SOLOW AND GROWTH ACCOUNTING:
A PERSPECTIVE FROM QUANTITATIVE ECONOMIC HISTORY

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August 2008

Revised draft of paper for HOPE Conference, *Robert Solow and the Development of Growth Economics*, Duke University, April 2008. I am grateful to Steven Durlauf, Mary Morgan and two anonymous referees for helpful comments on an earlier version. Lennart Schon and Gianni Toniolo kindly provided data. I am responsible for all errors.

1. Introduction

Robert Solow's (1957) paper was a landmark in the development of growth accounting. As is well-known, it was not the first paper to make an explicit decomposition of the sources of growth into contributions from factor inputs and from output per unit of total input. This had been done several times since the pioneering paper by Jan Tinbergen (1942). Nor was it original to claim that virtually all recent labour productivity growth in the United States had come from the residual contribution of total factor productivity (TFP); research at the NBER summarized by Solomon Fabricant (1954), and with more detail, by Moses Abramovitz (1956) had already come to pretty much the same conclusion. The culmination of the NBER work was the magisterial volume by John Kendrick (1961) which found that 80.0 and 88.5 per cent of the growth of labor productivity between 1869 and 1953 and between 1909 and 1948, respectively, was due to TFP.

But it was Solow (1957) that put the growth economics into growth accounting making clear its interpretation in terms of the distinction between shifts of and moves along the aggregate production function. If a Cobb-Douglas production function with constant returns to scale is assumed,

$$Y = AK^{\alpha}L^{1-\alpha} \qquad (1)$$

where Y is output, K is capital, L is labour and A is TFP while α and $(1 - \alpha)$ are the elasticities of output with respect to capital and labor, respectively, then the basic growth accounting formula is

$$\Delta\ln(Y/L) = \alpha\Delta\ln(K/L) + \Delta\ln A \qquad (2)$$

As Zvi Griliches said, "This clarified the meaning of what were heretofore relatively arcane index number calculations and brought the subject from the periphery of the field to the center" (1996, p. 1328).[1] Although, it was clear that the residual would capture any kind of shift in the production function, the interpretation that Solow's paper invited and that the concluding summary of his paper contained was that 7/8ths of the increase in American labor productivity between 1909 and 1949 was attributable to technical change (1957, p. 320).

The challenge was clearly to refine both understanding and measurement of the residual to go beyond 'crude TFP' as in equation (2). Solow himself soon proposed an alternative version of growth accounting which entailed calculating the effective stock of capital on the assumption that technical change was embodied in new vintages of capital. He suggested a formulation in which the embodied rate of technical change was 5 per cent per year and the elasticity of output with respect to capital was 0.36 implying that technical change contributed 1.8 per cent per year to US economic growth between 1929 and 1957 or only about 70 per cent of labor productivity growth (1963, p. 82).

However, the work of Edward Denison (1962) was a much more influential approach to accounting for the residual. This developed an explicit measurement of the contribution of labor quality, in particular thorough the effect of education on earnings, to recent American

[1] Solow (1957) was aware of the earlier contributions by Abramovitz and Fabricant which are cited. He clearly saw himself as clarifying the economic interpretation of their results and underlining the strong assumptions needed to interpret the residual as technical change (p. 317).

labor productivity growth and reduced the contribution of the residual to a little under half using the production function

$$Y = AK^{\alpha}(LE)^{1-\alpha} \qquad (3)$$

where E is the average educational quality of the labor force. The growth accounting formula becomes

$$\Delta\ln(Y/L) = \alpha[\Delta\ln(K/L)] + (1-\alpha)\Delta\ln E + \Delta\ln A \qquad (4)$$

Denison also suggested that economies of scale were responsible about half of the remaining residual though he had no way of justifying what was no more than an assumption. Shortly thereafter, Denison (1967) applied his methodology to early post-war European economic growth and offered a fuller but still unsubstantiated account of the sources of the residual distinguishing between economies of scale and improvements in resource allocation.[2] The trajectory of this work was to downsize rather sharply the contribution of technical change to labor productivity growth.

Another major development in the practice of growth accounting was the publication of Dale Jorgenson and Griliches (1967). These authors made revisions to the crude measure of TFP that reduced it from 1.6 to 0.1 per cent per year for the United States during 1945-65. They focused on the measurement of capital services and produced a much more sophisticated (and data-demanding) index of capital input growth while also correcting labour quality for changes in education in a conceptually similar way to Denison. Jorgenson and Griliches concluded that the residual accounted for only a small fraction of productivity growth and stressed that looking at (conventionally-measured) TFP growth as 'manna from heaven' was seriously misleading.

Up to this point, mainstream economic history had not really been touched by these developments and historical national income accounting was only beginning to produce estimates of long run growth in various countries. Simon Kuznets was at the center of efforts to improve this quantification and together with Abramovitz edited a series of commissioned monographs which aimed to develop long run growth accounts for industrialized countries. Several of these volumes eventually came to fruition including J-J. Carre et al. (1975) on France, Kazushi Ohkawa and Henry Rosovsky (1972) on Japan, and Robin Matthews et al. (1982) for the UK together with a succession of papers from the study of the United States culminating in Abramovitz and Paul David (2001).[3] Denison-style research was undertaken at the OECD and produced explicitly–comparable growth accounts for six countries from 1913 of which the best-known version was in Angus Maddison (1987) later updated in Maddison (1996). As further useable historical national income accounts have become available, the country coverage of long-run historical growth accounting has expanded and papers in this tradition continue to be published. In recent years, these have included Max Schulze (2007) on Austria-Hungary, Pedro Lains (2003) on Portugal, and Leandro Prados de la Escosura and Joan Roses (2007) on Spain.

[2] As Abramovitz, by no means an unsympathetic reviewer, said of Denison's earlier work, "Crucial questions regarding the sources of growth are settled...by the uthor's excathedra pronouncemnets". (1962, p. 763).
[3] Carre et al was originally published in French in 1972.

Clearly, growth accounting has played a considerable role in research on economic growth by economic historians. This paper seeks to assess the importance that variants of the technique have had and addresses the following questions.

- How has growth accounting been used by economic historians?
- What generalizations about the long-run sources of modern economic growth in the advanced countries emerged from this growth accounting?
- Where did the innovation of growth accounting most importantly change the lessons of history?

2. The Use of Growth Accounting in Economic History

This section considers how economic historians set about using the tools of growth accounting at the macroeconomic level. In the late 1950s and early 1960s there were good reasons for a renewed emphasis on the central task of economic history as quantifying and explaining long run growth given the burgeoning interest in economic development and the considerable funding opportunities to which this gave rise (de Rouvray, 2005). This was indeed the Kuznetsian agenda.

Kuznets himself was not an exponent of growth accounting but he did offer an informal analysis of the sources of long-run growth in advanced economies since the onset of modern economic growth in which he concluded that the growth of capital per worker could not have accounted for more than about a quarter of the growth of per capita income (Kuznets, 1971). Nevertheless, several growth-accounting studies appeared between 1972 and 1982 in the series that he edited with Abramovitz.

More than anything else, the early (pre-new growth economics) studies followed Denison's agenda of downsizing the residual and adopted (variants of) at least some of his adjustments to reduce the extent of unexplained TFP growth. The most comprehensive attempt was made by Maddison (1987). As shown in Table 1, these analyses all followed Denison in taking account of labor quality in particular in terms of adopting his approach to estimating the contribution of education. Although there were well-recognized doubts about this methodology, it had a stronger empirical foundation than his other major adjustments which were widely seen as ad hoc, it did not appear to require econometric wizardry and data were often reasonably easy to obtain.[4]

Solow's own suggestion that the way to address the issue of the embarrassing residual was to treat technical change as embodied in successive vintages of capital clearly had some appeal but seems to have been regarded as too difficult to implement in particular in terms of the econometrics of pinning down the rate of improvement of capital quality (Nadiri, 1970). Only Maddison attempted this refinement and he described his choice of an embodiment factor of 1.5 percent per year as 'illustrative' (1987, p. 663). The infrequency of attempts to implement the full Jorgenson-type methodology is perhaps attributable to its data demands.[5]

[4] Recent reviews of the evidence which do consider some of the econometric issues suggest that Denison's methodology is probably acceptable, see Krueger and Lindahl (2001).
[5] The Jorgenson approach is to construct a quantity index of capital services in which the growth rate of each capital asset is weighted by its user cost (rental price) adjusted for tax and assumed to be equal to its marginal

The more recent studies listed in Table 1 have appeared in the era of the new growth economics. In principle, this might have had significant effects on the formulae used for growth accounting because the specification of the production function would change (Barro, 1999). In practice, the methods used by economic historians have not been greatly affected. In particular, it has remained general practice to regard the share of profits in national income as an acceptable proxy for the elasticity of output with respect to capital, the key parameter, and to believe that this will normally be in the range 0.3 to 0.4. This is in accordance with assessments of the evidence both by growth–accounting practitioners (Collins and Bosworth, 1996) and by econometricians (Aiyar and Dalgaard, 2005).

In two cases research and development has been treated as a factor of production and in two other cases the Denison approach to adjusting labor inputs for educational quality has been superseded by the Augmented-Solow approach of treating human capital as a separate factor in the production function

$$Y = AK^{\gamma}H^{\mu}L^{\theta} \tag{5}$$

where γ, μ, and θ are the elasticities of output with respect to capital, human capital and labor, respectively, which sum to 1, and H is the stock of human capital.

The growth accounting formula becomes

$$\Delta\ln(Y/L) = \gamma\Delta\ln K + \mu\Delta\ln H - (1-\theta)\Delta\ln L + \Delta\ln A \tag{6}$$

Finally, Nicolo Rossi and Gianni Toniolo (1992) were unusual in not imposing conventional assumptions; rather they employed a data-demanding econometric methodology to estimate the true contribution of technical change to TFP growth by correcting for fixed factors of production, adjustment costs and scale economies.

The modal stance has been to benchmark growth performance on the basis of conventional assumptions that facilitate comparisons. In this tradition, the general belief of these authors is that TFP growth is only partly a reflection of technical change but detailed quantification of the sources of TFP growth has remained elusive. Maddison (1987), rather like Denison, concluded that much of the Solow residual was typically attributable to some combination of labor quality, improved allocation of resources, changes in the utilization of factors of production, reductions in technology gaps and economies of scale leaving only a modest share 'unexplained' – and perhaps reflecting disembodied technical change (cf. Table 2).

Maddison's list of the components of rapid TFP growth in the European Golden Age is broadly in line with conventional economic histories but precise quantification is, of course, very difficult and there is no consensus on the details.[6] Maddison himself acknowledged that his exercise was rather speculative and papers in the empirical–growth literature cast doubt

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product. This requires information on the rate of return, rate of depreciation and rate of price inflation for each asset. This is much more difficult to implement than the more usual perpetual-inventory approach based on adding up past investment expenditure at constant prices and assuming a lifetime for capital.

[6] It should be noted that the results of a data envelopment analysis also give strong support to the claim that TFP growth during the European Golden Age was boosted considerably by improvements over time in the efficiency of factor use (Jerzmanowski, 2007).

on its reliability without, however, amounting to an alternative decomposition. For example, Stephen Broadberry (1998) proposes a different calculation for the effect of structural change which would increase its magnitude considerably, Harald Badinger (2005) offers an econometric estimation of the productivity implications of economic integration which suggests foreign trade was more important than Maddison suggests, while the analysis of convergence provided by Robert Barro and Xavier Sala-i-Martin (1995) indicates that Maddison may have given too much weight to catch-up in addition to structural change.

Two cases where the authors thought hard about the applicability in a particular historical context of the standard assumptions of a Cobb-Douglas production function with neutral technical change deserve to be highlighted. Firstly, Abramovitz and David (1973) (2001) developed a view of the nineteenth-century US economy which focuses on the capital-using bias of technical change and a low elasticity of substitution (σ) between factors of production in that era such that conventionally-measured TFP growth *underestimates* the rate of technical change.[7] Secondly, Robert Allen (2003) confronted the suggestion that the Soviet growth experience is better represented by a production function with a very low elasticity of substitution which would imply that the conventional methodology overestimates capital's contribution to growth (because it fails to register the extent of diminishing returns to capital) and that TFP growth was quite respectable. He provides a convincing rebuttal of this argument noting inter alia that technological possibilities were similar to those in the West and that there is clear evidence of massive waste of capital which connotes negative TFP growth in the later years.

A further possible use of growth accounting is to evaluate the contribution of general purpose technologies to economic growth. This requires appropriate aggregation of sectoral TFP growth rates which was set out by Evsey Domar (1961) who demonstrated that the correct weights were sectoral gross outputs divided by GDP. The formula adopted later on by economists investigating the implications of ICT was

$$\Delta\ln(Y/L) = \alpha_{KO}\Delta\ln(KO/L) + \alpha_{KICT}\Delta\ln(KICT/L) + \phi\Delta\ln A_{ICT} + \eta\Delta\ln A_O \tag{7}$$

where ϕ and η are Domar weights, as above, KICT is capital used in ICT production, KO is the rest of the capital stock, A_{ICT} is TFP in ICT production and A_O is TFP in the rest of the economy. Given that ϕ and α_{KICT} are very small initially, it is easy to see why a new general purpose technology adds very little to overall labor productivity growth.[8]

In the 1960s the equivalent investigation concerned railroads and nineteenth century American growth and, indeed, the defining moment for cliometrics in the 1960s was the railroads controversy (de Rouvray, 2005). This famous debate revolved around the use of the social savings measure (roughly an upper bound approximation of the consumer surplus gain) by Robert Fogel (1964) to evaluate the counterfactual value of national income without the railroad. Obviously, an alternative way to measure the contribution of this new technology to economic growth would have been to use growth accounting with Domar weights. Indeed,

[7] In this context a factor-saving bias means that technological change acts as if it augments one factor of production by more than the other with implications for relative factor prices and also, if $\sigma \neq 1$, for factor shares. This means that the standard growth accounting formula has to be corrected to obtain an estimate of the 'true' rate of technological change.

[8] For the period 1973-95, the weights reported by Oliner and Sichel (2000) were ϕ = 1.4 per cent and α_{KICT} = 3.3 per cent.

the social savings approximates to the own TFP growth contribution of the new sector ($\phi\Delta\ln A_{rail}$) (Crafts, 2004).

Fogel's choice of methodology was understandable in terms of its links to cost-benefit analysis and of his desire to isolate the 'unique contribution' of railroads in his assault on the claim that railroads were indispensable to American economic growth in the nineteenth century.[9] Nevertheless, it slowed down the diffusion of growth accounting into economic history and was not really conducive to developing an understanding of why general purpose technologies have an effect on labor productivity growth that is very small at the outset but then rises through time and of why TFP growth might be quite modest in the throes of an industrial revolution.

3. Has Long-Run Labor Productivity Growth Been Dominated by TFP Growth ?

Solow's finding that 7/8ths of US labor productivity growth during 1909-1949 was accounted for by TFP growth (where no separate allowance is made for educational quality of the labor force) is still pretty much what would be obtained applying his method to today's data. This does not, however, mean that this result has also been found by economic historians consistently for other periods and different countries, even though Kuznets (1971) suggested that it probably would be.

Table 3 reports that on the basis of conventional growth accounting for the United States over the long run, the picture is one of dominance of 'Solow's TFP' (education + TFP in the table) from the late nineteenth century till the end of the post-World War II boom in the late 1960s. However, Table 3 also shows that before 1890 and after 1966 the sum of the education and TFP components contributes at best only 50 per cent of labor productivity growth.[10]

In fact, at face value, given that TFP growth is below 0.5 per cent per year prior to 1890, the estimates in Table 3 invite the conclusion that technical change was insignificant in the American economy for much of the nineteenth century and only came to prominence with the rise of the science-based industries and R & D in the so-called second industrial revolution. This runs counter to standard historical discussions, however, and is certainly not the interpretation in Abramovitz and David (1973) (2001). If, as they suggest, the nineteenth-century US economy was characterized by a low elasticity of substitution between factors together with capital-using technical change, then TFP growth may have been considerably stronger than shown in Table 3 which assumes that $\sigma = 1$. Whereas the crude TFP growth estimates give a rate of 0.24 per cent per year for 1835 to 1890, if, instead, estimates are obtained using the assumption of an aggregate production function with the properties that Abramovitz and David believe that the evidence supports, this would generate a revised estimate for TFP growth of 0.9 per cent per year and thus restore it to a dominant role.[11]

[9] Fogel did not include a capital-deepening component because he argued that in the absence of railroads the capital would have been accumulated in some other activity where it also would have obtained normal returns.
[10] Solow's estimates were for 'crude' TFP growth which equals the sum of education and TFP in Table 3.
[11] This calculation is based on the formula given by Rodrik (1997) that the correction to TFP growth = $0.5\alpha((1 - \sigma)/\sigma)(1 - \alpha)(\Delta K/K - \Delta L/L)(\Delta A_L/A_L - \Delta A_K/A_K)$ where the term in the last parenthesis captures the degree of factor-saving bias in technological progress measured as the difference between the rate of labor augmentation and the rate of capital augmentation. The formula is parameterized using values suggested in Abramovitz and David (2001), including $\sigma = 0.3$, and applying them to 1835-1890, the period which is singled out by these authors.

For the late-twentieth century slowdown, it is also likely that the impression given by Table 3 is misleading. Here the main issue relates to the measurement of output growth. Michael Boskin et al. (1996) thought that, for a variety of reasons, inflation had been overestimated (and thus real GDP growth and TFP growth had been underestimated by a similar amount) in the national accounts and that the correction required was of the order of 0.6 per cent per year. Again, this would raise the contribution of crude TFP growth well above that of capital-deepening without quite reaching the 7/8ths mark.[12]

The estimates reported earlier in the first three rows of Table 2 would suggest that, if Solow's methodology had been employed, a predominant role would have been found for unexplained TFP growth in other OECD countries in the period where TFP dominated in the United States. Maddison (1987) himself argued that the Solow residual could largely be explained and derived an 'unexplained' component reported in the last row of the table which is typically well below half that in row three. Maddison's preferred account of the European and Japanese Golden Age, 1950-1973, highlights large gains form improvements in efficiency and the quality of factors of production rather than disembodied technical change.

In Table 4 the picture of modern economic growth in Europe through the 1970s is filled out on the basis of a Solow-type growth accounting. The estimates reported there show only two cases (Great Britain in 1801-31 and Portugal in 1910-34) where the TFP contribution to labor productivity growth is as much as 80 per cent. A distinctive aspect of Table 4 is that as moderne conomic growth spread across nineteenth-century Europe TFP growth was initially quite modest and any tendency for TFP growth to dominate capital-deepening is generally a post-1890 or post take-off phenomenon.

As Paul Krugman (1994) highlighted, and, as economic historians in the Gerschenkronian tradition might have predicted, rapid catch-up growth in the east–Asian developmental states looks rather different from the earlier OECD experience.[13] In Korea, Singapore and Taiwan the contribution of capital deepening has been formidable and exceeded that of TFP growth in the period 1960 to 1990.[14] There is a strong contrast with the well-known cases of Italy, Japan and Spain in the Golden Age.[15] But Table 4 also shows that catch-up growth comes in different flavors in modern times as is reflected in the growth-accounting estimates for China and India.

Finally, as is well-known, growth in the Soviet Union did not follow the Solovian TFP-dominated trajectory. Table 4 shows that the Soviet economy succeeded for quite a while in mobilizing capital accumulation but had a weak record in TFP growth – note the comparison with Golden-Age western Europe – reflecting both poor resource allocation and inability to incentivize innovation (Ofer, 1987).

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[12] The Boskin bias in inflation measurement does not appear to generalize to other periods, cf. Costa (2001).

[13] In a very influential contribution, Alexander Gerschenkron (1962) proposed that the growth of 'backward' follower countries would differ from that their predecessors. In particular, there would be a much greater emphasis on capital accumulation and a key role for what would later be called the 'developmental state' in implementing this.

[14] Rodrik (1997) argued that the east Asian growth accounting estimates were biased; applying a similar correction formula to that in footnote 3 might add around 0.8 per cent per year to TFP growth which would change the detail but not the substance of this point.

[15] Portugal, however, is more similar to the east Asians.

In sum, it appears that the US growth record that Solow (1957) analyzed was far from typical of the experience of the industrialized economies in the two centuries since the Industrial revolution. Generally speaking, even without the refinements suggested by subsequent authors which tend to downsize the role of TFP, the contribution of TFP growth to labor productivity growth is well below 7/8ths. Had Solow's first growth-accounting estimate been made in the 1950s for Spain or Sweden, the results would have been far less sensational.

4. Growth Accounting and the Lessons of History

In the late 1950s the 'capital–fundamentalist' view of economic development predominated.. In terms of economic history this was encapsulated in the idea of take-off based on a doubling of the investment rate proposed by Walt Rostow (1960) and based on his understanding of the British industrial revolution. This was contested terrain, however, and was clearly not Kuznets's view of the transition to modern economic growth. Much of the work at this time in assembling the facts of long-run growth was in the end working to undermine Rostow's analysis and this was already clear at the major conference organized to review the evidence for the 'stages of economic growth' (Rostow, 1963). Solow attended this meeting and in his oral comments noted a much-reduced emphasis on capital accumulation as, prompted by the discovery of the residual, economic historians were in the process of turning to narratives which, in Donald McCloskey's striking (1981, p. 108) phrase, stressed ingenuity rather than abstention.

Growth accounting estimates for the British industrial revolution were produced by Charles Feinstein (1981) who interpreted the results as inconsistent with capital fundamentalism and highlighted the large proportion of labor productivity growth accounted for by TFP growth. Subsequent research produced much-revised estimates of the rate of economic growth in the late eighteenth and early nineteenth centuries (Crafts and Harley, 1992) which had implications for TFP growth prior to 1830, as shown in Table 5. While the conclusion that capital-deepening contributed relatively little to labor productivity growth was sustained, the TFP growth rate during the industrial revolution was markedly reduced, a result which seemed paradoxical to those brought up on the idea that famous inventions were the hallmark of this period.

Clearly, especially given the imperfections of the underlying economic data, a persuasive narrative is required if these estimates are to gain widespread acceptance. To some extent, this can be provided on the basis of the arithmetic of growth by pointing to the large weight of sectors such as domestic service that are known to have been untouched by technology and the small initial size of industries which were transformed, such as cotton textiles (Mokyr, 2004). And to some extent, the limits to TFP growth during the industrial revolution can be understood through the lens of endogenous growth theory which would point to weaknesses in incentive structures and in science, technology and education (Crafts, 1995).

Nevertheless, some of the strongest support comes from further explorations in growth accounting. Independent estimates based on the dual approach using evidence on real rewards to factors of production broadly support the Crafts-Harley view (Antras and Voth, 2003) which might be expected when it is remembered that the industrial revolution is notorious for the slow growth of real wages but the growth-accounting equivalences are often overlooked. Further insights come from examining the contribution of steam to labour productivity growth. Until about 1830 this was slight, as Table 5 reports. The major effect of steam on economic growth awaited the era of high-pressure steam in the second half of the nineteenth century.[16]

In fact, the British industrial revolution offers an interesting twist on the so-called Solow (1987) productivity paradox that 'you can see the computer age everywhere except in the productivity statistics'. Steam power was not in fact very cost effective initially and only about 165,000 horsepower were in use even as late as 1830 (Kanefsky, 1979) when the steam engine capital income share was 0.4 per cent and the steam-engines Domar weight was 1.7 per cent (Crafts, 2004). So, in this earlier episode the paradox is that you could see steam hardly anywhere and certainly not in the productivity statistics. The point in both cases is that the arithmetic of growth accounting as in equation (7) immediately reveals why the initial effect of new general purpose technologies such as steam and ICT will be underwhelming. That said, it is worth noting that by the standards of the steam age the growth contribution of ICT in the late 1980s was already quite stunning.[17]

Growth accounting underpins two key messages about modern economic growth which are now widely understood but were not well appreciated in the 1950s. First, the idea of a take-off into sustained economic growth based on a great leap forward in capital accumulation is a serious misunderstanding of the experience of the Industrial Revolution. Second, even really major technological breakthroughs have quite muted effects on economic growth at the level of the aggregate economy.

5. Conclusions

Growth accounting has been attractive to quantitative economic historians because it has been seen as a transparent yet flexible framework for describing the proximate sources of growth. On the whole, the use of the technique has been growth-theory 'lite' and has probably owed more to Denison than to Solow. Generally speaking, economic historians have opted for relatively simple versions of the technique and have been wary of adopting variants based on anything other those consistent with a Cobb-Douglas production function. This has been facilitated by a body of evidence that suggests that the share of profits in national income is a reasonable estimate of the elasticity of output with respect to capital. Issues relating to labor quality have been dealt with better than those relating to capital quality. Economic historians have not generally interpreted Solow's residual as a measure of technical change; indeed, they have argued that TFP growth can either over- or under-estimate technical change. Attempts to quantify components of Solow's residual, other than education, have not commanded widespread support.

Overall, research has confirmed that (crude) TFP growth is a more important source of labor productivity growth than physical capital–deepening. The Asian tigers appear to be the main exception to this generalization. Where it is possible to make long-run comparisons, the dominance of TFP growth over capital–deepening seems to have peaked in the

[16] This should not have been a surprise to anyone familiar with the early cliometrics literature which highlighted how small were the initial social savings of the steam engine (von Tunzelmann, 1978) and the railway (Hawke, 1970) but the implications for the interpretation of productivity growth were clarified only when these estimates were converted into their growth accounting equivalent in Crafts (2004).

[17] The contribution of steam to British labor productivity peaked at about 0.4 per cent per year in the third quarter of the nineteenth century about 100 years after James Watt's patent (Crafts, 2004). By contrast, the estimates in Oliner et al. (2007) show the contribution of ICT to American labor productivity growth as 0.74 per cent per year during 1973 to 1995.

mid–twentieth century when TFP growth was much more rapid than 100 years earlier. The extent to which the twentieth century was more technologically progressive than the nineteenth century is difficult to ascertain because the (uncertain) extent to which the conventional benchmarking assumptions of growth accounting result in measurement errors has probably varied a good deal over the long run. Awareness of this problem is greatly enhanced by an understanding of neoclassical growth theory and underlines that making this connection, as Solow did, was a major step forward, although its potential has been under–appreciated by economic historians.

The use of growth accounting in economic history has underpinned two big messages that were certainly not understood when Solow (1957) appeared. First, famous and far-reaching technological changes such as the invention of the steam engine raise the rate of growth of labor productivity appreciably only with a considerable lag. Second, the idea of the take-off propagated by Rostow is seriously misleading as a description of the transition to modern economic growth in the old industrial economies.

Table 1. Downsizing the Residual

a) Early Studies

	Education	Work Intensity	Capital Quality	Embodied Technical Change	Increasing Returns to Scale	Structural Change
Carre et al.	x		(x)			x
Ohkawa & Rosovsky	x		(x)			
Abramovitz & David	x		x			
Matthews et al.	x	x				
Bergson	x				x	x
Maddison	x		(x)	x	x	x

b) Recent Studies

	Education	Human Capital	Capital Quality	Embodied Technical Change	Research & Devel-opment	Capacity Utilization
Rossi & Toniolo						x
van Ark & de Jong	x				x	
Abramovitz & David	x		x	x	x	
Lains		x				
Schulze		x				
Prados & Roses	x		x			

Notes:
Abramovitz & David (1973) in early and Abramovitz & David (2001) in recent studies
"Capacity Utilization" indicates estimates based on Morrison (1988) methodology to allow for fixed factors, adjustment costs and economies of scale.
"Capital Quality" is full use of Jorgenson methodology and (x) in that column denotes adjustment simply for age of capital stock.
"Education" denotes use of Denison (1962)-type adjustments to labor inputs for years of schooling.
"Human Capital" indicates use of an Augmented–Solow approach with human capital as a separate factor of production as in Mankiw et al. (1992).

Table 2. Accounting for Growth in Maddison's Six-Country Study (% per year)

	France	*Germany*	*Japan*	*Netherlands*	*UK*	*USA*
1913-1950						
Y/HW Growth	2.01	1.05	1.72	1.58	1.57	2.42
K/HW	0.59	0.19	0.62	0.43	0.42	0.43
TFP	1.42	0.96	1.10	1.15	1.15	1.99
Capital Quality	0.45	0.45	0.45	0.45	0.45	0.45
Labor Quality	0.36	0.22	0.61	0.27	0.32	0.35
Capacity Use	0.00	–0.13	–0.24	0.00	0.00	0.00
Labor Hoarding	0.00	–0.20	–0.56	0.00	0.00	0.00
Catch-Up	0.00	0.00	0.00	0.00	0.00	0.00
Structural	0.09	0.20	0.62	0.00	–0.04	0.29
Foreign Trade	0.01	–0.04	0.02	0.05	0.00	0.01
Scale	0.03	0.04	0.07	0.07	0.04	0.08
Other	0.00	0.00	0.00	0.00	0.00	0.00
Unexplained	0.48	0.32	0.13	0.41	0.38	0.81
1950-1973						
Y/HW Growth	5.12	5.96	7.82	4.44	3.18	2.50
K/HW	1.10	1.64	2.02	1.09	1.04	0.65
TFP	4.02	4.32	5.80	3.35	2.14	1.85
Capital Quality	0.56	0.53	0.58	0.57	0.52	0.51
Labor Quality	0.35	0.18	0.52	0.40	0.09	0.29
Capacity Use	0.00	0.25	0.39	0.00	0.00	0.00
Labor Hoarding	0.00	0.32	0.90	0.00	0.00	0.00
Catch-Up	0.52	0.68	1.02	0.38	0.14	0.00
Structural	0.46	0.36	1.22	–0.07	0.10	0.12
Foreign Trade	0.19	0.21	0.26	0.65	0.16	0.05
Scale	0.15	0.18	0.28	0.14	0.09	0.11
Other	–0.02	–0.02	–0.02	0.22	–0.02	–0.04
Unexplained	1.81	1.63	0.64	1.06	1.06	0.81

Source: derived from Maddison (1987)

Table 3. Sources of US Labor Productivity Growth Over the Long Run (% per year)

	Labor Productivity	***Capital Deepening***	***Education***	***TFP***
1800-1855	0.4	0.2	0.0	0.2
1855-1890	1.1	0.7	0.0	0.4
1890-1905	1.9	0.5	0.1	1.3
1905-1927	2.0	0.5	0.2	1.3
1929-1948	2.0	0.1	0.4	1.5
1948-1966	3.1	0.8	0.4	1.9
1966-1989	1.2	0.6	0.3	0.3
1990-2003	1.8	0.9	0.1	0.8

Note: these estimates are obtained by the various authors on the basis of equations using the specification of equation (4).
Sources: Abramovitz and David (2001) except for final period from Bosworth and Collins (2003) as updated on website.

Table 4. Ingenuity and Abstention in the Shift to Modern Economic Growth (% per year)

	Labor Productivity Growth	*Capital-Deepening Contribution*	*TFP Growth*
Austria			
1870-1890	0.90	0.64	0.26
1890-1910	1.69	0.66	1.03
Germany			
1871-1891	1.10	0.39	0.71
1891-1911	1.76	0.58	1.18
Great Britain			
1700-1760	0.40	0.14	0.26
1760-1801	0.20	0.07	0.13
1801-1831	0.50	0.10	0.40
1831-1873	1.25	0.35	0.90
1873-1913	0.90	0.38	0.52
Hungary			
1870-1910	1.65	1.18	0.47
Italy			
1920-1938	0.88	0.38	0.50
1951-1973	4.51	1.61	2.90
Netherlands			
1850-1870	1.02	0.50	0.52
1870-1890	0.94	0.61	0.33
1890-1913	1.35	0.46	0.89
Portugal			
1910-1934	1.17	0.09	1.08
1934-1947	0.78	0.90	–0.12
1947-1973	4.47	2.46	2.01
Spain			
1850-1883	1.2	1.6	–0.4
1884-1920	1.0	0.8	0.2
1920-1929	2.0	0.6	1.4
1930-1952	0.0	0.3	–0.3
1951-1974	5.5	1.7	3.8
Sweden			
1850-1890	1.18	1.12	0.06
1890-1913	2.77	0.94	1.83
1913-1950	2.01	0.87	1.14
1950-1973	3.68	1.82	1.86
USSR			
1928-1940	2.5	2.0	0.5
1940-1950	1.5	–0.1	1.6
1950-1970	4.0	2.6	1.4
1970-1985	1.6	2.0	–0.4
Korea			
1960-1990	5.06	2.84	2.22
Singapore			

1960-1990	4.97	3.34	1.63
Taiwan			
1960-1990	6.07	3.17	2.90
China			
1978-2004	7.3	3.2	4.1
India			
1978-2004	3.3	1.3	2.0

Notes: all estimates impose equation (2) and are recalibrated with $\alpha = 0.35$; Great Britain is UK after 1831.
Sources: derived from data presented in the following original growth accounting studies: Austria and Hungary: Schulze (2007); Germany: Broadberry (1998); Great Britain: Crafts (1995) and Matthews et al. (1982); Italy: Rossi et al. (1992); Netherlands: Albers and Groote (1996); Portugal : Lains (2003); Spain: Prados de la Escosura and Roses (2007); Sweden: Krantz and Schon (2007) and Schon (2004); USSR: Ofer (1987); Korea, Singapore and Taiwan: Bosworth and Collins (2003); China and India: Bosworth and Collins (2008).

Table 5. Growth Accounting and the British Industrial Revolution (% per year)

	Labor Productivity	*Capital Deepening*	*Steam Capital Deepening*	*TFP*	*Steam TFP*
Feinstein (1981)					
1761-1800	0.3	0.1		0.2	
1801-1830	1.3	0.0		1.3	
1831-1860	1.1	0.3		0.8	
Crafts (1995)					
1760-1801	0.2	0.1		0.1	
1801-1831	0.5	0.1		0.4	
Crafts (2004)					
1760-1800			0.004		0.005
1800-1830			0.02		0.001
1830-1860			0.19		0.10

Note: steam contributions include both stationary steam engines and railways.

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