NEW INTERNATIONAL COMPARISONS OF PRODUCTIVITY PERFORMANCE: A SECTORAL ANALYSIS AND A COMPARISON OF UK PERFORMANCE

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Abstract

In this paper we present several new measures of gross-output-based total factor (multi-factor) productivity (TFP) at the sectoral level for manufacturing industries in the G7 economies. We calculate measures of both total factor productivity growth and comparative productivity levels. These are obtained by combining conventional OECD sectoral data on labour and capital inputs with data on intermediate inputs from national input-output tables. Additionally, we derive cyclically corrected measures of TFP growth that avoid the distortions contained in traditional measures of productivity growth. Consequently we argue that our measures provide a more accurate description of the underlying rate of productivity growth in the G7 economies. Our evidence shows little convergence of productivity in other G7 countries to US levels. A key conclusion from the UK's perspective is that in manufacturing, the productivity gap with other major industrialised countries, especially the USA and Germany, is bigger than has been reported in other recent studies (O'Mahony, 1999, HM Treasury, 2000).

Keywords: productivity growth; gross output; competitiveness; G7 economies; sectoral productivity growth.

JEL Codes: O47, D24

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1. Introduction

In recent years a large number of studies have appeared comparing productivity at the sectoral level across countries. There are two main reasons for this research effort. First, there is a need to understand the determinants of long-term trends in international competitiveness and standards of living. Second, there has been a response to the resurgence of growth theory and the need to verify the speed of international convergence in per-capita income. Our focus in this paper is on total factor productivity (TFP), i.e. output per unit of multiple input (labour, capital, and intermediate inputs). This is the concept, which is closest to the notion of 'underlying technical progress' in growth theory.[1]

Our contribution seeks to extend the existing literature in two important ways. First, most recent sectoral studies use value-added measures of output[2], analysing the contribution to output growth of two key inputs: labour and capital. Studies that focus on gross output and which therefore also account for intermediate inputs such as energy and raw materials are much rarer[3]. This is the approach followed in Jorgenson and Griliches (1967) and Jorgenson (1990). The reason why gross output data tends to be used less is because of the additional data requirements, in particular the availability of data on raw materials and other intermediate inputs. On the other hand, as we shall see below, the use of value added measures overestimate the role of technical progress. The reason for this upward bias of TFP growth using value added data is easy to demonstrate[4], and derives

[1] For an excellent survey of the key concepts underlying total factor productivity, see Hulten (2000).
[2] See van Ark (1993), van Ark and Pilat (1993), Dollar and Wolff (1993), Harrigan (1999), O'Mahony (1999).
[3] The only comparative studies using gross output data have involved the US and Japan.
[4] See Domar (1961).

from the fact that the value-added representation is a simplified version of the 'true' production function representation which includes intermediate inputs[5]. The size of this bias is likely to be greater for small open economies, as in these countries the proportion of imported intermediate inputs (and hence the gap between value added and gross output) is likely to be larger.

In this paper we estimate relative TFP levels and growth rates for manufacturing sectors in the G7 economies (except Japan) using gross output data. Gross output data has been obtained from national input-output model databases for the G7 economies, from which we also obtain data on intermediate inputs[6]. This data has then been combined with data on labour and capital inputs obtained from the OECD's ISDB database and from O'Mahony (1999)[7] to estimate TFP growth series.

Our second key contribution involves modifying standard Solow estimates of TFP growth for a number of economies to allow for cyclical variations in factor utilisation. It is a well-known feature of standard Solow measures of TFP growth that these display a strongly positive correlation with the business cycle.[8] These cyclical variations in TFP growth are due to changing intensity of factor use (changes in capacity utilisation, and in labour utilisation). To allow for mismeasurement in factor usage, some authors have

[5] This is shown formally in Appendix C. Of course, if other inputs, such as human capital, are excluded this might also under/overestimate the role of TFP growth. Although we do not allow for human capital in our estimates, there have been some studies which allow for this variable in estimating TFP growth at the aggregate level (e.g. see Oulton, 1998).

[6] These data have been provided by Inforum Group at the University of Maryland (see the technical note by Wilson and Mead (1999) which is available from our ESRC project web-site http://www.gla.ac.uk/economics/TFP/.

[7] The capital stock data for some of the countries in our sample were kindly provided by Mary O'Mahony. For full details of the sources of data employed, see the Data Appendix. A more detailed outline of the methods employed in constructing our data set is provided in Braun (1999). This technical note and the full data set are available freely from the ESRC project web-site http://www.gla.ac.uk/ /economics/TFP/.

[8] See Burnside *et al.* (1995), Basu (1996), Basu and Fernald (2000).

used data on electricity inputs (Burnside *et al.*, 1995), on raw materials inputs (Basu, 1996, Malley *et al.*, 2000, Basu and Kimball, 1997), and on labour hours (Basu and Fernald, 2000) to derive alternative measures of TFP growth. These studies on modified Solow TFP growth measures have been conducted exclusively on US data because of the need to use measures of intermediate inputs. This paper provides, for the first time, comparative modified measures of TFP growth for the other G7 economies. In applying these comparisons to the UK, we find that the TFP gap between the UK and German and USA manufacturing sector is much greater than suggested in previous studies (O'Mahony, 1999, HM Treasury, 2000).

2. Constructing Measures of Relative TFP Levels

A full exposition of methods to compare cross-country TFP levels is outlined by Harrigan (1999) using a value added specification with capital and labour, and the Caves *et al.* (1982) geometric mean index. In this paper we extend Harrigan's calculations to the use of gross output data so as to take account of raw materials usage in production. Essentially we construct a relative productivity index for countries A and B, TFP_{it}^{AB} which compares, for industry *i*, how much output each country can produce given a weighted measure of labour, (*l*) capital (*k*) and raw materials (*m*). The detailed methodology for constructing the indices of relative TFP levels for different countries and indices is outlined in Appendix A. An advantage of the TFP index used is that it is *transitive*[9], which is particularly useful in productivity comparisons involving more than two countries.

[9] Implying that, for three countries A,B,C and industry *i*, $TFP_i^{AB} = TFP_i^{AC} \times TFP_i^{CB}$

Our gross output data by sector is obtained from the Inforum[10] national input-output model database, which compiles input-output data from different countries. We have data on both current and real output measures, so that we do not encounter the problems caused by using aggregate GDP deflators as in van Ark (1993), Dollar and Wolff (1993) and Maskus (1991). The input-output database also gives us series for material inputs, as well as deflators. Obviously one caveat in using data from input-output tables is that the data is not available for all years, and hence this involves using some estimation techniques for intervening years. Full details are provided in Braun (1999) and Wilson and Mead (1999).

As discussed above, we combine this data on gross output and material inputs with data on labour and capital inputs, which are obtained from the OECDs international sectoral database (ISDB). However, because the capital stock data in ISDB is incomplete[11], this is supplemented with capital stock data compiled by O'Mahony (1999). To allow cross-country comparisons of output we convert this data into dollar terms[12].

Given the availability of data from our different sources, we were able to compute TFP comparisons for the sample period 1971-1995. However data limitations for some of the countries in our sample, mean that in these cases the sample period is curtailed

[10] See Wilson and Mead (1999) and http://inforumweb.umd.edu
[11] See Braun (1999) for further details.
[12] We convert data into dollar terms by using OECD purchasing power parity GDP deflators. As pointed out in Harrigan (1999) this potentially biases sectoral comparisons because it assumes that there are no price. differences across countries in individual industries. However, Harrigan (1999) is unable to overcome this except for one sector (machinery and equipment) for which he has sectoral price data.

(e.g. Italy 1981-95, Canada, 1971-90 the UK, 1971-90). In the case of Japan, data limitations for the capital stock did not allow us to construct comparable figures.

[Figure 1 here]

In Figure 1 we show the TFP levels for total manufacturing against a base of 100 for the USA in each year. Interestingly, our results confirm that only some countries (the UK, France and Italy) managed to close the TFP gap with the USA by 1995, and even then, by very little. Notice also that, whilst in 1971 Canada was closest to the USA in terms of productivity levels, its position seems to have declined relatively to the other countries. By 1995 the other economies had converged to a level where TFP was 30% below that of the USA.

As we shall see below, gross output TFP tends to show a much less marked upward trend than TFP calculated from value added data or indeed labour productivity data[13]. Indeed, the most notable feature of Figure 1 is the more rapid convergence from 1983 of the UK, and especially Italy, towards German TFP levels. From these figures, there is no longer a clear ranking amongst the European G7 economies in terms of TFP levels. Hence the stylised fact that there are large labour productivity differentials in the European economies (e.g. the UK's labour productivity gap against France and Germany) appears to be mainly attributable to factor accumulation. In this sense, it echoes the findings of Young (1995) for some East Asian economies.

[Figures 2-6 here]

[13] Note that, in the period 1973-86, Oulton and O'Mahony (1994) had found that TFP growth in the UK had been negative.

Next, we examine the patterns that emerge from our sectoral TFP level data. Figures 2-6 show how the level of TFP has evolved for a number of manufacturing sectors. The plots show the level of TFP on four (three in the case of Italy) intermediate dates (i.e. 1973, 79, 87, 93) over our available sample period. The following conclusions seem clear. First, the patterns of relative TFP levels tend to remain relatively constant over time. Those sectors in which a country has a relative advantage/disadvantage in terms of TFP relative to the USA remain the same. There are very few examples of major shifts.[14]

Second, there is only a handful of sectors in which the other G7 economies have a higher TFP level than the USA. An exception to this is the mineral products sector, where all the other countries in our sample have a higher productivity level than the USA. In some other sectors, some countries seem to match or, on occasions, overtake the USA. This is the case of Italy in the metal products sector, Germany in chemicals and rubber and electrical goods and agricultural and industrial machinery (until the late 1980s), and Canada in the paper and wood sectors.

Third, some sectors in individual countries show steady improvements in TFP, which do not seem attributable to cyclical effects. This appears to be the case for the transport equipment and electrical goods sectors in the UK, where there seems to have been a rapid convergence towards US TFP levels between 1973 and 1990. This convergence is also evident for mineral products in Germany and France, and basic metals, metal products and food in Italy. In contrast, Canada has shown some sharp

[14] Basic Metals in the case of the UK in 1987 and Other Manufacturing in France in 1979 are isolated examples, and might be due to cyclical effects which our relative TFP index does not abstract from.

divergence with the USA in a number of sectors, but notably paper and mineral products in recent years.

3. TFP Growth and Cyclical Effects

We now turn to measures of TFP growth. Standard methods of growth accounting since Solow (1957) have been based on a decomposition of total output growth into different components plus an unexplained ‘residual’, which is attributed to technical progress, i.e. TFP growth.

The problem with the Solow TFP residual is that it may not be an accurate measure of ‘true’ multi-factor productivity since it ignores the presence of market power and non-constant returns to scale (see Hall, 1991). As noted in the introduction, it also ignores problems of variable factor utilisation over the cycle.[15] Over the business cycle the utilisation of capital and labour varies. This leads to a mismeasurement of productivity growth, as it is not possible to measure the *effective* usage of labour and capital in production. To make some allowance for the variation in capital and labour utilisation over the cycle, a variety of corrections to the Solow residual have been proposed. Raw materials and energy usage provide a useful benchmark for an adjustment. Whilst labour and capital usage can vary, a firm has a limited ability to vary the intensity of its use of raw materials and energy inputs. Hence raw material inputs are much more directly related to production over the cycle, and one can use data on the relative use of raw material inputs and value added to calculate an appropriate adjustment. Burnside *et al.* (1995) focus on electricity use as a way of performing the adjustment, but we follow Basu (1996) and Malley *et al*. (2000) in using both raw material and energy inputs[16].

The adjustment scheme employed is outlined in full in Appendix B. Essentially it involves using the raw material and energy data at our disposal to examine the relative variations of value added and gross output over the cycle. This relationship is then used to perform the adjustment, given some assumption about the elasticity of substitution between raw materials and capital and labour. In the next section we report some estimates of cyclically adjusted TFP growth for the G7 economies which have been obtained using this method. We shall then compare this measure with the usual Solow residual.

4. Alternative Measures of TFP Growth for the G7 Economies

In addition to the Basu measures, we have constructed a variety of different measures of TFP growth for individual sectors for the G7 economies. First we have computed traditional Solow-type measures based on revenue shares (*Solv*), using the OECDs ISDB. For most sectors we have a sample period of 1971-95. In addition, using the gross output data from the Inforum input-output database, we construct a measure of the Solow residual based on gross output (*Solg*). Then we compute Hall-type cost-based TFP growth measures, allowing for non-constant returns to scale, estimating the γ

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[15] See Burnside *et al.* (1995), Basu (1996), Malley *et al*. (2000).

[16] There are alternative adjustment schemes. Basu and Kimball (1997) focus on the use of hours to adjust for varying labour usage and gross investment flows to capture the variation in the intensity of capital usage. Basu and Fernald (2000) propose the use of labour hours as a way of adjusting the intensity of use of both labour and capital. For a comparison of the merits of different schemes to adjust for the procyclicality of productivity measures see Basu and Fernald (2000).

parameter[17]. These have been computed both using the capital stock data available from the OECD ISDB (*Irsi)* and with the capital stock data from O'Mahony (1999) (*Irso*). In practice the two measures make very little difference. As an illustration, Figure 7 plots the difference between *Irso* and *Irsi* for total manufacturing in the US. As can be seen the maximum difference between the two series is –0.14% in 1995.

[Figure 7 here]

Regarding the Basu modified TFP measures, we again compute two variants, one which requires the use of a series of raw materials prices, and another which does not. This allowed us to check whether our materials prices series made a substantial difference to the TFP series obtained. In the first variant (*Basuo)* we deflate the current price series on intermediate inputs using output prices, which is clearly sub-optimal[18]. In the second variant (*Basui*) we employ our price series for raw materials to deflate the current price series for intermediate inputs[19]. The difference between the two series is shown in Figure 8, again for US total manufacturing. This shows clearly that, at times when commodity prices change rapidly (as in the case of the 1973-74 and 1979-80 oil shocks, or the commodity price slump of 1985-87), the *Basuo* measure will substantial mismeasure TFP growth (the largest deviations are of the order of magnitude of 2-3%). As a result, we will generally employ the *Basui* measure, even though this sometimes curtails the size of our sample. This figure also demonstrates the usefulness of using our

[17] For comparison purposes, we also compute cost based shares in which we do not estimate γ, but assume constant returns to scale. These TFP growth series are not discussed in detail here, but are freely available to download from our ESRC project web-site http://www.gla.ac.uk/economics/TFP/.

[18] In this case we obviously have to assume a zero elasticity of substitution between value added and raw materials (σ=0 from Appendix B), as from equation (B.15) in Appendix B we cannot compute the correction without a series for materials prices in any other case.

[19] Again we impose σ=0 (see Appendix B, equation B.15) for ease of comparison with the *Basuo* series.

adjusted gross output TFP measures. Without access to a series of raw material prices to perform the Basu correction, the resulting TFP series could be greatly distorted.

[Figures 8 and 9 here]

We now turn to a comparison of different TFP series. First, in Figure 9 we plot the Solow gross output and value added TFP growth measures. Again, we use the case of total manufacturing in the US, as the same pattern emerges for the other sectors and countries. It is clearly apparent, as discussed in the introduction, that added value measures of Solow residuals (*Solv*) tend to exaggerate the growth rate of technical progress compared to gross output figures (*Solg*) because they do not take into account the role of intermediate inputs. In addition, *Solv* has a more marked cyclical pattern, as measured capital and labour input do not adequately capture the cycle. Indeed this is the phenomenon, which the Basu (1996) correction is designed to address.

We now compare the gross output Solow measures (*Solg*) to those obtained using the Basu correction. Table 1 reports the variance ratio of the Solow residual *Solg* to the Basu-adjusted series, as well as the difference in the average TFP growth rates as measured by these two series. In Table 1 we used the value $\sigma=0.5$ in the Basu adjustment, except in the case of Japan, where lack of a materials price data series for each sector forced us to use the $\sigma=0$ adjustment. Two points should be noted. First, as anticipated, the Basu measure of TFP growth is much less cyclical, and hence the variance ratio tends to exceed unity in the vast majority of cases[20]. Second, the Solow measure of TFP growth tends to lead to a higher average rate of TFP growth. The Basu measure tends to suggest a much smaller rate of TFP growth. Indeed, in many cases the rate of TFP growth is negative over parts of the sample period. This again suggests that the cyclicality of the Solow measure might lead not only to a more volatile measure of TFP growth, but also to an overestimate of underlying technical progress on average.

[Table 1 here]

Finally, we examine how the sectoral rate of TFP growth differs between countries when it is measured by the Basu-adjusted measure. Again, for ease of exposition, we focus on one single version of the adjusted measure, using $\sigma=0.5$. To examine the implications of the Basu TFP growth figures, we first use the Basu figures to augment the level TFP data for total manufacturing shown in Figure 1. Using the values for level TFP at the beginning of the sample (as plotted in Figure 1), we use the Basu figures to examine the implications for relative productivity levels for six of the G7 countries[21]. This is shown in Figure 10. Unfortunately due to the absence of materials data we were unable to compute the Basu TFP growth rate for the UK beyond 1987. To allow a comparison towards the latter part of the sample, we extrapolate the UK's TFP level using the average Basu TFP growth rate between 1971-87. Interestingly, Figure 10 shows a very different picture[22] from Figure 1. Not only has there not been a convergence in TFP levels with the US but, using the cyclically adjusted figures, German and Canadian TFP levels still seem to be well above those of France, Italy and the UK. France and Italy show almost no growth in TFP levels, whilst the UK shows a reasonably

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[20] The very large values in the case of Italy occur because the Basu-adjusted TFP growth measure is extremely small over the sample period. Essentially the Basu correction leads to a very flat TFP growth rate.

[21] Recall that we do not have TFP level data using the Caves-Christensen-Diewert index for Japan.

rapid convergence, especially since the late 1980s, towards the levels measured in Italy. Overall the average TFP growth rate as measured using the Basu-adjusted series shows some moderate growth rate only in the case of the UK (0.04% per year) and Canada (0.02% per year). In the case of the USA (0.07% per year) and Germany (0.03% per year) the growth in TFP is negligible.

[Figure 10 here]

Next we examine whether similar patterns in TFP growth emerge across similar sectors in different countries. For each of the main sectors in our sample we plot the average rate of Basu-adjusted TFP growth for several sub-periods of our sample (1973-79, 1980-89, and 1990-95)[23]. These are shown in Figures 11-23.

[Figure 11-23 here]

Interestingly similar patterns do emerge between the same industry in different countries, as one might expect. Some industries show a marked improvement in TFP throughout the sample period.[24] In other cases there appears to be uniformly a decline in TFP over time, across all countries.[25] Even where the performance is more mixed, we observe a correlation between the experience of different countries at different points in time. For example, in transport equipment most countries experienced a positive TFP

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[22] Note that in the case of the USA, we now allow TFP levels to change from 100. Figure 1 was drawn relative to a constant index of 100 for the USA. In practice, given the low growth in TFP in the USA shown in Figure 10, this change in exposition matters little.

[23] For some of the countries the final period calculated is 1990-93 (e.g. Canada) because of the reduced size of the sample over which materials input data was available. For the UK and France the data for the 1990s was not available (for France the data stops in 1991, and in the UK's case in 1987), again because of limitations to the raw materials data obtained from the input-output tables. In the case of Germany, Japan, France and Italy no data was available before 1979.

[24] For example food, except in Germany; paper; chemicals, except in France and Italy in the 1980s where the performance outweighs the gains of the 1990s.

[25] Wood; mineral products, except in Canada and in Japan in the 1990s; metal products, again except in Japan in the 1990s.

growth in the 1980s, and there seems to have been a small decline in the 1990s. Textiles TFP growth improved in the 1980s in all countries except Japan and Germany.

Despite these similarities, there are some notable cases where the performance across countries has differed considerably. For instance in the case of office machinery and data equipment the performance of Germany in the 1990s and Japan in the 1980s stands in sharp contrast to the stagnation in TFP in the USA. In electrical goods, Germany's relative decline in the 1990s is in marked contrast to the USA and Japan. In the general heading of 'other manufacturing', Canada has shown a remarkable improvement in the 1980s and 1990s. In traditional sectors such as food and textiles, again Germany has fared much worse in the 1980s and 1990s.

5. Comparing the UK's Productivity Performance to other G7 Economies

There have been several attempts in recent years to compare the UK's performance in terms of productivity levels with that of other industrialised economies. O'Mahony (1999) and HM Treasury (2000) highlight the fact that the UK appears to have a 20% gap in terms of total factor productivity compared to the USA and France, and 15% with respect to Germany. It is suggested that the UK's under-performance in terms of TFP is not as great as in terms of labour productivity, because of the UK's lower capital stock. This in turn suggests that the UK's lower labour productivity could be raised by encouraging more investment, and this is a key element of the government's policy framework (see HM Treasury, 2000).

But how reliable are these previous estimates of the TFP gap? Let us compare our TFP levels adjusted for cyclical effects (Figure 10) to those reported in O'Mahony (1999), and which are used by HM Treasury (2000). Because our data is based on raw materials data from input-output tables, our latest data period[26] for a useful comparison is 1994, whilst the data reported in O'Mahony (1999) and HM Treasury (2000) relates to 1999. Nevertheless, the two dates are close enough given the low rates of growth of TFP to offer a meaningful comparison. Figure 24 compares our relative TFP levels data to those reported in previous contributions[27].

[Figure 24 here]

Figure 24 confirms the finding of previous studies that the UK faces a serious productivity gap in terms of TFP, but suggests that this gap is much bigger compared to Germany and the USA than suggested in HM Treasury (2000). Our results, which it should be recalled refer exclusively to the *manufacturing sector*, suggest a gap of 60% compared to the USA, and over 25% with Germany. It confirms a gap of just under 20% with France, and shows that even Italy[28] had a slight advantage in terms of TFP (3% ahead of UK TFP) in 1995. What these results suggest is that in the manufacturing sector, the UK is not just suffering from a problem of low investment, but that a lower rate of innovation is a real problem. The only bright light on the horizon is that our data shows that, over the period 1990-95, the UK was closing the gap on other G7 economies, and had just about caught up with Italy in terms of manufacturing TFP.

[26] In the case of France, we had to use 1992, at this was the last available data point for which raw material data was available.
[27] For ease of comparison, we have rebased our indices so that the UK's TFP level is 100.

7. Conclusions

This paper has produced new international comparative data on total factor (multiple-input) productivity measures, comparing a number of manufacturing sectors across the G7 economies. By collecting sectoral data on the use of intermediate inputs, we are able to calculate gross output measures of TFP growth, and of TFP levels. This provides a more accurate view of underlying TFP growth across the G7 economies. Existing value-added and cyclically unadjusted measures tend to overestimate TFP growth, and hence the impact of underlying technical progress. Given the importance of the accurate measurement of underlying productivity growth for economic policy (see HM Treasury 2000), this emphasises the need to obtain more robust measures of TFP, using the techniques outlined in this paper.

A second use of the sectoral data on intermediate inputs is that it allows us to adjust cost-based TFP growth figures in such a way as to eliminate the distortion in existing measures due to variable factor utilisation of the business cycle. Again, this allows us to obtain a more accurate measure of underlying technical progress. Overall, the Basu modified TFP growth figures offer a different perspective on TFP growth, i.e. they suggest that multi-factor productivity growth in the last two decades has not been growing as dramatically as implied standard Solow TFP measures. We demonstrate that there has been little convergence between the G7 economies (with the exception of the UK) if the Basu-adjusted series rather than the conventional Solow series measure TFP growth is used. Finally we show that the Basu measure shows similar patterns across the

[28] There is no comparative value for Italy from HM Treasury (2000).

G7 economies at the sectoral level but that, occasionally, the experience of individual countries deviates from that of other industrialised economies.

A key conclusion from the UK's perspective is that in manufacturing, the productivity gap with other major industrialised countries, especially the USA and Germany, is bigger than has been reported in other recent studies (O'Mahony, 1999, HM Treasury, 2000). Our data shows that the UK was closing the gap in the mid-1990s, but that a considerable amount of ground needs to be made up.

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Data Appendix

For further details on sources and construction of data see Braun (1999). This technical note and the full data set is available freely from the ESRC project web-site http://www.gla.ac.uk/economics/TFP/.

Data employed and sources:
OECD ISDB data (NB all monetary measures in local currencies):

DEP	Capital consumption (constant prices)
CAP	Capital stock (1990 prices) - includes OECD's own estimates
EE	No. employees
ET	Total employment
PGK	Gross capital stock (current prices)
GK	Gross capital stock (1990 prices)
PNK	Net capital stock (current prices)
NK	Net capital stock (1990 prices)
PINV	Gross fixed capital formation (current prices)
INV	Gross fixed capital formation (1990 prices)
EQTO	Ratio of equipment to total capital
WSSS	Total compensation (current prices)

Capital Data from O'Mahony (1999)

OS	Net stock of structures (constant US$1993)
OE	Net stock of equipment (constant US$1993)
OSD	Structures investment deflator (base year adjusted to 1990)
OSE	Equipment investment deflator (base year adjusted to 1990)

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Q	Real gross output
PQ	Current price gross output
MAT	Real materials
M	Current price materials
Q_P	Output price
M_P	Materials price

APPENDIX A

A full outline of how to use indices to compare cross-country TFP levels is provided by Harrigan (1999). He uses a value-added specification with capital and labour of the Caves *et al.* (1982) geometric mean index. We extend Harrigan's specification as our data is based on gross output and needs to take account of raw materials usage in production.

Hence we define, for each industry *i*, the relative TFP index between two countries A and B at time t as:

$$TFP_{it}^{AB} = \left(\frac{y_{it}^{A}}{y_{it}^{B}}\right)\left(\frac{\bar{l}^{A}}{l_t^{A}}\right)^{\sigma_{lt}^{A}}\left(\frac{\bar{k}^{A}}{k_t^{A}}\right)^{\sigma_{kt}^{A}}\left(\frac{\bar{m}^{A}}{m_t^{A}}\right)^{1-\sigma_{lt}^{A}-\sigma_{kt}^{A}}\left(\frac{l_t^{B}}{\bar{l}^{B}}\right)^{\sigma_{lt}^{B}}\left(\frac{k_t^{B}}{\bar{k}^{B}}\right)^{\sigma_{k}^{B}}\left(\frac{m_t^{B}}{\bar{m}^{B}}\right)^{1-\sigma_{lt}^{B}-\sigma_{kt}^{B}} \quad \text{(A.1)}$$

where *y* is gross output, *l*, *k*, and *m* are measures of labour input, capital and materials respectively; $\bar{x}$ indicates the sample mean of the variable *x*, and $\sigma_j \quad j = k,l$ are defined from the inputs shares in total cost, s_j such that $\sigma_{jt} = (s_{jt} + \bar{s}_j)/2$. As indicated by Caves *et al*. (1982) and Harrigan (1999), this Caves-Christensen-Diewert index is superlative, as it is exact if the production function has the flexible translog functional form.

APPENDIX B

B.1 The Solow Residual

To illustrate the relationship between the traditional Solow residual and the Basu measure of TFP, it is convenient to start by restating the standard definitions used in the literature on productivity growth. Consider the following production function:

$$Y_t = \Theta_t F[L_t, K_t, M_t] \tag{B.1}$$

where, Θ_t represents an index of Hicks neutral technical progress; F is a homogenous production function of some degree, γ. As before, Y_t is gross real output; and L_t, K_t and M_t are labour, capital, and real material inputs respectively.

Taking logs of both sides of (2) and then differentiating with respect to time gives

$$\frac{\dot{Y}}{Y} = \frac{\dot{\Theta}}{\Theta} + \frac{\Theta F_L L}{Y}\left(\frac{\dot{L}}{L}\right) + \frac{\Theta F_K K}{Y}\left(\frac{\dot{K}}{K}\right) + \frac{\Theta F_M M}{Y}\left(\frac{\dot{M}}{M}\right). \tag{B.2}$$

where, $\Theta F_{N,}$ ΘF_M and ΘF_K are the marginal products of labour, material inputs and capital respectively. The firm is assumed to minimise(s) total cost:

$$C = wL + rK + P_m M \tag{B.3}$$

subject to the production constraint in (B.2), to determine the optimal levels of capital and labour to employ. The symbols w, P_m and r are the nominal wage per worker, the price of material inputs and the rental rate of capital respectively. The first-order conditions from minimising (B.2) subject to (B.3) are

$$\Theta F_L = \frac{w\gamma}{\lambda},\ \Theta F_K = \frac{r\gamma}{\lambda},\ \text{and } \Theta F_M = \frac{P_m \gamma}{\lambda} \tag{B.4}$$

where the Langrangian multiplier λ is defined as marginal cost.

Solow's (1957) original residual was derived assuming (i) constant returns to scale ($\gamma = 1$) and (ii) perfect competition in the factor and product markets. To measure marginal cost, Solow assumes that it is *observable* at the market price of output, P. Accordingly the marginal products of capital and labour in (B.4) can be rewritten as

$$\Theta F_L = \frac{w}{P},\ \Theta F_K = \frac{r}{P}, \text{and } \Theta F_M = \frac{P_m}{P}\ . \tag{B.5}$$

Substituting the marginal products in (B.5) back into (B.2) gives

$$\frac{\dot{Y}}{Y}=\alpha_t^l\left(\frac{\dot{L}}{L}\right)+\alpha_t^k\left(\frac{\dot{K}}{K}\right)+\alpha_t^m\left(\frac{\dot{M}}{M}\right)+\frac{\dot{\Theta}}{\Theta}, \text{ where} \tag{B.6}$$

$$\alpha_t^l=\frac{wL}{PY},\ \alpha_t^k=\frac{rK}{PY},\ \text{and } \alpha_t^m=[1-\alpha_t^l-\alpha_t^k]=\frac{P_mM}{PY}\quad .$$

To compute the growth in TFP between any two periods *t* and *t-s* $\Delta\theta_{t,t-s}$ one can compute the Tornqvist discrete time approximation to the Divisia index (see Diewert, 1976):

$$\Delta y_{t,t-s}=\tilde{\alpha}^l_{t,t-s}\Delta n_{t,t-s}+\tilde{\alpha}^k_{t,t-s}\Delta k_{t,t-s}+\tilde{\alpha}^m_{t,t-s}\Delta m_{t,t-s}+\Delta\theta_{t,t-s}\text{, where}$$

$$\Delta \mathrm{y}_{t,t\text{-}s}=\log\left(\frac{Y_t}{Y_{t-s}}\right),\ \Delta l_{t,t-s}=\log\left(\frac{L_t}{L_{t-s}}\right),\ \Delta m_{t,t-s}=\log\left(\frac{M_t}{M_{t-s}}\right),\ \Delta k_{t,t-s}=\log\left(\frac{K_t}{K_{t-s}}\right),$$
$$\Delta\theta_{t,t-s}=\log\left(\frac{\Theta_t}{\Theta_{t-s}}\right),\ \tilde{\alpha}_t^l=\left[\alpha_t^l+\alpha_{t-s}^l\right]/2,\ \tilde{\alpha}^m_{t,t-s}=\left[\alpha_t^m+\alpha_{t-s}^m\right]/2,\ \tilde{\alpha}^k_{t,t-s}=\left[\alpha_t^k+\alpha_{t-s}^k\right]/2. \tag{B 7}$$

Total factor productivity growth or the Solow residual is therefore measured as the difference between output growth and weighted input growth, e.g.

$$\%\Delta TFP_{Solow}\equiv\Delta\widehat{\theta}_{t,t-s}=\Delta y_{t,t-s}-\tilde{\alpha}^n_{t,t-s}\Delta n_{t,t-s}-\tilde{\alpha}^k_{t,t-s}\Delta k_{t,t-s}-\tilde{\alpha}^m_{t,t-s}\Delta m_{t,t-s}\,. \tag{B.8}$$

B.2 Cost Based Total Factor Productivity

Hall (1990) derives an alternative measure of TFP which does not require an assumption regarding competition, to address potential problems of mismeasurement due to the assumption of constant returns to scale ($\gamma=1$). In contrast to Solow, Hall assumes that marginal cost, λ is not observable as the market price of output, *P*. Instead of measuring each input's shares in revenue, (*PY*) he uses their shares in cost[29].

Using the cost-shares, the marginal products in (B.4) can be rewritten as

$$\Theta F_L=\frac{w\gamma Y}{wL+rK+P_mM},\ \Theta F_M=\frac{P_m\gamma Y}{wL+rK+P_mM}\ \text{ and }\ \Theta F_K=\frac{r\gamma Y}{wN+rK+P_mM}. \tag{B.9}$$

Again, output growth is found by substituting (B.9) into (B.2) and solving for Δy_t, e.g.

[29] Note that the cost shares are defined as ($C=wL+rK+P_mM$). Further note that if $PY>C$, due to monopoly profits, then Solow's revenue shares will underestimate the elasticity of output with respect to all inputs.

$$\Delta y_{t,t-s} = \gamma[\tilde{\alpha}^{l'}_{t,t-s}\Delta l_{t,t-s} + \tilde{\alpha}^{k'}_{t,t-s}\Delta k_{t,t-s} + \tilde{\alpha}^{m'}_{t,t-s}\Delta m_{t,t-s}] + \Delta\widehat{\theta}'_{t,t-s}, \tag{B.10}$$

where the α' denote cost shares,

$$\tilde{\alpha}^{l'}_{t,t-s} = \left[\alpha^{l'}_t + \alpha^{l'}_{t-s}\right]/2;\ \tilde{\alpha}^{m'}_{t,t-s} = \left[\alpha^{m'}_t + \alpha^{m'}_{t-s}\right]/2;\ \tilde{\alpha}^{k'}_{t,t-s} = \left[\alpha^{k'}_t + \alpha^{k'}_{t-s}\right]/2;$$
$$\alpha^{l'}_t = \frac{wL}{C};\ \alpha^{k'}_t = \frac{rK}{C};\ \alpha^{m'}_t = (1-\alpha^{l'}_t - \alpha^{k'}_t) = \frac{P_m M}{C};\ C = wL + rK + P_m M.$$

From which we can find the cost-based Hall TFP growth measure, $\Delta\widehat{\theta}'_{t,t-s}$, which is related to the Solow measure as follows:

$$\%\Delta TFP_{Hall} \equiv \Delta\widehat{\theta}'_{t,t-s} = \%\Delta TFP_{Solow} - \left\{(\gamma-1)[\tilde{\alpha}^{l'}_{t,t-s}\Delta l_{t,t-s} + \tilde{\alpha}^{k'}_{t,t-s}\Delta k_{t.t-s} + \tilde{\alpha}^{m'}_{t,t-s}\Delta m_{t,t-s}]\right\} \tag{B.11}$$

Note that if γ=1 and *PY=C* then $\%\Delta TFP_{Hall} = \%\Delta TFP_{Solow}$. Note that, unlike the Solow revenue-based residual, constructing the Hall measure of TFP growth requires a measure of returns to scale, γ, which usually has to be estimated. (The estimation method employed is described in Braun, 1999)

B.3 Basu's Cost-Based and Utilisation Adjusted Total Factor Productivity

Basu (1996) further develops Hall's cost-based TFP measure to obtain a measure of TFP growth which is net of cyclical changes in factor utilisation[30]. Basu's adjustment relies on the use of material inputs data as an indicator of cyclical factor utilisation[31]. The key to this adjustment is the observation that, unlike employment and capital, material inputs do not have an utilisation dimension. Hence one can use relative changes in the input of raw materials and other measured factor inputs (capital and labour) to deduce the extent to which factor utilisation changes over the cycle.

Basu considers the following production function instead of (B.1):

$$Y_t = \Theta_t F[(G_t \cdot L_t),(Z_t \cdot K_t), M_t] \tag{B.12}$$

where, G and Z are the levels of labour and capital utilisation. Using the same methods as previously, we can derive the following alternative cost-based TFP measure, net of factor utilisation:

[30] Following Basu and Kimball (1997) we decided to exclude capital quality adjustments from the analysis because the adjustment is based on implicit rental rates that are inconsistent with the assumption of imperfect competition which is adjusted in computed adjusted TFP. For example, the capital adjustment assumes that economic profits are zero.
[31] It is therefore similar in spirit to the adjustment proposed in Burnside *et al* (1995), which uses data on electricity usage to adjust TFP growth. However, the Basu (1996) adjustment is more broad-based, as it relies on using all available data on intermediate inputs.

$$\%\Delta TFP_{Basu} = \underbrace{\Delta y_{t,t-s} - \gamma[\tilde{\alpha}^{n'}_{t,t-s}\Delta n_{t,t-s} + \tilde{\alpha}^{m'}_{t,t-s}\Delta m_{t,t-s} + \tilde{\alpha}^{k'}_{t,t-s}\Delta k_{t,t-s}]}_{\%\Delta TFP_{Hall}} - \underbrace{\gamma[\tilde{\alpha}^{n'}_{t,t-s}\Delta g_{t,t-s} + \tilde{\alpha}^{k'}_{t,t-s}\Delta z_{t,t-s}]}_{u_t} \quad \text{(B.13)}$$

where the shares are defined as in Hall.

In other words, $\%\Delta\mathrm{TFP}_{Basu}$ in (B.13) is equal to $\%\Delta\mathrm{TFP}_{Hall}$ net of changes induced by capacity utilisation. However, the problem with (B.13) is that some of the components of u_t are *unobservable* (i.e. Δg and Δz). To derive the relationship between *unobserved* capital and labour inputs and *observable* or measured material inputs, Basu makes use of the following more restricted production function:

$$Y = \Theta F[\mathrm{V}\{(G\cdot L),(Z\cdot K)\}, H\{M\}] \quad \text{(B.14)}$$

where the value-added function, V and the material costs functions, H are assumed to have constant returns to scale. Note that the function F, however, still has the same properties as set out in (B.2). Log-linearising (B.14) and using the first-order conditions for cost minimisation the growth rate in value added, $\Delta v_{t,t-s}$ can be expressed as

$$\Delta v_{t,t-s} = \Delta m_{t,t-s} - \sigma(\Delta p_{vt,t-s} - \Delta p_{mt,t-s}) \quad \text{(B.15)}$$

where, Δm_t is material cost growth, $\sigma \geq 0$ is the (local) elasticity of substitution between value-added and materials (with $\sigma = 0$ representing the Leontief case and $\sigma = 1$ the Cobb-Douglas unit-elastic case), and $\Delta p_{vt}, \Delta p_{mt}$ measure value-added and materials inflation, respectively[32].

The growth in value-added can next be expressed as a Divisia index in terms of the growth in observed capital and labour input and unobserved utilisation over the interval between *t* and *t-s*, e.g.

$$\Delta v_{t,t-s} = \frac{\tilde{\alpha}^{n'}_{t,t-s}(\Delta n_{t,t-s} + \Delta g_{t,t-s}) + \tilde{\alpha}^{k'}_{t,t-s}(\Delta k_{t,t-s} + \Delta z_{t,t-s})}{\tilde{\alpha}^{n'}_{t,t-s} + \tilde{\alpha}^{k'}_{t,t-s}} \quad \text{(B.16)}$$

Substituting (17) into (16) for Δv_t, rearranging and substituting the resulting expression, which is equal to $u_t(=\tilde{\alpha}^{n'}_{t,t-s}\Delta g_{t,t-s} + \tilde{\alpha}^{k'}_{t,t-s}\Delta z_{t,t-s})$, into (14) yields a modified measure of TFP growth:

$$\%\Delta TFP_{Basu} = \Delta y_{t,t-s} - \gamma[[\Delta m_{t,t-s} - \sigma(\tilde{\alpha}^{n'}_{t,t-s} + \tilde{\alpha}^{k'}_{t,t-s})(\Delta p_{vt,t-s} - \Delta p_{mt,t-s})]] \quad \text{(B.17)}$$

Note that unlike (B.13), TFP growth in (B.17) is defined in terms of only *observable* magnitudes. However, unlike Solow, estimates have to be obtained or values have to be imposed of γ and σ.

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[32] Bruno (1984) reviews a number of papers and reports a consensus range for σ between 0.3-0.4. A more recent study by Rotemberg and Woodford (1992) provide an estimate σ of 0.7 (which is the baseline value used by Basu (1996)). In Malley *et al*. (2000) we experiment with values ranging from $\sigma = 0$ to $\sigma = 1$.

To derive the utilisation adjusted measure of TFP growth one has to perform an instrumental variable (*IV*) estimation of (B.17) to identify γ and hence $\%\Delta TFP_{Basu}$. *IV* estimation is required in this context due to the obvious endogeneity of the regressors. In this study, we employ the same set of instruments proposed by Ramey (1989) and Hall (1990) and augmented by Caballero and Lyons (1992) and Basu (1996)[33]. The value of σ has to be imposed. Both Basu (1996) and Malley *et al*. (2000) find that values of σ in the range of 0 to 1 tend to produce very similar results. In what follows, we experiment again with different values of σ.

[33] The instruments in include the growth rate of military spending and the growth rate of the price of oil (deflated by the prices of manufacturing durables and nondurables in each of the countries). These instruments are chosen because they cause important movements in employment, material costs, capital accumulation and output but are uncorrelated with the random component of TFP growth (see Braun, 1999).

APPENDIX C

Consider the general production function (B.1) in Appendix B:

$$Y_t = \Theta_t F[L_t, K_t, M_t] \tag{C.1}$$

Ignoring intensity effects, and assuming separability, this can be expressed in terms of value added as:

$$Y_t = \Theta_t F[V_t(K_t, L_t, t), M_t] \tag{C.2}$$

From (C.1) and (C.2) we can write down the TFP growth rate defined in terms of gross output *g* and for the growth rate in value added:

$$\left(\frac{\dot{\Theta}}{\Theta}\right)^g = \frac{\dot{Y}}{Y} - \alpha_t^l \left(\frac{\dot{L}}{L}\right) + \alpha_t^k \left(\frac{\dot{K}}{K}\right) + \alpha_t^m \left(\frac{\dot{M}}{M}\right) \tag{C.3}$$

$$\frac{\dot{V}}{V} = (1/\alpha_t^v)\frac{\dot{Y}}{Y} - (\alpha_t^m / \alpha_t^v)\left(\frac{\dot{M}}{M}\right) \tag{C.4}$$

where α_t^v is the elasticity of gross output with respect to value added (the share of nominal value added in gross output). If instead of its fundamental relation, (C.1) we try to estimate TFP growth from value added data, we obtain:

$$\left(\frac{\dot{\Theta}}{\Theta}\right)^v = \frac{\dot{V}}{V} - (\alpha_t^k / \alpha_t^v)\frac{\dot{K}}{K} - (\alpha_t^l / \alpha_t^v)\left(\frac{\dot{L}}{L}\right) \tag{C.5}$$

where $\alpha_t^l + \alpha_t^k = \alpha_t^v$. It then follows that:

$$\left(\frac{\dot{\Theta}}{\Theta}\right)^v = (1/\alpha_t^v)\left[\frac{\dot{Y}}{Y} - \alpha_t^l \left(\frac{\dot{L}}{L}\right) + \alpha_t^k \left(\frac{\dot{K}}{K}\right) + \alpha_t^m \left(\frac{\dot{M}}{M}\right)\right] = (1/\alpha_t^v)\left(\frac{\dot{\Theta}}{\Theta}\right)^g \tag{C.6}$$

As $\alpha_t^v < 1$, it follows that TFP computed from value added data over-estimates ‘true’ TFP growth.

Table 1: Variance Ratio of Solow and Basu TFP Growth Measures

Sector	Total Manuf	Food	Textile	Wood	Paper	Chem	Min.l Prod.	Basic Metals	Other Manuf	Metal Prod Ex Mach.	Electr, Goods	Trans. Equip.	Office and Data Proc.	Agric & Ind. Mach.
USA	12.47	3.77	21.03	4.62	14.16	8.92	22.84	23.56	33.94	25.18	27.44	2.56	55.93	15.35
Canada	1.62	4.18	3.23	9.45	10.66	5.55	35.28	5.78	2.11	n.a	n.a	n.a	n.a	n.a
Germany	1.79	0.90	0.57	1.35	0.73	0.84	2.13	0.76	0.65	2.90	0.66	0.77	0.58	1.85
France	2.02	0.81	1.02	0.80	0.47	1.44	1.64	1.36	0.07	0.81	1.21	0.38	1.14	n.a
UK	3.62	35.09	17.06	n.a	10.90	34.25	432.09	27.00	7.03	n.a	n.a	n.a	n.a	n.a
Japan	0.23	0.76	0.39	0.29	0.15	1.14	4.36	n.a	n.a	n.a	n.a	n.a	n.a	0.58
Italy	38.86	1.23	1835.1	1.75	715.36	581.3	747.86	313.96	508.32	97.64	508.32	147.78	n.a	n.a

Table 2: Differential in Average TFP Growth Rates from Solow and Basu Measures

Sector	Total Manuf	Food	Textile	Wood	Paper	Chem	Min.l Prod.	Basic Metals	Other Manuf	Metal Prod Ex Mach.	Electr, Goods	Trans. Equip.	Office and Data Proc.	Agric & Ind. Mach.
USA	0.33	-0.005	0.81	0.94	0.35	0.31	0.82	0.39	0.53	0.32	1.18	0.32	-0.06	0.30
Canada	0.09	-0.22	0.13	1.17	-0.11	0.43	0.26	0.27	-0.40	n.a	n.a	n.a	n.a	n.a
Germany	0.40	0.64	1.16	0.51	0.16	-0.03	1.01	0.56	0.85	0.36	1.02	-0.27	0.77	0.10
France	0.58	-0.07	0.46	0.60	0.19	0.35	0.71	0.21	2.07	4.04	0.67	0.75	0.35	n.a
UK	0.45	0.51	1.29	n.a	1.14	1.43	-7.25	2.13	4.08	n.a	n.a	n.a	n.a	n.a
Japan	0.32	-1.04	-0.23	0.46	-0.91	-0.50	12.27	n.a	n.a	n.a	n.a	n.a	n.a	-0.96
Italy	-0.06	-0.77	0.02	0.61	-0.54	0.41	-0.46	-0.01	0.17	-0.94	0.17	-0.53	n.a	n.a