18. New Zealand	3115	5178	1.19	(13)
19. UK	3263	5032	1.01	(16=)
20. Australia	3801	5505	0.88	(19)

(b) 1900-1950

	Y/P 1900	Y/P 1950	Growth Rate	(Rank)
1. Portugal	1408	2132	0.85	(15)
2. Finland	1620	4131	1.90	(3=)
3. Italy	1746	3425	1.36	(9=)
4. Norway	1762	4969	2.10	(1)
5. Chile	1949	3827	1.36	(9=)
6. Spain	2040	2397	0.33	(21)
7. Ireland	2495	3518	0.70	(18)
8. Sweden	2561	6738	1.95	(2)
9. Argentina	2756	4987	1.20	(12)
10. Canada	2758	7047	1.90	(3=)
11. France	2849	5221	1.22	(11)
12. Austria	2901	3731	0.52	(20)
13. Denmark	2902	6683	1.69	(7)
14. Germany	3134	4281	0.64	(19)
15. Switzerland	3531	8939	1.88	(5)
16. Netherlands	3533	5850	1.01	(14)
17. Belgium	3652	5346	0.78	(17)
18. USA	4096	9573	1.72	(6)
19. Australia	4299	7218	1.04	(13)
20. New Zealand	4320	8495	1.37	(8)
21. UK	4593	6847	0.82	(16)

(c) 1950-73

	Y/P 1950	Y/P 1973	Growth Rate	(Rank)
1. Portugal	2132	7568	5.68	(2)
2. Peru	2263	3953	2.46	(17)
3. Spain	2397	8739	5.80	(1)
4. Italy	3425	10409	4.93	(4)
5. Ireland	3518	7023	3.05	(14)
6. Austria	3731	11308	4.92	(5)
7. Chile	3827	5028	1.20	(23)
8. Finland	4131	10768	4.25	(6)
9. Germany	4281	13152	5.00	(3)
10. Norway	4969	10229	3.19	(10)
11. Argentina	4987	7970	2.06	(20)
12. France	5221	12940	4.03	(7)
13. Belgium	5346	11905	3.54	(8)
14. Netherlands	5850	12763	3.45	(9)
15. Denmark	6683	13416	3.08	(11=)
16. Sweden	6738	13494	3.07	(13)
17. UK	6847	11992	2.47	(16)
18. Canada	7047	13644	2.91	(15)
19. Australia	7218	12485	2.41	(19)
20. Venezuela	7424	10717	1.62	(22)
21. New Zealand	8495	12575	1.73	(21)
22. Switzerland	8939	17953	3.08	(11=)
23. USA	9573	16607	2.42	(18)

(d) 1973-92

	Y/P 1973	Y/P 1992	Growth Rate	(Rank)
1. Ireland	7023	11711	2.73	(3)
2. Portugal	7568	11130	2.05	(6=)
3. Argentina	7970	7616	-0.23	(21)
4. Spain	8739	12498	1.91	(9)
5. Norway	10229	17543	2.88	(2)
6. Italy	10409	16229	2.37	(4)
7. Venezuela	10717	9163	-0.73	(22)
8. Finland	10768	14646	1.64	(12)
9. Japan	11017	19425	3.03	(1)
10. Austria	11308	17160	2.22	(5)
11. Belgium	11905	17165	1.95	(8)
12. UK	11992	15738	1.45	(15)
13. Australia	12485	16237	1.40	(16)
14. New Zealand	12575	13947	0.56	(20)
15. Netherlands	12763	16898	1.49	(14)
16. France	12940	17959	1.75	(10)
17. Germany	13152	19351	2.05	(6=)
18. Denmark	13416	18293	1.65	(11)
19. Sweden	13494	16927	1.20	(18)
20. Canada	13644	18159	1.52	(13)
21. USA	16607	21558	1.39	(17)
22. Switzerland	17953	21036	0.86	(19)

Notes: All income levels are measured in 1990 International Dollars and all growth rates are endpoint calculations measured per annum. The sample of countries in each period is based on a threshold income level of $1000 in 1870, $1400 in 1900, $2100 in 1950 and $7000 in 1973.

Source: Derived from Maddison (1995).

Several features of Table 1 stand out. First, given the (conventional) periodization of the table, the difference in average growth rates across phases is apparent - in particular the 3.3% of the 1950-73 'Golden Age' is more than double the mean of any other period. Second, 'catching-up' in the sense of an inverse correlation between initial income level and subsequent growth is stronger after 1950 with the highest rank correlation coefficient of 0.54 in 1950-73. Third, there are still large discrepancies in real income levels in 1992 even in this sample of countries although the coefficient of variation among the original 20 listed for 1870 falls from 0.36 in 1870 to 0.31 in 1900, and from 0.37 in 1950 to 0.23 in 1973 and 0.21 in 1992. In Barro and Sala-i-Martin's (1991) terminology the 1950-73 period emerges as a period of unusually strong b- and σ-convergence; this remark applies even more strongly to the European subset (Crafts and Toniolo, 1996).

Economic historians tend generally to believe quite strongly in the notion of different phases in economic growth. Thus the interwar period is taken to be an era when the breakdown of international commodity and factor markets tended to impede economic growth and convergence tendencies (Williamson, 1995), the possibilities for and extent of technology transfer are argued to have been much greater after World War II than previously (Nelson and Wright, 1992), the pace and nature of technological change are held to have been transformed in the early twentieth century (Abramovitz, 1993) and so on.

Table 2. Estimated Trend Rates of Growth of Output per Person: Predetermined Breaks, Unrestricted Model

% p.a.	T_1-1914	15-19	20-39	40-50	51-73	74-89
Segment k	1	2	3	4	5	6
Australia	0.36	0.31	0.62	2.08	2.32	1.90
Austria	1.31**	-4.44**	1.29**	-0.32	5.50**	1.83**
Belgium	0.90**	-0.63	1.01	-0.17	3.90**	2.09*
Canada	2.46**	-0.05	0.89	3.98*	2.47	2.91
Denmark	1.77**	-0.39*	1.58	0.91	3.46**	1.59**
Finland	1.45**	-1.71**	3.25**	1.56**	4.12**	2.83**
France	0.96**	0.85	0.78	0.70	4.92**	1.42**
Germany	1.47**	-2.19*	2.91	3.28	5.11**	1.26**
Italy	1.47**	3.16	0.21	1.01	5.31**	2.05**
Japan	1.48**	3.35	1.95	-2.76**	8.03**	2.70**
Netherlands	-0.42	6.01	-0.08	0.84	4.16*	0.96*
Norway	1.13**	2.45	2.28	1.96	3.49**	3.48
Spain	0.87**	2.22	-0.15	-0.66	4.95**	1.56**
Sweden	1.52**	-3.04**	3.03**	2.63	3.42*	1.62**
Switzerland	0.57	2.02	1.69	3.28	2.91	0.84**
U.K.	1.04**	-1.47**	1.56**	1.20	2.24*	1.83
U.S.A.	1.70**	1.58	0.86	3.76*	1.54*	1.89

T_1 is the series starting date; * and ** denote that a change in trend growth at the break T_k is significant at the 5% and 1% levels.

Source: Crafts and Mills (1996).

In a European context, there may be strong reasons for seeing both the World Wars as exogenous shocks which led to a changed economic environment which impinged on growth performance (Maddison, 1991). The early post World War II years have generally been seen as providing an unusually favourable climate for growth and for catching-up by follower countries in terms of a reconstruction stimulus, technological opportunities, macroeconomic stability and a policy framework of international liberalization and domestic postwar settlements conducive to wage moderation and high investment (Abramovitz, 1986; Boltho, 1982; Dumke, 1990; Eichengreen, 1996).

Table 2 reports the results of estimating a segmented trend model for 17 countries using predetermined break points which match Maddison's epochal account based on Crafts and Mills (1996). The model is

$$x_t = \gamma_0 + \gamma_1 t + \Sigma_i = \overset{2}{\underset{6}{\gamma_i}} D_{it} + u_t \qquad (1)$$

where x is the logarithm of output per person and $D_{it} = (t - T_i).1(t>T_i)$, 1(.) is the indicator function and $T_i = 2, ...,6$ correspond to the break years 1914, 1919, 1939, 1950, and 1973. This segmented trend stationary process was treated as the alternative to the unit root null. The test statistics reported in Appendix 1 provide convincing evidence that all output per person series are stationary around a segmented trend, a finding which remains when the final breakpoint is allowed to be determined endogenously. The error u_t was then modelled by an autoregressive process

$$u_t = \rho u_{t-1} + \Sigma_i \delta_i \Delta u_{t-i} + a_t \qquad (2)$$

and equations (1) and (2) were jointly estimated.

The analysis underlying Table 2 reveals a number of interesting features of the long run growth process. First, the hypothesis of a 'Golden Age' of growth for European countries in the early postwar period is not rejected. Second, the hypotheses that after the Golden Age European countries were either back to the pre-depression and war trend path or a parallel path with higher productivity are rejected for all countries except Denmark. Third, in all European countries GDP/hour worked relative to the USA is higher in 1989 than in 1913.

Regression analysis of international cross-sections for the recent past is favourable to the hypothesis of conditional (β) convergence in the Barro and Sala-i-Martin sense that growth is inversely related to initial productivity relative to the leading economy (Dowrick and Nguyen, 1989; Levine and Renelt, 1992). Two points should be noted about this finding, neither of which should be too surprising given Tables 1 and 2.

First, regression analysis of the long-run Maddison dataset suggests that the null hypothesis of no catching-up cannot be rejected outside of the unusual 1950-73 period (van de Klundert and van Schaik, 1996). Second, conditional convergence in the postwar cross-sections does not imply ultimate convergence in the strong sense that the long-term forecasts of output per person are equal. Bernard and Durlauf (1995) reject this hypothesis using cointegration techniques on the Maddison dataset.

Research in economic history has for many years made extensive use of growth accounting and much attention has been paid to the behaviour of the Solow residual.

Obviously, the advent of the new growth economics potentially undermines the assumptions on which this work has been based. Current research does, however, suggest that profits share may be a reasonable approximation for the elasticity of output with respect to physical capital investment where externalities are probably small (King and Levine, 1994; Oulton and O'Mahony, 1994). In this event, it is interesting to consider traditional estimates of Solow's residual which can be thought of as the explicandum of the new growth economics, either to be explained by an endogenous innovation model or to be explained away by better measurement of broad capital formation.

The estimates in Table 3 are based on traditional growth accounting, are necessarily crude for earlier periods and are not strictly comparable over time or between the two countries in the sense that the precise details of the methods used to produce them are not exactly the same. Nevertheless the broad outline shown by the table is useful and deserves to be addressed by the new growth economics. Three points might be noted about Table 3. First, for the United States, there has been much greater TFP growth during most of the twentieth than in the nineteenth century. Second, the American acceleration in TFP growth in the early twentieth century was not matched by the UK. Third, there may also have been a change in the factor-saving bias of technological change between the nineteenth and the twentieth centuries from physical capital-using to intangible (human and knowledge) capital-using (Abramovitz 1993, p. 224).

The most ambitious growth accounting exercises by an economic historian are those of Maddison whose latest estimates are reported in Table 4. An intriguing feature of his work is the attempt to attribute TFP growth to specific sources. This represents essentially a set of hypotheses based on a reading of the historical experience rather than a series of estimated results and requires strong assumptions, for example on the counterfactual productivity performance had there been a different pattern of structural change in employment. The unusually rapid European growth in the Golden Age is seen as resulting to a large extent

Table 3. Total Factor Productivity Growth in the Long Run (% per annum)

	USA		UK
1800-55	0.2	1780-1831	0.3
1855-1905	0.5	1831-73	0.8
1905-27	1.7	1873-1913	0.5
1929-48	1.8	1924-37	0.6
1948-66	2.2	1951-73	2.1
1966-89	0.8	1973-92	0.6

Sources: Abramovitz (1993), Crafts (1995b), Maddison (1996), Matthews et al. (1982)

Table 4. Maddison on the Sources of Growth (% per annum)

	1913-50	1950-73	1973-92
France			
GDP	1.15	5.02	2.26
Total Factor Input	0.48	1.96	1.61
Non-Residential Capital	0.63	1.59	1.26
Education	0.36	0.36	0.67
Total Factor Productivity	0.67	3.06	0.65
Foreign Trade Effect	0.03	0.37	0.12
Catch-Up Effect	0.00	0.46	0.31
Structural Effect	0.04	0.36	0.15
Scale Effect	0.03	0.15	0.07
Unexplained	0.57	1.72	0.00

<u>Germany</u>			
GDP	1.28	5.99	2.30
Total Factor Input	1.00	2.71	0.77
Non-Residential Capital	0.59	2.20	0.93
Education	0.24	0.19	0.11
Total Factor Productivity	0.28	3.28	1.53
Foreign Trade Effect	-0.13	0.48	0.15
Catch-Up Effect	0.00	0.62	0.31
Structural Effect	0.20	0.36	0.17
Scale Effect	0.04	0.18	0.07
Unexplained	0.17	1.64	0.83
<u>United Kingdom</u>			
GDP	1.29	2.96	1.59
Total Factor Input	0.94	1.71	0.96
Non-Residential Capital	0.72	1.64	0.93
Education	0.33	0.18	0.43
Total Factor Productivity	0.35	1.25	0.63
Foreign Trade Effect	0.01	0.32	0.15
Catch-Up Effect	0.00	0.08	0.20
Structural Effect	-0.04	0.10	-0.09
Scale Effect	0.04	0.09	0.05
Unexplained	0.34	0.66	0.32
<u>United States</u>			
GDP	2.79	3.91	2.39
Total Factor Input	1.53	2.34	2.22
Non-Residential Capital	0.81	1.05	0.90
Education	0.41	0.48	0.46
Total Factor Productivity	1.26	1.57	0.17
Foreign Trade Effect	0.04	0.11	0.05
Catch-Up Effect	0.00	0.00	0.00
Structural Effect	0.29	0.10	-0.17
Scale Effect	0.08	0.12	0.07
Unexplained	0.85	1.24	0.22

<u>Note</u>: Some factor inputs not listed separately in this table.

<u>Sources</u>: Derived from Maddison (1991) (1996).

from high TFP growth which in turn derives from several sources, although the related factors of trade liberalization and technology transfer clearly underwrite this episode.

Four aspects of the estimates in Table 4 require comment. First, it is striking how little part human capital formation appears to play in why growth rates differed. In the table years of education impact through the contribution of the labour force. This raises issues both of weighting and of measurement, i.e., the use of schooling as a proxy variable. Second, a good deal of the variation over time and across countries in TFP growth is regarded even by Maddison as unexplained. Third, no explicit role for research and development expenditure is identified. Fourth, even so, it is apparent that this approach would stress that it is quite wrong to equate TFP growth with technological progress or a fortion with the effects of R and D according to the historical evidence. Table 4 indicates both the size of the challenge to endogenous growth theory in terms of what needs to be accounted for and also explains why both economic historians and growth economists became so frustrated with traditional growth economics.

It should also be remembered that there is a substantial literature of empirical studies of technological change contributed by economic historians and other researchers in the field of technology economics which has gone, so far, largely unconsulted by growth economists. While in many ways this is broadly supportive of the endogenous innovation models of growth, this research suggests the need for further refinement of the early work in new growth theory.

First, in judging the performance of the endogenous innovation models over time it is important to allow for the notion of phases in growth discussed earlier. More importantly, work by economic historians of technology suggests that it is important to take into account 'technological opportunity' when seeking to explain either the inputs into or the outputs from R and D. A fully Schumpeterian vision would embrace not only creative destruction but also technologically based long waves in economic growth (von Tunzelmann, 1995). Empirical research on the determinants of R and D and patenting underlines the importance of technological opportunity in research based on experience since 1950 both in Europe and America (Pakes and Schankerman, 1984; Stoneman, 1979). At the same time these studies tend to be consistent with the endogenous innovation growth models in that they also find that appropriability conditions matter, as does market size and demand growth. Perhaps the most comprehensive paper which confirms all these points is that of Jaffe (1988).

Second, in considering the rise of the American technological lead from the late nineteenth to the mid twentieth century, the historical literature anticipates and confirms the broad outlines of an explanation along the lines of the endogenous innovation branch of new growth theory. Thus the American research effort is seen as having been stimulated by the scale effects of a better integrated and ever larger domestic market well beyond that of any European country (Chandler, 1990; Nelson and Wright, 1992). By the 1930s the volume of R and D in the US was about ten times that of the UK (Edgerton and Horrocks 1994, p. 233) while American population and GDP which had been similar to that of the UK in the 1860s were now three times and four times larger respectively (Maddison, 1995). Detailed research on the motivation for the development of American industrial research also stresses rapid growth of educational programmes which increased the supply of chemists and engineers, the strengthening of protection for intellectual property and the growing realization that on-going research acted to increase market power (Mowery and Rosenberg, 1989; Reich, 1985).

It would not, however, be plausible to attribute all the increase in TFP growth since the mid nineteenth century to R and D. It seems plausible that R and D spending was between 2.5 and 3 percentage points of GDP higher in 1948-66 than in 1855-1905. Using the 40 per cent social rate of return to R and D suggested by Griliches (1995, p. 60) would imply that TFP growth would have been raised by between 1.0 and 1.2 percentage points, whereas the total change is of the order of 1.7 percentage points.

Third, in assessing the predictions of the (neo-Schumpeterian) endogenous innovation growth models, it is important to distinguish between the importance of the appropriability of returns and monopoly or concentration as factors promoting innovative activity. Empirical evidence suggests that appropriability is related in particular to lead times over rivals rather than patents (Levin et al., 1987) and that large business units may have advantage in exploiting learning curves and spreading fixed costs (Cohen, 1995) but that rivalry among big firms is advantageous in promoting R and D (Patel and Pavitt, 1992) while collusion among British manufacturing firms in the postwar period seems to have retarded productivity growth (Broadberry and Crafts, 1995) and in properly specified regression studies there is no relation between concentration and R and D (Cohen, 1995). As theorists have begun to recognize (Aghion and Howitt, 1995), history suggests that the implication in many current new growth models that market powerr is good for growth needs to be handled with care.

3. Endogenous Innovation Models of Growth: How Well do They Work in Economic History?

In this section I wish to explore the value added from approaching economic history from the perspective of endogenous growth theory. To do so, I shall consider three highly controversial phases of British economic growth with the aim of asking both whether the new growth models improve our understanding and/or help to resolve old debates and also whether existing historical accounts suggest ways in which work in growth economics could be strengthened. Each of these episodes will be treated in a highly selective fashion with no pretension to providing a balanced or comprehensive survey of the literature.

(a) The Industrial Revolution Reconsidered [1]

Trying to explain why the First Industrial Revolution happened in Britain over several decades in the late eighteenth and early nineteenth century is one of the classic historical questions. The current state of the ongoing debate is well summarized in the contributions to

Floud and McCloskey (1994). Recent research has also devoted considerable effort to better estimates of the growth rate at this time, an exercise which is fraught with index number problems and hampered by data imperfections (Crafts and Harley, 1992). It is now widely believed that the overall acceleration of economic growth was fairly modest but argument lingers on (Cuenca Esteban, 1994, 1995; Harley and Crafts, 1995).

Table 5 displays what seem to be the most plausible growth estimates, set out in a fairly conventional periodization, together with data on factor accumulation and TFP growth estimates using basic growth accounting assumptions, as in Table 3. It is noticeable that by modern standards investment in both physical and human capital was sparse and rose only slowly. The correlation between changes in TFP growth and broad capital accumulation as measured is clearly quite small. In fact, looking at this table from a factor accumulation perspective, it is not at all obvious that we can full explain the speeding up of economic growth during the Industrial revolution and our ex ante expectations of growth would probably have been low, as were Adam Smith's (Wrigley 1987, p. 21).[2]

The central themes of the endogenous innovation growth models have a strong echo in the classic debate on the causes of the Industrial Revolution. Writings in the property rights tradition have stressed the importance of the early development of the patent system in England (Dutton, 1984; North and Thomas, 1973) and the old theme of transport improvements and integration of the market as a stimulus to innovation has recently been reasserted by Szostak (1991). Examples of careful calculation and profit-maximizing behaviour in weighing alternative strategies to exploit the value of discoveries once invented abound in recent work on technical change in the eighteenth and early nineteenth centuries (Macleod, 1992).

Table 5. Broad Capital Accumulation and Growth in Britain, 1760-1913

(All data in percent except years of schooling)

	1760-80	1780-1801	1801-31	1831-73	1873-99	1899-1913
Investment/GDP	5.7	6.3	8.3	8.7	8.3	8.7
Equipment Investment/GDP	1.1	1.3	1.6	1.9	2.0	2.2
Male Literacy	62	62	65	70	86	98
School Enrolment						
Primary[a]			36	76	94	100
Secondary[b]				17	30	55
Years of Schooling[c]			2.30	4.21	5.32	6.75
GDP Growth	0.6	1.3	1.9	2.4	2.1	1.4
TFP Growth	0.0	0.1	0.4	0.75	0.75	0.05

Notes:

a. Estimates refer to 1818, 1851, 1881, 1906.

b. Estimates refer to 1867, 1895, 1913.

c. Estimates refer to cohort of workers born before 1805, to 1871, 1891 and 1911.

Sources: Investment estimates are from Feinstein (1988, pp. 431-2); literacy is based on Schofield (1973, pp. 441-6); primary school enrolment derived from Mitch (1982, p. 10) and Mitchell (1988, p. 15, 799); secondary school enrolment derived from Great Britain (1867/8, p.815) (1895, p. 424) and Mitchell (1988., p. 863); GDP growth and TFP growth based on Crafts and Harley (1992) and Matthews et al. (1982).

Nevertheless, the most authoritative recent discussion of technological change in this period by Mokyr (1990) stresses other aspects which are not part of the basic endogenous innovation growth model.. Mokyr suggests that 'A technological definition of the Industrial Revolution is a cluster of macroinventions leading to an acceleration in micro-inventions' (1993, p. 22). 'Macroinventions' are radical new ideas which are unpredictable and should be seen as exogenous technological shocks. 'Microinventions' come through improvement, adaptation and diffusion of a technology, and learning by doing. They are conditioned by economic factors and account for the majority of productivity improvement but within any particular technology are subject to diminishing returns.

It is a central feature of research on the Industrial Revolution that the full impact of technological changes often took many decades to be realized - for example, the steam engine (Kanefsky, 1979; von Tunzelmann, 1978) - and often involved extensive learning - for example, the iron industry (Allen, 1983; Hyde, 1977). A recent econometric analysis of the renewal of patent rights in the period 1852-76 obtained three important results. First, the value of patent rights was much smaller relative to physical investment and GDP and, second, the positive influence of a larger market on renewals was much smaller than in modern times. Third, in contrast to the modern period, the stock of patents already extant has a positive effect on expected returns to further invention (Sullivan, 1994). The plausible interpretation given by the author is that R and D mattered much less 150 years ago, that exogenous discovery mattered much more and that it tended to trigger further innovation through microinvention.

In terms of trend growth this account suggests that the technological changes associated with the classic Industrial Revolution would tend to promote a period of steadily increasing output and productivity growth as learning and diffusion took place followed by decreasing output and productivity growth as microinvention ran into diminishing returns. The increases in factor accumulation during the period would neither fully explain growth nor be sufficient to sustain growth at the peak rate. This would be consistent with the findings of Crafts and Mills (1994) that trend growth of industrial output varied significantly between periods and that the most satisfactory model is a segmented quadratic trend with endogenous break points found at 1776, 1834 and 1874.[3]

During the classic Industrial Revolution years exogenous technological change was a central element in the acceleration of economic growth. Furthermore, productivity improvement through learning was far more important than that obtained through high fixed cost investment in R and D. This offers further support for the view that changes in technological opportunity over time may need to be allowed for in applying endogenous growth models to the long run. While the basic endogenous innovation growth models cannot encompass this experience, a stochastic version of the expanded model, proposed by Young (1993), which embraces learning effects, may be more appropriate.

Young's model has two important features. First, there is a stagnation equilibrium in which, if market size is too small relative to the expected costs of invention, there will be no discoveries and also no learning. Second, in general, the steady state rate of growth depends not only on incentives to inventive activity but also on the rate of learning, which for any particular technology is bounded (Young 1993, pp. 444-8). Economic historians of the Industrial Revolution should particularly applaud this last formulation and hope for further exploration of learning in endogenous innovation growth models.

Young sees the eighteenth century British experience basically as an escape from the stagnation equilbrium and emphasizes that, once this breakthrough had occurred, learning by doing was crucial to the success of inventions like James Watt's steam engine (1993, p. 446, 465). However, while Young anticipates that differences in market size may be more important than differences in learning capabilities in determining growth rates; Mokyr argues that in explaining British pre-eminence in the early nineteenth century the opposite is probably the case. He interprets the historical evidence relating to skills and experience to be that "The key to British technological success was that it had a comparative advantage in microinventions" (1993, p. 33).

It must also be stressed that Young (1993) does not account for the timing of the Industrial Revolution and it may well be too much to expect of an endogenous innovation growth models that it could convincingly do this. The important contributions of these models may lie rather in terms of explaining why TFP growth was so low even in Britain in the early nineteenth century and in terms of comparing the expected growth potential of different countries at this time.

Five characteristics of the economic environment of 200 years ago might lead to predictions of modest TFP growth using endogenous innovation models and would explain the lack of research laboratories. First, the size of markets was very small by today's standards. For example, using the estimates in Maddison (1995), in 1820 real GDP in the UK was about 10 per cent of its 1950 level. Second, the costs of invention were high insofar as the contributions that science and formal education made to technological progress were modest (Mokyr, 1990). Third, the protection offered by the patent system was less secure and the costs of taking a patent out were still very high relative to the later nineteenth century (Dutton, 1984). Fourth, in the years of 'Old Corruption' rent-seeking in the law, the bureaucracy, the Church and the military remained a very attractive alternative to entrepreneurship and led to an adverse allocation of talent (Rubinstein, 1983).[4] Fifth, realization of the profits from invention was made difficult by the need also to ensure that workers did not ex-post mis-appropriate them and this required further ingenuity of the pioneers.[5]

Similarly, five aspects of the British economy might be seen as making for generally higher TFP growth potential than in France without, however, explaining the location of (exogenous) macroinventions. First, despite a higher GDP in the larger French economy, better integration of markets and a large empire made for a larger effective market size (Szostak, 1991). Second, the percentage of the population urbanized, which reduced the costs of acquiring and developing knowledge, was twice the French level (Bairoch, 1991). Third, the superior skill base of the British labour force and, especially, expertise in using coal-based technologies, enhanced learning in Britain and limited technology transfer to France (Harris, 1976). Fourth, there is little doubt that rent-seeking was much more prevalent in eighteenth century France (Root, 1991). Fifth, a lower direct tax rate may have been favourable to Britain.[6]

(b) Did Late Victorian Britain Really Fail?

The late nineteenth and early twentieth century is generally recognized as the period when economic and technological leadership passed from the UK to the United States. Table 1 shows that USA moving ahead in terms of real GDP/person and the growth accounting of Table 3 indicates that in the early twentieth century American TFP growth accelerated to a new higher rate while British TFP growth failed to do so. Table 5 highlights the 'climacteric' that Matthews et al. (1982) claim occurred during 1899-1913 when weak growth of GDP was associated with a dramatic slowdown in TFP growth.

Not surprisingly, this episode has provoked much criticism of British performance with suggestions that there was an avoidable growth failure, associated with alleged weaknesses in institutions and policy reflected in inadequate investment and company management. In the terminology of Abramovitz (1986) this might be seen as a weakening of 'social capability'. This alleged failure became a focus of attention for the vanguard of the new economic historians who attempted an exoneration of British entrepreneurs and capital markets, arguing that resources were allocated efficiently and technical choices were made rationally according to profit-maximizing criteria. The answer given to the question 'Did Victorian Britain fail?' was a resounding 'No!'; McCloskey summed up, as follows: "There is, indeed, little left of the dismal picture of British failure painted by historians. The alternative is a picture of an economy not stagnating but growing as rapidly as permitted by the growth of its resources and the effective exploitation of the available technology" (1970, p. 451). The controversy is well covered by the material in Floud and McCloskey (1994).

Two points should be noted about the growth economics which was used either implicitly or explicitly by the new economic historians twenty five years ago. First, the traditional Solow model was an important underpinning of arguments that denied that a higher domestic investment rate could have produced faster growth and which examined choices of technique with existing technology but did not take seriously the question of what determined the steady-state TFP growth rate. Second, the world was not seen as one of unconditional convergence. In particular, the stress placed on different factor endowments in a world of imperfect factor mobility implied that steady state income and productivity would differ and, that, given its advantages in terms of natural resources, it might be expected that American income per head and labour productivity would exceed British levels.

Subsequent research in this tradition has strengthened these arguments about convergence. Two particular themes stand out. First, research in the history of technology has stressed the importance of learning effects in nineteenth century productivity improvement while recognizing that international transfer of such tacit knowledge was often difficult (Nelson and Wright, 1992). Second, it has been strongly argued that British firms were generally rational to regard the new American mass production technologies as inappropriate in British conditions and to continue with craft production methods both because of the absence of a large standardized domestic demand and because of the greater availability of skilled labour together with the entrenched tradition of craft unions' organization of the shopfloor (Broadberry, 1994).

How might the debate over British economic performance in the pre-1914 period be modified by the advent of endogenous innovation growth theory? Clearly, this can be used to compare TFP growth in the UK and the USA and to add a further dimension to the analysis of business investment decisions. The straightforward prediction of the basic Grossman-Helpman model is that in the late nineteenth and early twentieth centuries not only would economic circumstances favour an upsurge of innovative activity in the United States but that this would be much less the case in Britain. Table 6 reveals the reasons.

On the eve of World War I the United States was much the larger economy, was producing substantially more college graduates in key disciplines and had relatively cheaper technical personnel. In the light of the evidence on induced innovation, both cost and demand conditions might explain relatively low research and development spending in the UK without implying entrepreneurial failure. By the 1930s, when relatively reliable data are available, the United States was spending at least twice as high a share of its GDP on research and development as either Britain or Germany, the leading European countries (Edgerton and Horrocks, 1994). The rank correlation of revealed comparative advantage in 1937 with research and development intensity is + 0.72 for the USA but -0.33 for the UK (Crafts, 1989, p. 132, 134).

Table 6. The Economic Environment of R and D in Early Twentieth Century UK and USA

(a) Factors Influencing Size of R and D Effort

	UK	USA
Population (mn., 1913)	45.6	97.6
Real GDP ($int1990bn, 1913)	230	518
University Students (th., 1910)	27.7	355
Science/Technology	3.0	65
Engineers/Unskilled Pay Ratio 1913/4	4.63	3.71

(b) Revealed Comparative Advantage Rankings

	UK		USA	
	1913	1937	1913	1937
Agricultural Equipment	10	16	2	1
Cars and Aircraft	12	11	4	2
Industrial Equipment	5	7	3	3
Electricals	8	5	5	4
Iron and Steel	3	9	9	5
Non-Ferrous Metals	16	15	1	6

Books and Films	13	8	10	7
Chemicals	11	12	12	8
Metal Manufactures	7	13	6	9
Brick and Glass	14	10	11	10
Wood and Leather	15	14	7	11
Rail and Ships	1	3	8	12
Fancy Goods	9	4	13	13
Apparel	6	6	14	14
Alcohol and Tobacco	4	1	15	15
Textiles	2	2	16	16

<u>Sources</u>:

Population and real GDP: Maddison (1995). University students: Mitchell (1988) (1993) with science and technology component from Pollard (1989, p. 196) and Blank and Stigler (1957, p. 6, 75). Pay Ratio: Routh (1980, p. 63, 120) for UK; for USA calculated using Blank and Stigler (1957, p. 124) and Melman (1956, p. 206). Revealed Comparative Advantage is based on relative export market shares by sectors and is derived from Crafts (1989, Table 1).

The importance of this for differences in TFP growth must not be exaggerated, however. On the basis of the modern rate of return evidence, the discrepancy might be expected to have raised the growth rate of TFP in the USA by, say, 0.4 percentage points relative to the UK - less than half the gap shown in Table 4 for the interwar years. Table 4 suggests that a fairly similar impact may have resulted from structural change. It would also be anachronistic to attribute much of the 0.4 per cent TFP growth gap which seems to have existed throughout the 40 years or so before 1914 to a gap in R and D while the so-called climacteric coincides with the beginnings of serious industrial research in Britain.[7]

Indeed, while the historical literature certainly recognizes the greater incentives to purposive investment in R and D which were emerging in the United States, the major stress in economic historians' accounts of nineteenth century British and American technical progress, since the pioneering work of Rosenberg (1972) and David (1975), has been that American advantages derived mostly from relatively strong learning effects particularly with natural resource intensive technologies favoured by American factor endowments. It has also been shown that late nineteenth/early twentieth century American comparative advantage in manufacturing increasingly lay in natural resource intensive exports (Wright, 1990). Table 8 confirms that the two economies were quite dissimilar in terms of revealed comparative advantage in exporting.

All this suggests that the growth model most relevant for pre-1914 Anglo-American comparisons may be that of Krugman-Lucas (Krugman, 1987; Lucas, 1988) rather than Grossman-Helpman. In the original Krugman-Lucas model, specialization according to comparative advantage delivers persistently different growth rates where human capital is augmented by learning at sectorally different rates. Kennedy (1987) stressed that the sectors associated with strong productivity advance were smaller in the UK and, in a highly controversial counterfactual simulation, claimed that the growth rate during 1873-1913 could have been raised very substantially by structural shifts towards sectors with more growth potential. He attributed the failure to achieve this transformation largely to imperfections in the capital market, an argument which is also much disputed (Michie, 1988).

Two points deserve discussion. First, Lucas (1993) has proposed a more realistic version of his 1988 model in which learning in any particular sector is bounded, as with the Young (1993) model considered earlier. In the long-run persistently faster growth will then depend on continually renewing comparative advantage and re-specializing in new fast-learning sectors; in the Lucas model this can be achieved through learning spillovers. What is clear about the UK in the long nineteenth century is that this did not happen. What remains for further research is to explore more deeply the reasons for this - were learning spillovers generally very weak, did natural resource endowments dominate the outcome, or were there institutional obstacles to the necessary restructuring?

Second, models of the Krugman-Lucas kind are more intuitively appealing when applied to the past both because spontaneous learning rather than R and D mattered more and because international spillovers of learning were smaller. At the same time, it is important to remember that issues of social capability related to the appropriability of returns to innovation also played a part in the inability of British firms to assimilate American improvements. In particular, the distinctively British system of industrial relations, which had emerged during the Industrial Revolution which relied on craft control to police effort levels, was an obstacle to emulating capital and management intensive methods (Lewchuk, 1987). High sunk cost investment in new technologies was vulnerable to workers' opportunistic behaviour.

Four reflections might be made arising from this brief survey. First, the advent of endogenous growth theory opens up possibilities of longrun divergences in growth rates not readily contemplated in the early days of new economic history. Interestingly, slower growth may have resulted from factor endowments and scale effects such that the fundamental conclusions of the new economic history regarding 'avoidable failure' still apply. Second, there are also reasons to think that British industrial relations may have inhibited the rapid elimination of 'ideas gaps' between the US and the UK. If so, it should recognized that reforming these institutional arrangements involved both high switching costs and large externalities. Third, while entrepreneurial failure arguments are probably not re-instated by new growth economics, criticisms (implicit or explicit) of British economic policy might well be strengthened in term sof failure to reform institutions or to modify industrial and trade policies or to expand education opportunities more rapidly. Fourth, among the ways of predicting growth rate effects, an R and D based model seems more suited to the second and third quarters of the twentieth century than to late Victorian times when a model incorporating strong differences in learning effects may be more helpful. As Nelson and Wright (1992, p. 1936, 1961) point out, the scope of networks of cumulative technological learning at that time seems to be mostly national rather than international which implies that catching-up could be difficult and any tendencies to β-convergence were much weaker.[8]

(c) British Relative Economic Decline in the Golden Age: Beyond Proximate Explanations?[9]

The early postwar period saw British growth of GDP/person and TFP growth reach all time highs and yet, as Tables 1 and 4 reveal, in terms of international comparisons British performance appears to have been disappointing and this can be seen as a period of relative economic decline. Obviously, this has had a high profile and has provoked a great deal of comment. A useful introduction to this topic by a traditional economic historian is provided by Alford (1988).

Alford's summary, written in innocence of endogenous growth theory, indicates the seriousness of the challenge facing econometric historians: "technical economic analysis has provided much understanding of what we have termed proximate causes of economic performance but not of fundamental causes... in our view, of particular importance are the nature and operation of certain institutions" (1988, p. 102). The new growth economics may have the potential to rectify this situation and to identify impacts of industrial relations, capital markets and political decision-making on growth outcomes - just the kind of explanatory framework that writers like Alford have in mind.

The message of Tables 1 and 4 appears to be as follows. The UK had less scope for catching-up than most countries in 1950 but even so the Golden Age growth rate is disappointing relative to other European countries such as Denmark and Sweden with similar income levels. On a growth accounting basis, a shortfall in 'unexplained' TFP growth appears to be a major contributor to the growth shortfall relative to countries like France and West Germany. The economic history literature has long been interested in growth based on catch-up - at least since the time of Gerschenkron (1962). A strong emphasis has emerged that catch-up is by no means automatic but depends on what Abramovitz (1986) called 'social capability'. This entails the ability effectively to assimilate the required technical and organizational changes which in turn depends on institutional arrangements and the incentives facing political decision-makers as well as investments in intangible capital. Low 'social capability' would tend to imply in the terminology of Romer (1993) that 'idea gaps' matter as well as 'object gaps' in retarding economic growth.

Prima facie, the UK seems to be a country with a relatively weak social capability which fails to take full advantage of its opportunities in the new postwar economic environment.

Broadly speaking, econometric analysis and further accounting exercises confirm these initial impressions, although they also call for some refinements to this somewhat crude picture. Both Dowrick and Nguyen (1989) and van de Klundert and van Schaik (1996) find in cross-country growth regressions that British growth is well below what might be predicted on the basis of capital accumulation and initial income levels. Crafts (1995c) looks at regional growth in 1950-73 in a conditional convergence framework and finds that a British dummy variable implies growth slower by about 0.5% per year. Similarly, comparing the UK with its European peer group on the basis of the cross-section regression results in Levine-Renelt (1992) also indicates an unexplained shortfall of growth over and above that which might be attributed to factor accumulation and scope for catch-up (Bean and Crafts, 1996, Table 4). This clearly involved inhibitions to productivity growth outside the sphere of R and D.

Denison's detailed growth accounting exercise led him to conclude that very substantial productivity gaps in 1960 should be attributed to differences in work-effort, restrictive labour practices and management quality amounting to 14.3 per cent between UK and France and 13.2 per cent between UK and West Germany (1968, p. 274). This would certainly correspond to the weight of qualitative evidence in the large number of studies of use of labour listed in Pratten and Atkinson (1976) and the case studies in Prais (1981) which suggest that in many industries difficulties of agreeing reductions in staff numbers slowed down the introduction of new technology.

A later growth accounting exercise for manufacturing in 1979, which paid careful attention to the impact of workers' skills and stocks of R and D, found that German TFP exceeded British TFP by 17.7 per cent (O'Mahony and Wagner 1994, p. 24). O'Mahony and Wagner measure skills by vocational qualifications and show that the UK workers had far less at the intermediate level in 1979 (1994, p. 15). This is not an aspect of human capital formation typically considered in either growth accounting or regression based growth studies which take into account education rather than training. In a companion study, O'Mahony (1992) undertook an econometric analysis of relative productivity in a cross section of British and German industry. Her results suggest that growth accounting may also somewhat underestimate the importance of skill formation - and thus exaggerate TFP differences - by failing to allow for externalities. An upper bound is that about 0.4 percentage points of the unexplained TFP growth difference for 1950-73 in Table 4 between the UK and Germany might actually be accounted for in this way.

To an unthinking economist steeped in R and D based endogenous innovation models, it may seem odd to accuse the UK of having a low social capability for growth and surprising that TFP growth was disappointing, given the British record of spending the second largest proportion in the OECD of its GDP on research and development until the mid-1960s (United Nations, 1964). In fact, these figures are misleading since they include a huge government financed component centred on defence and including economically disastrous progammes to support aerospace and nuclear power (Edgerton, 1996). In the years 1967-75 industry-financed R and D actually declined at 0.5 per cent per year while in France and Germany this was growing at nearly 6 per cent per year (Patel and Pavitt, 1989). The British share of patents granted to non-Americans in the USA fell from 23.4 per cent in 1958 to 10.8 per cent in 1979 (Pavitt and Soete, 1982) while Verspagen (1996) in an econometric analysis found that, in contrast to France and Germany, British R and D expenditure had virtually no impact on productivity growth.

This review clearly underlines the need for growth economists to devote more time to the construction of data. The inadequacy, at least for comparisons within the OECD, of standardly used proxies for human capital formation and of conventional R and D statistics has been revealed. Nevertheless, it seems there is an innovation and TFP growth failure to be explained in Golden Age Britain, even though there is some doubt about its precise magnitude. There were institutional idiosyncrasies which have attracted considerable attention and which might be encompassed within extensions of the endogenous innovation growth model framework. In particular, British capital markets and industrial relations fall into this category.

An important aspect of the postwar British capital market has been the development of the hostile takeover on a large scale. Jenkinson and Mayer (1992) concluded that the British rules of the game created a unique exposure to this risk and that it normally entails the exit of existing top management. This might be expected to promote short-termism and to dampen enthusiasm for long-term investments such as R and D whose payoffs might not result until after the change in ownership (Franks and Mayer, 1990). Mayer (1992) found that large British firms generally felt compelled to maintain dividends at the expense of R and D. In terms of the Grossman-Helpman model, this can be thought of as tantamount to a reduction in market power in reducing the appropriability of profits from discoveries and thus can be expected to have reduced both the allocation of resources to innovation and the longrun growth of TFP.

Crouch has chronicled changes in West European industrial relations systems and has stressed the transformation which occurred in many countries between the 1920s and the early 1950s. Against a background of widespread centralization of bargaining and even adoption of corporatist structures, he saw a case of unusual continuity: "there is in Europe only one case of a powerful, long-established but decentralized unionism - that of Britain" (1993, p.337). The British system of industrial relations was characterized by multiple unionism, by an absence of legally enforceable contracts and by legal immunities extending to most forms of industrial action. Increasingly bargaining took place with shop stewards rather than union bosses (Batstone, 1988).

Individual firms basically had to accept these rules of the game and it is clear that they impacted adversely on the productivity of foreign multinationals operating in the UK as well as domestic firms (Lewchuk, 1987; Pratten, 1976). Eichengreen (1996) traced out the implications for investment and catch-up growth and concluded that they were adverse; in the UK it was harder for the two sides of industry to make commitments to wage moderation in exchange for productivity enhancing investments. In the postwar context these arrangements would be a more serious handicap than hitherto both because workers' bargaining power was enhanced in a situation of full employment in the labour market with weak competition in product markets and also because the enhanced scope for technology transfer meant the foregone productivity growth would be greater.

Grout (1984) showed how bargaining between management and unions can lead to underinvestment in the absence of binding contracts, because ex post the workforce can expropriate some of the quasi-rents. When this insight is integrated into an endogenous innovation growth model, the implication is that profits from discoveries are reduced as are the incentive for innovative activity and the growth rate. The disincentives are more severe the greater the more powerful are the workforce and with multiple bargaining. This both increases the inefficiency and, by encouraging free-riding behaviour, undermines the possibility of solving the problem via a reputational equilibrium. Bean and Crafts (1996) provide a formal model and econometric estimates of the implication of multiple unionism. Their results, which are set out in Appendix 3, indicate that in British manufacturing during 1954-79 the presence of multiple unionism reduced TFP growth by between 0.75 and 1.1 per cent per year.

The endogenous innovation approach to growth argues that the growth rate could have been increased by appropriate government interventions. Yet the historical record suggests that, despite considerable efforts in this direction, supply-side policy was at best ineffective and at worst harmful (Crafts, 1991). There seem to have been three reasons for this. First, there were mistakes due to inexperience or policies which had unintended consequences. The reform of the Companies Act in 1948 which sought to address issues raised by interwar scandals but which led to the development of the hostile takeover is a good example. Second, governments implicitly believed in the wrong growth model and concentrated on subsidizing physical investment rather than facilitating reduction of the ideas gap and TFP growth. An extreme version of this policy error was seen in Northern Ireland (Crafts, 1995c).

Third, and perhaps most fundamental, political decision-makers saw votes to be lost rather than won through incurring short term pain from supply-side reform even though the long term rewards could have been considerable, given that credible promises of compensation to possible losers were not feasible. Price and Sanders (1994) implicitly justify the rationality of this short-termism by politicians; in an econometric study they showed that short term macroeconomic performance had powerful effects on government popularity and that the reforming Thatcher government would have lost office long before seeing any payoff but for the Falklands War. The short term imperative was to negotiate (tacit or overt) social contracts with the trade unions, especially when substantial macroeconomic problems arose, for example, during postwar reconstruction (Crafts, 1993) or during the oil crisis. These involved in part wage restraint in return for abandoning attempts at reform of industrial relations.

This discussion should be taken to indicate some of the potential of the new growth economics to address the issues which economic historians like Alford (1988) see at the heart of comparative growth performance. Obviously, it is not a balanced or complete account of a complex growth process. Equally clearly, it is the spirit rather than the letter of the well-known models which is applicable. Ultimately, models in which institutions impacting on innovative activity, as well as innovation itself, are endogenous will be required to obtain a deeper understanding of Britain's relative economic decline.

4. The Golden Age and After

The renewal of interest in growth economics has been remarkable for an explosion of regressions seeking to explain cross-country differences in growth rates based on evidence drawn from the post-1960 period for which large samples of purchasing power parity adjusted national income estimates are available. Much of this work is ably reviewed in Levine and Renelt (1992). A good deal has been learnt from this research programme but a longer run view drawing on findings in economic history helps both to place these results in perspective and also to underline some limitations of this approach. In particular, it is important to note both that the cross-section regressions are generally affected by the special circumstances of the Golden Age and taht they say relatively little about the roles that policy and institutions play.

Levine and Renelt (1992) argue that relatively few of the cross-section results will bear much weight but that a basic robust regression relates growth of output per person positively to the share of investment in GDP, school enrolment rates and negatively to the initial income level which would capture scope for catch-up. In Barro and Martin's framework this would be a world of conditional convergence. Such a regression could be used to provide an alternative form of growth accounting to the traditional one of Maddison (1996). In Table 7, an illustration of this is reported using a specification which also includes government consumption expenditure, for which there appears to be a robust (negative) relationship in the OECD, if not across the whole world (Dowrick, 1992).

Taken at face value the results in Table 7 indicate the following. First, the acceleration in growth in the Golden Age is attributed largely to greater investment in both physical and human capital rather than greater scope for catch-up in terms of a larger income gap. Second, compared with the traditional growth accounting of Table 4, this approach attributes more of the acceleration in growth to human capital and less to TFP growth; 1.41 percentage points of the 1.72 increase in growth between 1923-38 and 1950-73 is attributed to broad capital accumulation. Third, the slowdown after 1973 is attributed much more to erosion of catch-up opportunities than in the Maddison estimates of Table 4. Fourth, and by no means least, the speed-up in growth in the Golden Age has a substantial unexplained component (of about a third). It is noticeable that the variables listed in Table 6 do not capture changes in 'social capability'; this may account for at least some of the 'unexplained' increase in growth in the 'Golden Age'.

Recently, more attention has been given to the role of policy choices in growth outcomes. Sachs and Warner (1995) find that openness is a key criterion in facilitating catch-up and their openness dummy variable has a 2 percentage point effect on growth in a conditional convergence set up. Taylor (1995) explores this result further and concludes that

Table 7. Accounting for Changes in European Output/Head Growth using a Levine-Renelt Approach (% per year)

	1923-38	1950-73	1973-89
Constant	2.01	2.01	2.01
Initial GDP/Head	-2.43	-2.49	-3.55
Investment/GDP	1.42	2.22	2.06
Secondary Enrolment	0.16	0.68	0.79
Primary Enrolment	1.90	1.99	1.79
Government/GDP	-0.62	-0.87	-1.27
Predicted	2.44	3.54	1.83
Actual	2.12	3.84	2.14

Notes: Estimates are for the unweighted average of European countries in Maddison's 1991 database excluding Belgium and Switzerland.

Sources: The estimates are derived using equation (ii) in Levine and Renelt (1992) with population growth and irrelevant dummies ignored. The initial income variable was expressed as a percentage of the US level in each year and was then multiplied by 1960 US income per person. Basic sources of national accounts data were Maddison (1991) (1995a) and OECD, Economic outlook supplemented for interwar investment by Maddison (1992) and for interwar government consumption expenditure by den Bakker et al. (1990), Feinstein (1972), Hansen (1974), Hjerrpe (1989), Krantz and Nilsson (1975) Rossi et al (1992), Sommariva and Tullio (1986) and Villa (1993).

distortions associated with absence of openness played a significant role in the growth failures of Latin American economies in this period.

Economic historians studying the postwar period against the background of earlier times have argued that for a number of reasons an interval of very rapid TFP growth was possible in Europe; essentially these arguments are similar to those identified, but perhaps not reliably quantified, in the well-known growth accounting studies of Denison (1967) and Maddison (1991). Kindleberger (1967) stressed factors which promoted the redeployment of 'surplus labour' from agriculture. Dumke (1990) emphasized the rapid productivity growth accruing from reconstruction of war damaged economies. Owen (1983) pointed to the strong impact of trade liberalization in promoting cost reductions in the style later envisaged by the Cecchini Report.

In the context of an unprecedented American technological lead, productivity assistance missions strove to speed up imitation of American technology and organization. Attracted by the new economic environment, an American 'invasion' of Europe developed. Thus, while in 1930-48 American companies established 93 operations in Britain and 33 in Germany, in 1949-71 the figures were 544 and 330 respectively (Chandler 1990, pp. 158-9). Nevertheless, success in 'technology transfer' varied and seems to have been affected by institutional and policy differences. The bargaining equilibrium between firms and their workers in the context of British industrial relations seems to have limited the productivity gains from exposure to American ideas (Broadberry and Crafts, 1995) while differing national strategies of human capital accumulation seem to have affected the ability to convert information into an effective knowledge base for developing indigenous technological capabilities (von Tunzelmann, 1995). These would not, however, be captured by the enrollment ratios of Table 7.

Econometric evidence can be found to provide some support for the view that reductions in the ideas gap played a considerable part in the catch-up growth of the Golden Age. Verspagen (1996) augmented growth regressions for the OECD to include patenting performance and found that the results imply that postwar patenting had reduced the coeffficient of variation of labour productivity in 14 European countries by about 20 per cent by 1973. Coe and Helpman (1995) showed in a study for 1971-90 that TFP growth in European countries has been highly responsive to increases in foreign R and D capital stocks, more strongly so the more open the economy. Ben-David (1993) showed that the coefficient of variation in income levels in European countries was reduced sharply by specific episodes of European economic integration in the postwar period. Chou et al (1995) find econometrically that R and D efforts in OECD countries are substantially boosted by greater international integration.

Two points emerge from this discussion following on that of section 3c. First, it seems clear that both the detailed attribution of sources of growth by growth accounting and the implicit account of Golden Age growth of the new empirical growth economics are unconvincing. Key areas for further work would seem to include refinement of measures of human capital formation and continued econometric investigation of the determinants of TFP growth using the pointers provided by economic historians. Second, the historical evidence supports recent suggestions that growth regressions have tended to exaggerate the importance of accumulation relative to innovation and ideas (Romer, 1993) and have obscured the roles of institutions and policy in growth outcomes.[10] Interestingly, recent econometric re-evaluation of the standard international cross-section growth database seems to point to a similar conclusion. Islam (1995) re-estimates standard regressions using a panel data approach which permits the identification of country effects; he concludes both that these are large, that they reflect differences in TFP based on persistent differences in technology levels and institutions and (tentatively) that human capital may have its effects on growth indirectly through social capability rather than directly through factor accumulation.

In contrast with the recent explosion in empirical research based on recent international cross-sections, relatively little effort has been made to examine the implications of endogenous growth theory using time-series data, except insofar as the voluminous literature on unit-roots in GDP tests the general plausibility of these models. A pioneering attempt did, however, note that time-series testing might prove to be an uncomfortable experience for the new growth theory in that it appears that key characteristics of a country's economic activity are much more persistent than are its growth rates across decades (Easterly et al., 1993).

A recent paper by Jones (1995) marks a welcome change by considering OECD, and particularly, American growth over the period since 1900 in the context of predictions that might be drawn from the endogenous growth literature. While this paper makes a good start in exploiting the historical data, a review of its findings suggests quite strongly that historical skills are required to take full advantage of the possibilities.

Jones's main point is that while investments of the kind regarded as growth promoting by either branch of endogenous growth theory have risen steeply to record highs in the last 40 years or so growth rates of output and TFP are not higher than ever before. He argues that the rejection of the R and D based, endogenous innovation models is particularly strong; "The models posit that the growth rates of per capita output and TFP should be increasing with the level of resources devoted to R and D, which is wildly at odds with empirical evidence" (Jones 1995, p. 519). Jones finds the basic structure of R and D growth models to be appealing but not the endogenous growth implications.[11]

Clearly Jones's results represent a very strong challenge to R and D based endogenous grwoth models. Taking a long-run historical perspective and bearing in mind the work of growth accountants and studies of the impact of R and D on productivity, gives reaasons to doubt that his critique is quite so devastating as might appear at first sight. Three points should be considered.

First, as was noted earlier, TFP growth has accrued historically from a wide range of sources including structural change and, given the relatively low fractions of GDP spent on R and D, at least until recent times relatively little TFP growth can be attributed to this source. Equally, reasons for the slowdown in TFP growth in the OECD may lie elsewhere.

Second, direct evidence on the potency of R and D is somewhat mixed and bedevilled by measurement problems. Griliches (1994) reviews the evidence and concludes that on balance it is likely that R and D in the American manufacturing has had as strong an effect on TFP growth in 1978-89 as it had in 1958-73. Furthermore, it may be that our ability accurately to measure TFP growth has declined and that recent official estimates are understated through inadequate treatment of the now much larger services sector in OECD economies.

Third, earlier sections of the paper have stressed the special and unrepeatable features of the Golden Age in European growth, the need generally to consider phases of economic growth and the role that technological shocks can play in the growth process. Such effects are often felt with a substantial lag - electricity generation was achieved in the 1880s but its major impact on productivity was not felt until the 1920s (David, 1991). If, as some accounts of long-run technological change insist, major changes in 'techno-economic paradigm' involve creative destruction and grave adjustment problems, it could be that these initial effects of recent technological improvements show up in slower productivity growth but that the delayed effects are the opposite (Free man and Perez, 1988).

5. Concluding Comments

The major theme of this paper has been to consider the potential of endogenous innovation growth models of the genre proposed by Grossman and Helpman (1991) at the interface between economics and economic history and, in particular, to investigate the scope for fruitful interaction in this area. My initial supposition was that there was an excellent opportunity for mutually beneficial trade and the survey tends to support this view.

The central feature of this approach is that productivity growth results from purposive search for innovations in which the ability to appropriate profits to cover the fixed costs of discovery determines the resources devoted to innovative activity and thus the growth rate. This provides a key point of tangency with economic historians who are always keen to emphasize the role of institutions. These can have crucial effects on the resource allocation process underlying the endogenous growth outcomes. Moreover, for new economic historians, who have always been keen to argue that long run differences in economic performance are not to be explained in ways which violate the hypotheses of rational expectations and profit-maximization by agents who use available information efficently, the potential attractions of endogenizing productivity growth in this way are apparent.

Each of the case studies set out in section 4 indicated that new insights and better hypotheses could result from employing the new growth economics in conjunction with existing knowledge. At the same time, it is clear that work in economic history will benefit from further work on learning effects in this framework and that sensitivity in using the models is required.

Where, more generally, are the likely gains for economic history from exposure to endogenous innovation growth theory? Three areas seem to be especially worth stressing.

(i) Unlike traditional neoclassical growth economics, the new models can readily allow scope for divergence and for a much richer menu of influences on growth outcomes. The dangers of a Panglossian view of the past and a selective and restrictive search for evidence in evaluating growth performance should be much reduced for the next generation of cliometricians. This branch of growth theory offers improved hypotheses to economic historians unhappy with earlier formal models of induced technological change based on arguments familiar to historical research, these models deserve to be taken seriously in economic history.

(ii) Institutions (and policymaking) can be placed right at the heart of the growth process in a rigorous way. This should help to focus attention on detailed characteristics of these arrangements and to explain why they really matter. Institutional arrangements will be an intrinsic part of historical accounts of economic growth partly because they exhibit substantial continuit and windows of opportunity for their reform may well be both narrow and infrequent. There is an opportunity to assimilate key arguments of traditional historians which were previously either excluded by assumption or treated at best discursively.

(iii) There can be a strong justification to resume the detailed consideration of the reasons for differences in TFP growth rather than to abandon the idea as old fashioned or simply a reflection of measurement error. Informed by new ideas, better techniques of measuring real output and imaginative investigation of the notion of 'social capability', it may be possible to refine and extend the estimates of the growth accounting pioneers.

Empirical growth economics has relied thus far rather heavily on regression analysis of international cross-sections drawn from the recent past. This has been useful but lacks the persepective that can be gained from a long run vantage point which takes into account the growth performance has been due in at least some measure to the industrial relations environment, and in particular to its fragmentary, craft-based union structure.

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changing socio-economic environment. So what can growth economics learn from the concerns and research of economic historians? Three points stand out.

(i) Serious exploration of the effects of institutions and policies on economic growth is welcome but to provide adequate understanding of why growth rates differ among first world countries and over time will require much better quantification of key variables impacting on TFP growth and of TFP growth itself than hitherto. Measurement issues are much more serious in this area than growth economists presently seem willing to acknowledge.

(ii) The view of TFP growth embodied in most endogenous innovation models is lopsided. Undue attention is paid to R and D as opposed to learning as a source of productivity improvement and to patents and market size as opposed to other determinants of the profitability of innovation. Similarly, a more explicit focus on the role of international technology transfer in the growth process seems overdue.

(iii) Now that more economists are turning their attention to longer run growth data it would be timely for modelling exercises to bear in mind other implications of the Schumpeterian vision than those currently stressed by endogenous growth theory, notably that breaks in trend rates of growth may be expected to occur quite often. Failing that, at least the special nature of catch-up during the Golden Age must be carefully allowed for both in interpreting results from the Summers-Heston dataset and in thinking about the growth slowdown of the last 20 years.

Finally, one of the most exciting avenues of research for economic historians and economists to pursue together using an endogenous innovation framework is the political economy of growth. This should aim for an understanding both of what the key effects of policy on growth have been and also of how the incentive structures facing politicians and private agents generate growth retarding or growth enhancing interventions. This will more likely be successfully achieved through a portfolio of detailed case studies of individual countries than through regressing growth rates against standard political variables.

Footnotes

1. This section draws on Crafts (1995a) which contains a much fuller version of the argument.

2. This point can be reinforced by considering the experience in terms of the robust growth regression in Levine and Renelt (1992) as in Crafts (1995a).

3. Three points might be made about time series modelling of growth in the nineteenth century. First, we can expect the trend rate of growth to vary even in the absence of traumatic shocks. Second, there are no strong priors concerning break-points. Third, the modelling strategy outlined in the text permits rejection of the hypothesis of a unit root in industrial output. More details of the Crafts and Mills (1994) results can be found in Appendix 2.

4. Murphy et al. (1991) provide an endogenous growth model in which the relative attractions of rentseeking and productive entrepreneurship determine the allocation of talent and thus the rate of technological progress and the growth rate.

5. Issues of this kind are discussed in more depth in the following two subsections. For an endogenous growth model in which bargaining power and structures between firms and their workers affects the growth of TFP see Bean and Crafts (1996). For discussion of this problem and attempts to solve it in a large cotton textiles firm in the early nineteenth century see Huberman (1991).

6. Although the marginal direct tax rate was lower, indirect tax rates were considerably higher in Britain than in France (Mathias and O'Brien, 1976). In the simplest Grossman-Helpman model the key would be that a lower direct tax rate tend to raise the rate of innovation through its effect on the net rate of return. In the more refined

models, which allow for effects from the relative price of human capital, indirect taxes could have an impact - positive or negative - depending on whether human capital (used intensively in innovation) is made cheaper as a result of its imposition and the use the government makes of the proceeds. See Grossman and Helpman (1991, pp. 66-7 and 267-75).

7. The 0.4 per cent gap for 1873-1913 is based on the sources underlying Table 4. It may be more appropriate to dwell on this longer period despite the attention given to 1899-1913 by some British authors. Time series analysis does not support the suggestion that there was a significant change in trend growth in this period (Crafts et al., 1989) and the TFP growth measure seems to reflect mistakes in investment linked to highly volatile expectations (Crafts and Mills, 1992).

8. Barro and Martin (1991) find that β- convergence is apparent in the states of the United States from 1880, the start of their sample period, onwards. The remarks in the text imply that such a result is more likely to have applied within a country than across the world.

9. This section draws on Bean and Crafts (1995) and on Crafts (1995c) which contain much fuller accounts.

10. Early applications of endogenous growth ideas to policy debates display similar tendencies. For example, Baldwin's well known (1989) discussion of the growth effects of the EU's Single Market Programme looks to dynamic effects occurring automatically through Rebelo-style faster capital stock growth whereas the endogenous innovation approach would see the impact of 1992 as much more ambiguous and essentially dependent on the mode of implementation and its effects on rent-seeking, on the appropriability of returns as public procurement practices

changes and on the extent to which the market is widened acting through R and D rather than capital accumulation.

11. Jones (1995) regards the prediction of scale effects as the undesirable feature of the R and D based growth models. He points out that this can be modified such that growth still arises as a result of profit-maximizing search for innovations but such that the conventional Solow result returns, namely that the long-run growth rate cannot be raised through interventions to subsidize R and D or investment. He shows this as follows using a simplified model.

$$Y = K^{1-\alpha}(AL_y)^{\alpha} \qquad (3)$$

$$\dot{A}/A = \delta L_a \qquad (4)$$

$$g_y = g_a = \delta s^* L \qquad (5)$$

Equations (3) - (5) comprise a conventional endogenous innovation model in which the steady-state growth rate depends on the rate of growth of knowledge (A) which in turn depends on the share of labour (s^*) optimally allocated to R and D. Jones suggests the following modification to (4)

$$A/A = (L_a/A^{1-\phi}), \text{ where } \phi < 1 \qquad (6)$$

which implies, using (3), that

$$g_y = g_a = n/(1 - \phi) \qquad (7)$$

where n is the rate of population growth and (7) is, in effect, a modified concept of the old natural rate of growth.

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APPENDIX 1

Conventional (augmented) Dickey-Fuller tests, reported in Table A1, suggest that all series contain a single unit root except the U.S., which rejects the unit root null hypothesis in favour of a trend stationary alternative at less than the 5% significance level.

Of course, such a conclusion is unsurprising if, rather than the alternative to the unit root null being a trend stationary process, it is a segmented trend. Campbell and Perron (1991, Rule 4) show that the power of these unit root tests goes to zero as the sample size increases when the trend function contains a shift in the slope!

The discussion in the text suggests that the relevant alternative to consider here is indeed a segmented trend stationary process, but one in which there is more than one break in the trend. We interpret the Maddison hypothesis as specifying breaks in trend at 1914, 1939, 1950 and 1973. Moreover, we regard these break points as being exogenously determined and consequently they are used for all series: we thus avoid the problems of pre-testing bias that have been a major criticism of Perron's (1989) testing approach. Note that if there is more than one break in trend but only a single break is fitted then, again from Campbell and Perron's Rule 4, the power of a unit root test still goes to zero as the sample size increases.

Thus, with x_t denoting the logarithm of output per person, the segmented trend model can be written as

$$xt = \gamma_0 + \gamma_1 t + \Sigma^6{}_{i=2}\gamma_i D_{it} + u_t \qquad (8)$$

where $D_{it} = (t - T_i) \cdot 1(t{>}T_i)$, $1(\cdot)$ is the indicator function and $T_i = 2,...,6$ correspond to the break years 1914, 1919, 1939, 1950 and 1973. Following Campbell and Perron (1991), the unit root hypothesis can be tested by estimating the regression (1), obtaining the residuals u_t, and using the t-statistic for testing $\pi = 0$ in the auxiliary regression.

$$\nabla\hat{u}_t = \pi\hat{u}_{t-1} + \Sigma_i\delta_i\nabla\hat{u}_{t-i} + a_t \qquad (9)$$

where enough lags of $\Delta\hat{u}_t$ are included to ensure that a_t is white noise. The distribution of the test statistic, t_π, under the null depends upon the sample size and the number and placing of the breaks T_i and thus it can only be obtained by Monte Carlo simulation. For each series, we obtained the empirical distribution of t_π by assuming that x_t was generated by a random walk with a drift given by the sample mean of ∇x_t and simulating this process 5000 times, each time fitting the model (8) and calculating t_π from (9).

The unit root tests so calculated are shown in the Table A2 and lead to a number of rejections of the unit root null: it is rejected at the 5% significance level in favour of the segmented trend model for Austria, Belgium, Denmark, Finland, France, Japan, Sweden, and the U.K., and at the 10% level for Germany, the Netherlands, Norway and the U.S., but not for Australia, Canada, Italy, Spain or Switzerland.

However, it is well known that unit root tests of this type have notoriously low power against an alternative of a maximum autoregressive root that is large but nonetheless smaller than unity. Such an alternative is particularly plausible here, for it allows fairly long, perhaps cyclical, movements away from a long-term trend path. We thus supplement the Dickey-Fuller statistic with three further pieces of information: the estimated maximum autoregressive root, $\hat{\rho} = 1 + \hat{\pi}$, the Phillips and Ploberger (1994) Bayesian posterior odds in favour of a unit root, and the number of sample autocorrelations of $\hat{u}_t$ that are observed before the sample autocorrelation function becomes non-positive, a statistic that has been shown by Leybourne (1994) to be a particularly simple and robust test for a unit root.

These are all reported in Table A2 as well and provide convincing evidence that, in fact, all output per person series are stationary around a segmented trend: no roots are estimated to be greater than .83, the Bayesian posterior odds in favour of there being a unit root are all extremely small, and the number of positive autocorrelations of $\hat{u}_t$ that are observed before a negative value is encountered are all much smaller than would be expected if there were unit roots present in each series.

Given these findings, we may then assume that, as in (9), the error u_t can be modelled by an autoregressive process:

$$u_t = \rho u_{t-1} + \Sigma_i \delta_i \Delta u_{t-i} + a_t \qquad (10)$$

Equations (1) and (3) can then be jointly estimated, and trend rates of growth across segments calculated as $\Sigma^k{}_{i=1}\gamma_i$ for the kth segment (the period up to the first break at $T_2 = 1914$ being the first segment, etc.). The order of the autocorrelation for u_t was determined individually for each country using goodness-of-fit criteria.

In general, the estimated trend growth rates for European countries during 1951-1973 are a lot higher than those estimated for other periods and the label Golden Age does seem to be justified. As might be expected, a similar comment applies to Japan but not to the North American countries, which are, of course, not eligible for a phase of rapid catch-up growth.

However, while there is a clear case for treating the break points at 1914, 1919, 1939 and 1950 as exogenous and relevant to all countries, treating the final break at 1973 in the same fashion is rather more contentious. Some views of the world would perhaps envisage an earlier endogenous slowdown as reconstruction was completed. For example, in Germany this might often be located in the literature in the mid-1950s (Dumke, 1990). This breakpoint might also be expected to vary in timing across countries, as also might a slowdown based on the exhaustion of catch-up opportunities. We therefore wish to reconsider our initial results in the light of estimates obtained by allowing the final breakpoint to be determined endogenously for each country. This will permit an examination of the robustness of the findings in Tables A2 and A3 and also provide a suitable framework within which to test hypotheses of a return to historical trend growth paths following the Golden Age.

We can determine the final break point endogenously by jointly fitting equations (8) and (10) for a range of final break years, using, for example, a minimum residual variance criteria. Table A4 thus reports the final breakpoints obtained for each country after searching over the interval 1951 to 1980, along with the same information about the presence of a unit root, *conditional* on this endogenously determined break, as was given in Table A2. Significance levels are not reported for the Dickey-Fuller statistics because of the conditional nature of the test, but it is clear from this information that, once again, all series appear to be stationary around a segmented trend.

Table A1. Unit Root Tests: Output per Person

Augmented Dickey-Fuller tests

		x		∇x	
	Start	τ_τ	$\hat{\rho}$	τ_μ	$\hat{\rho}$
Australia	1870	-1.37[2]	0.965	-10.64[0]	0.015**
Austria	1870	-1.61[0]	0.950	-10.06[0]	0.063**
Belgium	1870	-1.04[1]	0.978	-5.02[4]	0.118**
Canada	1870	-2.93[1]	0.895	-8.16[0]	0.270**
Denmark	1870	-1.57[2]	0.950	-10.72[0]	0.003**
Finland	1870	-1.47[4]	0.968	-6.12[3]	0.077**
France	1870	-2.03[3]	0.947	-5.47[4]	0.099**
Germany	1870	-1.90[2]	0.935	-8.94[1]	-0.161**
Italy	1870	-1.66[1]	0.963	-8.35[0]	0.247**
Japan	1885	-1.17[0]	0.970	-9.23[0]	0.80**
Netherlands	1900	-2.47[1]	0.893	-7.16[1]	0.030**
Norway	1870	-1.06[0]	0.979	-10.17[0]	0.054**
Spain	1860	-0.56[1]	0.991	-9.21[0]	0.190**
Sweden	1870	-1.72[5]	0.968	-4.88[4]	0.175**
Switzerland	1899	-1.08[1]	0.984	-5.57[0]	0.462**
U.K.	1870	-0.92[4]	0.974	-6.65[2]	0.118**
U.S.	1870	-4.04[1]*	0.826	-6.59[3]	-0.025**

τ_τ is computed from a regression of x_t on a constant, t, x_{t-1} and k lags of ∇x_t : the value of k is shown in brackets [·]. τ_μ is computed from the regression of ∇x_t^2 on a constant, ∇X_{t-1} and k lags of $\nabla^2 x_t$, $\hat{\rho}$ is the coefficient on the lagged dependent variable in both regressions. * and ** denote significance at the .05 and .01 levels respectively. x is the logarithm of output per person: all samples end in 1989.

Source: Crafts and Mills (1996).

Table A2. Unit Root Tests Against the Segmented Trend Alternative: Exogenous Breaks

	τ_{π}	$\hat{\rho}$	Bayesian Posterior Odds	c
Australia	-4.15	0.83	0.011	5
Austria	-5.53**	0.63	<0.001	3
Belgium	-5.55**	0.73	0.012	4
Canada	-4.91	0.70	0.003	4
Denmark	-5.89**	0.64	0.001	4
Finland	-7.07**	0.41	<0.001	3
France	-5.90**	0.69	<0.001	4
Germany	-5.28*	0.51	<0.001	3
Italy	-4.52	0.79	0.048	5
Japan	-6.02**	0.25	<0.001	2
Netherlands	-5.03*	0.67	0.099	4
Norway	-5.41*	0.53	<0.001	4
Spain	-4.17	0.76	0.020	5
Sweden	-6.28**	0.59	<0.001	4
Switzerland	-4.61	0.75	0.016	4
U.K.	-6.11**	0.61	<0.001	3
U.S.	-5.23*	0.66	<0.001	3

The test statistic τ_{π} and the estimator $\hat{\rho} = 1 + \hat{\pi}$ are as defined in the text (see equations (8) and (9)). * and ** denote significance at 10% and 5% levels, respectively, with critical values computed via Monte Carlo simulation as discussed in the text. The Bayesian Posterior Odds are defined as 1/BLR, where BLR is the Bayes model likelihood ratio criterion of Phillips and Ploberger (1994). c is the number of positive sample autocorrelations of $\hat{u}_t$ observed before a nonpositive value is encountered. Using the table of critical values given in Leybourne (1994), all c values reject the null of a unit root at the 1% significance level.

Source: Crafts and Mills (1996).

Table A3. Unit Root Tests Against the Segmented Trend Alternative: Endogenously Determined Final Break

	T_6	τ_π	$\hat{\rho}$	Bayesian Posterior Odds	c
Australia	1975	-4.00	0.78	0.0006	5
Austria	1957	-6.23	0.40	<0.001	2
Belgium	1974	-5.58	0.65	0.030	4
Canada	1954	-5.47	0.69	<0.001	3
Denmark	1969	-5.98	0.55	0.007	4
Finland	1974	-7.09	0.51	<0.001	3
France	1957	-6.58	0.62	<0.001	4
Germany	1955	-6.62	0.25	<0.001	2
Italy	1969	-4.62	0.75	0.027	4
Japan	1970	-6.14	0.19	<0.001	2
Netherlands	1955	-5.42	0.60	0.061	3
Norway	1954	-5.52	0.53	<0.001	4
Spain	1973	-4.17	0.76	0.005	5
Sweden	1971	-6.26	0.54	<0.001	4
Switzerland	1970	-4.08	0.73	0.007	4
U.K.	1973	-6.11	0.61	<0.001	3
U.S.	1958	-5.51	0.67	<0.001	3

The test statistics are as in Table A2, except that they are computed from equations (8) and (9) with the regressor D_6 defined using the estimated break point ($\hat{T}_6$) recorded in the first column.

Source: Crafts and Mills (1996).

APPENDIX 2

In the *basic structural model* (BSM) the logarithm of industrial production, y_t, is additively decomposed into a trend μ_t, and a cycle, ψ_t,

$$y_t = \mu_t + \psi_t \tag{11}$$

such that the trend is modelled as

$$\mu_t = \mu_{t-1} + \beta_{t-1} + \eta_t \tag{12}$$

$$\beta_t = \beta_{t-1} + \zeta_t \tag{13}$$

and the cycle is modelled either as an AR(2) process,

$$\psi_t = \rho_1 \psi_{t-1} + \rho_2 \psi_{t-2} + \ _t \tag{14}$$

or as an explicit sinusoidal process.

The errors η_t, ζ_t and $_t$ are independent white noise disturbances with variances, $\sigma_\eta^2, \sigma_\zeta^2$ and σ_ω^2. The trend component is thus modelled as a *stochastic* linear trend, which would collapse to a *deterministic* linear trend if the variances σ_h^2 and σ_ζ^2 wereboth zero, and to a random walk with a drift if only $\sigma_\zeta^2 = 0$.

Table A4. BSM Estimates for Subperiods

	σ_η^2 ($x10^{-3}$)	σ_ζ^2 ($x10^{-5}$)	σ_ω^2 ($x10^{-4}$)
1700-1913	2.26	0.55	0
	(10.03)	(0)	
1700-1780	3.04	2.70	0
	(5.98)	(0.96)	
1781-1829	1.90	4.50	0
	(4.47)	(0.94)	
1781-1850	2.11	0.18	0
	(5.76)	(0)	
1813-1913	1.91	2.66	0
	(6.61)	(1.19)	
1830-1913	1.66	4.31	0
	(5.87)	(1.26)	
1830-1872	1.83	0.77	0
	(4.40)	(0.72)	
1851-1913	0	0.10	6.67
	(0)	(0)	(4.85)

1873-1913	0	8.03	4.51
	(0)	(1.52)	(3.37)

(t-ratios in parentheses)

Given that the index may contain structural breaks, the BSM was estimated not only over the complete sample period of 1700 to 1913, but also over various sub-periods suggested by the literature. These estimates are shown in Table A4, from which it would appear that σ_ζ^2 was close to zero for subperiods which included the middle part of the nineteenth century, while σ_η^2 was close to zero for the latter part of the sample period, this being the only time when there was a significant cycle, its estimated period being approximately 8 years (all estimations were performed using a sinusoidal process for ψ_t).

It is clear from these estimates that a single BSM fitted over the entire sample period is unlikely to provide a completely satisfactory fit, and further evidence that this is the case can be provided from another source. The complete sample estimates show that although σ_η^2 is reliably positive, σ_ζ^2 is very small and could be taken as being essentially zero. Although σ_ω^2 is zero, there is, in fact, no cyclical behaviour in the error component.

With $\sigma_\zeta^t = 0$ and ψ_t modelled as a noncyclical AR(1) process, it is easy to show that ∇y_t must follow an ARMA(1,2) process with drift. Fitting such a model obtains

$$\underset{}{\nabla y_t} = \underset{(0.001)}{0.018} - \underset{(0.125)}{0.691}\nabla y_{t-1} + a_t + \underset{(0.129)}{0.570}a_{t-1} - \underset{(0.115)}{0.214}a_{t-2},\ \sigma_a = 4.64\% \qquad (15)$$

Although this model appears to be quite satisfactory on the basis of standard diagnostic checks, on further analysis we find that ∇y_t contains a significant time trend, for including t as an additional regressor in (15) above yields a t-statistic of 3.23. This implies that ∇y_t is nonstationary; $\nabla^2 y_t$ is stationary, though, albeit around a non-zero mean and with a unit root in its moving average part. The presence of such a non-zero mean has the important implication that y_t cannot be regarded as being generated from a BSM.

Given these twin findings of structural instability in the BSM and of a complete sample ARMA process for ∇y_t that does not admit a BSM representation, it would seem fruitful to consider an alternative approach to modelling trends and cycles in the Revised Best Guess index. The presence of a linear trend in ∇y_t implies a quadratic trend in y_t, but the strong possibility of structural breaks suggests that a segmented quadratic trend model should be considered. Segmented (or grafted) polynomials have a long history in fitting smooth trend functions to time series, have a firm mathematical foundation and, in their equivalent guise of spline functions, have been used to examine structural change in econometrics Fuller (1976), Poirier (1977). They have been used in a similar context by Hausman and Watts (1980).

The historiography suggests that major changes in the growth rate of the index took place in the years 1765-1785, 1815-1835, and 1855-1875. We thus chose to model the series as having three breaks, denoted T_1, T_2, and T_3, respectively, so that the following trend component was considered.

$$\mu_t = \beta_o + \beta_1 t + \beta_2 t^2 + \sum_{i=1}^{3} \upsilon_i D_{it} \tag{16}$$

where $D_{it} = (t - T_i)^2$ if $t > T_i$ and zero otherwise, and $1764 < T_1 < 1786$, $1814 < T_2 < 1836$ and $1854 < T_3 < 1876$. The times of the breaks were determined by minimizing the residual sum of squares from the regression using (16) for all possible combinations of T_1, T_2, and T_3. The minimizing combination was found to be $T_1 = 1776$, $T_2 = 1834$, and $T_3 = 1874$.

Table A5. Segmented Quadratic Model

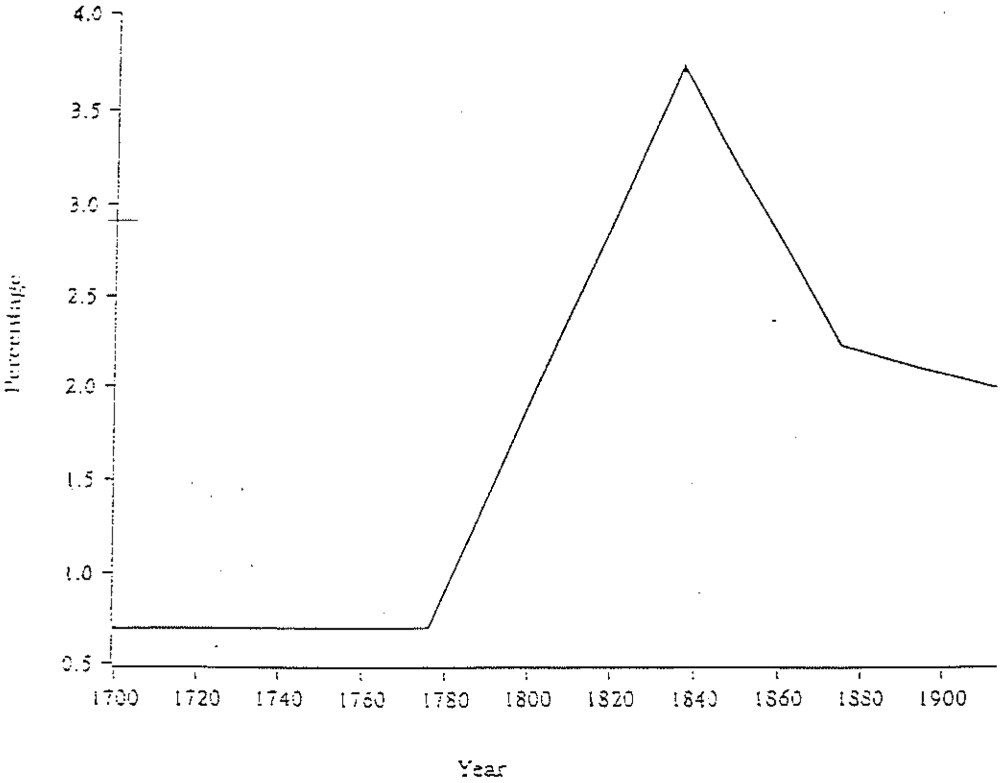
	OLS		GLS	
	Est	t-ratio	Est	t-ratio
β_o	0.730	50.20	0.725	41.70
β_1	0.0064	9.47	0.0070	25.23
$\beta_2 \times 10^{-4}$	0.006	0.99	-	-
$\upsilon_1 \times 10^{-4}$	2.499	20.58	2.628	35.74
$\upsilon_2 \times 10^{-4}$	-4.395	-23.95	-4.550	-16.85
$\upsilon_3 \times 10^{-4}$	1.422	3.66	1.675	2.62
ρ	-		0.520	8.76
σ_u	4.90%		4.18%	
dw	0.96		1.92	
t_π	-8.10		-	

Table A5 presents the OLS estimates from fitting this model. A unit root test on the fitted residuals ψ_t produces a test statistic of -8.10. Although critical values are only obtainable via Monte Carlo simulation, it is clear that such a large value is sufficient to reject the hypothesis of a unit root, and this is confirmed by re-estimating the equation by GLS assuming an AR(1) process for ψ_t, the estimates of which are also shown in Table 2. Extending the order of the AR error process did not produce significant coefficients, thus confirming that, for the sample as a whole, there is no cyclical behaviour about trend. However, as we have seen from the sub-sample BSM estimates, there is strong evidence of a cycle in the later years of the sample period. We thus investigated the possibility of there being a shifting autoregressive error process, with the same break points being used as above. No breaks in the process were found at 1776 or 1834, but an important break was isolated at 1874, leading to the model

$$\psi_t = \begin{cases} 0.533\psi_{t-1} + a_t & t \leq 1874 \\ 0.533\psi_{t-1} - 0.486\psi_{t-3} + a_t & t > 1874 \end{cases} \qquad \sigma_a = 3.93\% \qquad (17)$$

where ψ_t are the residuals obtained as $yt - \mu_t$, μ_t being the trend fitted from the GLS estimates. The complex roots in the post-1874 AR(3) process yield a period of 9 years, which accords well with the estimated cycle from the BSM model fitted over a similar sub-period.

Figure 1. Trend Growth in Industrial Production



APPENDIX 3

The model presented in greater detail in Bean and Crafts (1996) can be summarized as follows. The engine of growth is an expansion in the number of varieties of capital input. The Ramsey Rule is used to obtain equilibrium growth

$$g = \dot{C}_t/C_t = \sigma(r_t - \Theta) \qquad (18)$$

where r_t is the market interest rate and Θ is the time preference rate. The interest rate is equal to the net marginal product of capital.

Firms decide how much capital to instal and then bargaining over wages and employment occurs. Growth is lower than in the competitive equilibrium because of the Grout-style inefficiency whereby unions capture some of capital's quasi-rents. This drives down both the interest rate and the growth rate. The net return on capital is then shown to be lower, ceteris paribus, the more unions the firm bargains with and the lower is the firm's relative bargaining power.

Table A6 reports empirical evidence on this, and other, explanations for Britain's relatively poor post-war growth performance from a panel study of British industrial performance. Ideally one would like to test the hypothesis using firm-level data, but unfortunately at present the best we can do if we wish to examine both time-series and cross-section variation is the three-digit industrial level. The dependent variable in these regressions is thus the average annual growth rate of total factor productivity in 137 industries (Orders III-XIX of the 1968 Standard Industrial Classification) over eight periods (1954-8, 1958-63, 1963-8, 1968-73, 1973-6, 1976-9, 1979-82, and 1982-6; data is not available for all industries over all periods so the panel is unbalanced). This data is taken from Table H.11 of Oulton and O'Mahony (1994), which contains more details about its construction, including the linking of data from the 1968 and 1980 SICs.

The independent variables include the following: the average annual rate of growth of the capital stock in the industry (from Table H.3 of Oulton and O'Mahony); the fraction of workplaces within the industry in which there is at least one recognised union for manual labour (from the 1980 Workplace Industrial Relations Survey); the fraction of workplaces within the industry in which there is more than one manual union (also from the 1980 WIRS); a multiple union dummy that takes the value zero before 1979 and is the same as the previous variable for 1979-82 and 1982-6; an employment "shock" dummy which takes the value zero before 1979 and the proportionate fall in employment during 1979-82 for 1979-82 and 1982-6 (from Table H.4 of Oulton and O'Mahony); the five-firm concentration ratio in the industry (from the Census of Production); the ratio of imports to home demand (from Wells and Imber (1977) and Business Monitor); and a set of common time dummies.

The rationale behind the inclusion of these variables is as follows. The growth rate of the capital stock is included to pick up externalities from physical capital formation onto knowledge creation. Since the variable in question relates to capital formation within the industry this variable should be thought of as relating to "local", rather than economy-wide, externalities. The latter will be related to the total rate of capital accumulation in the economy and so will be captured by the time dummies. Because the rate of capital accumulation may be correlated with the rate of total factor productivity growth, we treat it as endogenous and instrument it with lagged capital growth.

The next four variables capture the impact of the industrial relations environment, in particular the impact of multiple unions. The multiple union dummy permits the adverse effects of multiple unions to be ameliorated during the 1980s as a result of the reduction in union power brought abut by the twin effects of the 1980-82 recession and the Thatcher government's industrial relations reforms. The employment shock dummy is intended to capture the idea that the transformation of industrial relations was greatest in those industries subject to the greatest shake-out of employment in the 1980-82 recession; this variable has been widely employed in other work on the 1980s UK productivity resurgence.

The concentration ratio and the level of import penetration are intended to capture the intensity of domestic and foreign competition. Theory suggests the impact of these variables could go either way. On the one hand a protected market position allows managers to opt for a quiet life and rest on their laurels. On the other hand it allows larger and more durable quasi-rents from innovation so promoting growth.

All of the regressions include a full set of common time dummies; these are highly significant, with a marginal significance level close to zero. Unfortunately there is no time series dimension available for the industrial relations variables, the 1980 WIRS being the first of its kind. Consequently it is not possible to include a full set of three-digit industry dummies and still identify the industrial relations effects. However we have tried including a set of fifteen Order-level dummies. The first column of Table A6 includes these, while the second column omits them (they are just significant at the 1% level). Fortunately the results do not seem to be too sensitive to their exclusion. In addition the Durbin-Watson statistics in both regressions are very close to 2, while if a lagged dependent variable is included in the regression it invariably attracts a small, statistically insignificant, coefficient. Consequently we are led to conclude that industry fixed effects are relatively unimportant and their omission should not bias the results unduly.

Both sets of empirical results suggest that the presence of multiple unions significantly depresses total factor productivity growth, with multiple union workplaces having exhibited an annual rate of total factor productivity growth some 3/4-1 percentage points lower than that achieved by single union workplaces over the 1954-79 period. Once the presence of multiple unions is controlled for, there appears to be no residual effect from union recognition. This suggests that cooperative outcomes that avoid the Grout-style inefficiencies may have been relatively easy to establish in single union workplaces.

Table A6. Panel Regressions of Total Factor Productivity Growth in British Industry

Dependent Variable: Total Factor Productivity Growth

	With Order Dummies	No Order Dummies
Capital Growth	0.153	0.141
	(1.49)	(2.11)
Union Recognition	-0.086	0.055
	(0.25)	(0.17)
Multiple Unions	-0.754	-1.112
	(2.06)	(3.38)
Multiple Union Dummy	0.689	0.668
	(1.33)	(1.28)
Employment Shock	-0.130	-0.134
	(3.36)	(3.62)
Concentration Ratio	0.703	0.388
	(1.22)	(0.96)
Import Share	-0.301	0.561
	(0.47)	(1.07)
Standard Error	2.391	2.689

R^2	0.210	0.196
Durbin-Watson	2.042	1.959
No. of Observations	794	794

Notes: t-statistics in parentheses; coefficients on Time and Order Dummies omitted for brevity.

Turning next to the impact of the 1980-82 recession and the industrial relations reforms of the Thatcher government, we find that the coefficient on the multiple union dummy is positively signed and of the same order of magnitude as the coefficient on the multiple union variable itself. This suggests that the adverse effect of multi-unionism has been significantly ameliorated during the eighties; indeed the implication of the estimates containing the Order-level industry dummies is that the effect had been almost completely eradicated. The results are therefore in line with those of Machin and Stewart (1994) who, using the 1990 WIRS and a subjective measure of productivity growth, find no effect from multi-unionism during the late eighties. The employment shock variable is also highly significant in line with most earlier work.

Neither of the variables intended to capture the impact of the firm's competitive environment seem to play any major role. If anything the results seem to suggest that a high degree of competition, at least from domestic firms, may tend to depress total factor productivity growth, but clearly there is insufficient information in the data to draw any firm conclusions.

These estimates are, of course, only preliminary and may be subject to reappraisal in the light of further work. They do, however, support the view that Britain's poor post-war