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1

AN OVERVIEW

INTRODUCTION

This is a book about productivity. There are several possible concepts of productivity but the one on which we focus is multi-factor productivity (MFP), frequently also known as total factor productivity (TFP). Human beings will always be interested in *labour* productivity, whether measured as output per person or per person-hour. This is simply because in the long run the standard of living of everyone can only be raised if labour productivity increases. If robots ever take over the world, they will presumably be interested in robot productivity for similar reasons. But from the point of view of economic analysis, MFP, or more precisely the *growth* of MFP, is the more fundamental concept, at least if we are interested in understanding the causes of increasing labour productivity.

The interpretation of MFP

Theoretically, MFP growth is the rate at which output would have increased in some period, if all inputs had remained constant. In principle, MFP growth should be measured as the difference between the growth of output and the growth of total input. The growth of total input should in turn be measured as a weighted sum of the growth rates of individual inputs. In practice, it is customary to use the shares of the inputs in the value of output as the weights.[1] This procedure is adopted first because it is practical and secondly because it is hoped or believed that the resulting figure will be close to what MFP growth is meant to be in theory. If we calculate MFP growth over some time period and it turns out to be about zero, then we can at least say that any growth in labour productivity which occurred in this period must have been due to increased use of the other inputs. So we have at least a proximate explanation for rising labour productivity. If on the other hand MFP growth turns out to account for a substantial part of the rise in labour productivity, then we are clearly in need of some deeper explanation.

It might be thought that MFP growth would usually be zero, at least over the long term. Imagine that in a steel mill the quantities of all types of labour, of capital equipment, of energy, and of raw materials were held constant. Why should we expect to see any increase in output at all? It is true that it might be possible to raise output by some reorganisation of the

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flow of work or by the removal of restrictive practices (without changing labour effort of any sort) but such changes would be of a one-off nature. Alternatively, workers' skills might rise with experience (learning by doing). But in the absence of other changes, opportunities to learn would soon be exhausted (Arrow, 1962). It seems therefore that, aside from such temporary episodes, MFP growth should be generally zero. We cannot test this view directly since so far as we are aware MFP growth has not been measured at the level of an individual steel mill, but most usually at the level of the whole economy or of broad sectors within the economy. However at these levels, measures of MFP growth are almost invariably positive and of an economically significant size. To take the most striking example, Solow's pioneering calculation of MFP growth in the private non-farm sector of the US economy for 1909–49 found that 87.5 per cent of the growth of output per head over this period should be ascribed to MFP, and only 12.5 per cent to capital accumulation (Solow, 1957). Similar results were reported a little earlier by Abramovitz (1956), who commented: 'Since we know little about the causes of productivity increase, the indicated importance of this element [that is, MFP growth] may be taken to be some sort of measure of our ignorance about the causes of economic growth . . .'. When these findings first appeared, a debate started which has not so far been resolved.

One argument was that MFP growth should be interpreted as the effect of technical progress, but a difficulty with this argument, many people claimed, is that technical progress usually has to be incorporated into new capital goods and calculations of MFP growth already allowed for the effect of capital accumulation. It seemed implausible that the effects of scientific advances could be costlessly incorporated into production processes, thus effortlessly raising output and output per person over long periods of time. Another approach was to argue that the results of Solow and other pioneers were due to the crudity of the measurements: when measured properly, MFP growth would turn out to be negligible. In fact, the hidden agenda of much growth accounting (as the activity of measuring MFP growth came to be called) may be interpreted as an attempt to reduce the size of the measured residual. An early attempt along these lines was that of Jorgenson and Griliches (1967) who, by using more refined procedures (for example, Divisia index numbers) and better and more disaggregated data, reached a diametrically opposite conclusion to Solow's. They claimed that the residual was effectively zero for 1945–65: the growth of inputs accounted for 97 per cent of the growth of US private domestic product. However this claim has not withstood the test of time. In Jorgenson's later and still more refined calculations for a similar period, 1947–66, MFP growth now averages 1.28 per cent per annum and accounts for 32 per cent of the growth of output and for 42 per cent of the

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growth of output per person-hour.[2] Thus increasing refinement of measurement has indeed reduced the size of MFP but has far from eliminated it as an apparent cause of long-run growth.

Our approach

Numerous calculations of MFP growth have now been made for different countries and different time periods. Estimates are routinely produced by the US Bureau of Labour Statistics and by the OECD. There is a danger in fact of a blurring of the distinction between the theoretical concept of MFP growth, which as we shall see in chapter 2 can be given a rigorous foundation in the theory of production, and any particular empirical measure of MFP growth. It is one of the themes of this book that measurement matters: at every stage of an MFP calculation empirical and conceptual issues must be faced. Alternative decisions by the researcher can have profound effects on the resulting estimates. That is why it is important to follow a consistent methodology and this is what we have attempted to do.

A distinctive feature of our approach is that it starts from the level of individual industries. By contrast, most MFP estimates have been either at the level of the whole economy or of broad sectors such as manufacturing. We also provide estimates of MFP growth in manufacturing, but we do so by aggregating up from the industry-level estimates, a method which we will argue is superior: it also produces strikingly different results. A further advantage of industry-level estimates is that they constitute a wealth of data which can be put to use in testing hypotheses relating to, for example, increasing returns, a topic which has aroused much interest in recent years. Briefly, our estimates cover more than 130 industries, nearly all within UK manufacturing over a 32-year period, 1954–86. We believe that they are the most detailed that have so far been produced and also the most methodologically consistent. Our methodology is a neo-classical one (inspired in the main by Jorgenson *et al.*, 1987) so we are conscious that it will not command universal assent. But we hope that even those who are impatient with growth accounting will find something of value here. After all, to calculate MFP growth, one must first calculate outputs and inputs, so those who reject our methodology can put our estimates to their own preferred use.

Numerous studies of productivity have been conducted at the National Institute (see Matthews, 1988, for a review). Usually these have looked at labour productivity and often they have involved international comparisons, in an attempt both to measure and to explain the productivity gap between Britain and its competitors (for example, Prais, 1981; Smith *et al.*, 1982; Davies and Caves, 1987; O'Mahony, 1992a). Because our estimates of MFP growth are at a very disaggregated level, direct inter-

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national comparisons would have been difficult because of differences in systems of industrial classification and we have not attempted any. Important insights into the reasons for Britain's comparatively low level of industrial productivity have also been derived from case studies of particular industries (for example, Steedman and Wagner, 1987 and 1989). By contrast the present study, in the tradition of Fabricant (1944) for the US and Salter (1966) and Wragg and Robertson (1978) for the UK, aims to be broader both in time span and coverage than earlier work, though at the price of being in consequence less deep.

A guide to the book

The remainder of this chapter will present an overview of the questions to be discussed and the main findings. Before launching into this, a brief guide to the chapters which are to follow is in order. Chapter 2 provides a detailed exposition of the theory of growth accounting, at the level of the industry. Issues to be discussed there include aggregation over types of inputs, the appropriate concept of output (gross output or value added), and returns to scale. This chapter also outlines the data sources and methods. Because of its complexity and interest, the part of the theory which relates to fixed capital is the subject of a separate chapter (chapter 3). Aggregation, this time over different vintages of the same type of capital, will again be an issue. Here will also be found a discussion of the perpetual inventory method of estimating capital stocks, a critique of the methods currently employed by the Central Statistical Office (CSO), and some sensitivity tests of the effect of different assumptions about asset life on capital stock estimates. Readers who are prepared to rely on the summary account of methodology and data which follows in the present chapter can skip chapters 2 and 3 and press on to chapter 4, which presents the estimates of MFP growth themselves at the industry level and discusses their main characteristics. The approach here is descriptive, seeing what the data can tell us; later, chapters 6 and 7 adopt a more analytical approach. In chapter 4 we look first at average behaviour and also at the extent of variability across industries. We also discuss the presence in our estimates of a number of empirical regularities which have been detected in other data sets by earlier workers, such as the positive relationship between output growth and productivity growth known as 'Fabricant's Law'. Chapter 5 is devoted to MFP estimates at a higher level of aggregation, UK manufacturing as a whole. A number of different methods are discussed, but the preferred method is a 'bottom-up' one, based on the industry-level estimates. Chapter 6 looks at the worldwide slowdown in productivity growth which occurred following the first oil shock of 1973. It asks whether the rise in energy prices, or in raw material prices generally, can account for the slowdown. In chapter

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7, we revert to the industry-level estimates and ask whether the weight assigned to physical capital is too low – in other words, does investment in physical capital explain a great deal more of productivity growth than our method allows? We also ask, do the estimates of outputs and inputs reveal any sign of the presence of increasing returns to scale or the effects of externalities?

SUMMARY OF FINDINGS

The theoretical framework (chapter 2)

The estimation of MFP growth rates at the industry level in this book follows the methodology developed in Jorgenson, Gollop and Fraumeni (1987). Their approach ultimately rests on Solow (1957) who showed that, under certain conditions, the growth rate of MFP can be estimated as the growth rate of output minus the growth rate of total input, where the latter is equal to the sum of the value-share-weighted growth rates of individual inputs. The assumptions on which the approach rests are that producers are price takers in both output and input markets, so that output prices are equal to the marginal costs of production, and that the technology is characterised by constant returns to scale. These assumptions are very convenient, since they allow us to estimate MFP growth without having to estimate the parameters of the production function; the latter procedure would be difficult to implement since our data set has few time series observations.

In the light of the new growth theory (Romer, 1986; Lucas, 1988), which emphasises externalities and learning effects, this approach may seem at first old-fashioned. The new theory has rightly generated a great deal of intellectual excitement. But it is not yet clear that the factors which it emphasises are actually the crucial ones empirically.[3] In any case, it is important to realise that the calculation of inputs and outputs is not affected by the new theory, only the final stage, the calculation of MFP growth itself, may become problematical. Even if one of the new growth theories is true, it may affect the interpretation rather than the validity of MFP calculations: for example, in one of the models in Lucas (1988), MFP growth can be correctly interpreted as the rate at which an appropriately defined measure of human capital is accumulating. Finally, it is possible to use the estimates, derived on the assumptions of constant returns, absence of externalities, and so on, to *test* whether the patterns of productivity growth are indeed consistent with the assumptions (see particularly chapter 7).

Jorgenson *et al.* (1987) assume that for each industry there exists a production function relating output to inputs, and to time. For the *i*th industry,

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$$Y_i = F^i(K_i, L_i, X_i, t), \qquad i = 1, \ldots, N, \qquad (1.1)$$

where Y is real gross output, X is real intermediate input, K is real capital stock, L is labour input, t is time, and N is the number of industries. Capital, labour and intermediate input are, in turn, aggregates of their respective components; for example, capital is an aggregate of any number of different types of fixed capital and of inventories, the number being limited only by practical considerations. Under the given assumptions, the growth rate of MFP in the ith industry, denoted by μ_i, is in continuous time:

$$\mu_i = \mathrm{d}\ln Y_i/\mathrm{d}t - v^i_K(\mathrm{d}\ln K_i/\mathrm{d}t) - v^i_L(\mathrm{d}\ln L_i/\mathrm{d}t) - v^i_X(\mathrm{d}\ln X_i/\mathrm{d}t), \quad (1.2)$$

where v^i_K, v^i_L and v^i_X are the value shares of capital, labour and intermediate input respectively in the value of output. For example,

$$v^i_X \equiv p^i_X X_i / q_i Y_i$$

where p^i_X is the price of intermediate input to the ith industry and q_i is the price of the output of the ith industry, with analogous definitions for the other shares. The last three terms on the right-hand side of (1.2) are a Divisia index of total input growth. Instantaneous growth rates cannot be measured in practice, but the growth rate of MFP over the discrete time interval $t - u$ to t can be approximated as follows:

$$\Delta_u \ln(\mathrm{MFP}) = \Delta_u \ln Y_i - \bar{v}^i_K \Delta_u \ln K_i - \bar{v}^i_L \Delta_u \ln L_i - \bar{v}^i_X \Delta_u \ln X_i.$$

Here Δ_u is the difference between a variable at time t and time $t - u$, divided by the length of the time interval (u): for example, $\Delta_u \ln Z \equiv [\ln Z(t) - \ln Z(t-u)]/u$. $\bar{v}^i_K$, $\bar{v}^i_X$ and $\bar{v}^i_L$ are the value shares of capital, labour and intermediate input respectively, averaged over periods t and $t - u$. For example,

$$\bar{v}^i_X \equiv (1/2)[v^i_X(t) + v^i_X(t-y)]$$

and similarly for the other shares. Note that the shares are observable and add up to one. The expression for MFP growth contains a discrete, Törnqvist approximation to the ideal Divisia index of total input. The aggregates X_i, K_i and L_i are in turn estimated as Törnqvist indices of their components.

In this book, the measure of output is a gross one, which is preferred on theoretical grounds to a net measure such as value added. Gross output is also more intuitive: the output of a baker is bread, not value added in baking. No use is made of the concept of value added in estimating MFP growth at the industry level. However, at the aggregate level, one (though not the preferred) estimate of MFP growth is based on value added.

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Sources for the measurement of output and inputs (chapter 2)

The primary, though far from the only, source for the estimates of MFP growth rates was the UK Census of Production. Our dependence on the Census was the main determinant of the period we chose to study, 1954–86. To achieve comparability over the chosen time span, the 1968 Standard Industrial Classification (SIC) was employed throughout, which allowed the estimation of MFP growth rates for more than 130 industries (nearly all in manufacturing) for at least some of this period and for 124 industries for the whole period.[4] The Census gives data on output, purchases of materials and services, stocks of inventories, and fixed investment (but not stocks of fixed capital), all in nominal terms. In addition, it gives numbers employed and average wages, but not hours worked. Data on prices and on hours worked were therefore obtained from alternative sources. Estimates were constructed for eight time periods within the overall span of 32 years: 1954–8, 1958–63, 1963–8, 1968–73, 1973–6, 1976–9, 1979–82 and 1982–6. With the exception of 1976 and 1982, these are all years of reasonably full capacity working.

The basis for the output estimates is the Census of Production concept of (nominal) gross output, adjusted to be consistent with national accounts definitions; the adjustments were to remove stock appreciation, and to avoid double-counting by excluding intra-industry purchases and sales, all of which are present in the original Census figures. The CSO's industry-level producer price indices, for home sales, were used to deflate nominal gross output.

We distinguish two types of intermediate input: first, purchases of materials and fuel and second non-industrial services (payments for transport, advertising and so on). Where available, the appropriate producer price indices were employed as deflators, otherwise deflators were constructed from other sources.

Labour input, for each type of worker, is measured by annual hours, which are computed as the product of numbers employed, weekly hours and weeks worked per year. Nine types of worker, five manual and four non-manual, are distinguished. The manual types are: full-time adult males; full-time adult females; part-time adult females; males aged under 21 and females aged under eighteen. The non-manual types are males; full-time females; part-time females and working proprietors.

We distinguish three kinds of fixed capital: plant & machinery; buildings & land; and vehicles – and two kinds of inventories: materials; and finished goods and work in progress. Stocks of fixed capital were estimated by the perpetual inventory method. For each stock, gross investment is cumulated over time, with allowance made for depreciation; the assumed rate of depreciation allows for both scrapping at the end of the

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assumed asset life and ageing or obsolescence in the period between installation and scrapping. That is, a 'net' capital stock concept is employed with depreciation assumed to be exponential.

Though it is convenient to speak of an industry-level capital aggregate, in the sense of an aggregate over different types of assets, strictly speaking such a concept is unnecessary: estimates of MFP growth can be constructed by considering each type of asset separately, though in practice the asset types distinguishable empirically may be more broadly defined than would be desirable (for example, 'plant & machinery'). However, aggregation becomes more of an issue when we recall that the stock of each type of asset is itself an aggregate of different vintages. The efficiency of an earlier vintage is lower than that of a later one both because of physical deterioration due to age and because of technical improvements embodied in later vintages. From the point of view of MFP measurement, it can be shown that different vintages of capital should be aggregated together by weighting each vintage by its relative marginal product. Under the assumptions followed elsewhere in this book, relative marginal products are measured by relative rental prices. If depreciation is exponential (or geometric), as the evidence suggests (at least for the US), then relative *rental* prices are equal to relative *asset* prices. In general, rental prices are not directly observable, but asset prices are much easier to measure.

The growth of fixed capital (chapter 3)

Estimates of the stocks of plant & machinery, of buildings and land, and of vehicles, were constructed for 140 industries (137 in manufacturing), using the Perpetual Inventory Method (PIM). Because there is much uncertainty about some crucial inputs required for the PIM, such as the length of the service life of assets or the rate at which assets depreciate due to ageing or obsolescence, a number of sensitivity analyses were performed. The most striking findings to emerge are as follows.

First, estimates of the levels of capital stocks are very sensitive to the assumptions required by the PIM. But estimates of the growth rates, which are what matter for MFP calculations, are *not* very sensitive. Second, the growth rates of the capital stocks have been slowing down steadily since the 1960s, particularly that of buildings. Third, the average age of the capital stock has risen since 1973 and, if no role is allowed for premature scrapping in the 1980s, was higher in 1985 than it had been in 1963. Fourth, the average age of plant in 1979 was some 11–15 years (depending on assumption) and about half of it was less than ten years old. The average age of buildings was some 23–29 years and on average about half of all buildings were less than twenty years old. Finally, it has frequently been argued that official PIM estimates overstate the size of

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Table 1.1. *Growth rates of industry output and inputs: means and standard deviations (% p.a.)*

Period	*N*	MFP	*Y*	*K*	*L*	*X*
Means						
1954–73	124	0.88	3.32	3.81	−0.77	3.59
1973–86	133	−0.47	−1.17	1.00	−4.18	0.48
1954–86	124	0.35	1.50	2.64	−2.16	2.31
Standard deviations						
1954–73	124	1.00	3.14	2.30	2.49	3.10
1973–86	133	1.56	3.07	1.89	2.66	3.17
1954–86	124	0.86	2.57	1.87	2.02	2.51

Source: Table 4.1.
Note: *N*: Number of industries.

the capital stock because they assume a fixed asset life and make no allowance for premature scrapping. Allegedly, much energy-intensive equipment was scrapped because of obsolescence following the 1973 oil price shock. Much more extensive scrapping occurred, it is often thought, as a result of the recession of the early 1980s. Though our estimates use different assumptions to those of the CSO, they are potentially vulnerable to the same criticism. Based on movements in the capital–output ratio in manufacturing as a whole in the period up to 1973, and relative to our PIM estimates, we find that premature scrapping may have reduced the stock of plant by 17 per cent and that of buildings by 7 per cent in 1986; in 1979 the corresponding figures were 9 per cent and 2 per cent. But other evidence suggests that scrapping in the 1973–9 period was *not* very significant. And an alternative calculation suggests that these estimates may be too high for 1986 as well: according to the latter, the upper limit for the reduction due to premature scrapping on the plant & machinery estimates in 1986 was about 10 per cent; the upper limit for buildings would be lower still because of the greater probability that buildings can be sold rather than scrapped when no longer needed.[5] However, all such estimates are extremely speculative and so, though there was undoubtedly *some* premature scrapping as a result of the 1980–81 recession, no adjustment was made to the PIM estimates.

The industry-level estimates (chapter 4)

As an average across all industries, MFP grew at 0.88 per cent per annum from 1954–73; thereafter it fell at 0.47 per cent per annum (table 1.1).[6] Closer examination shows that MFP actually fell from 1973–82, but grew again from 1982–6. Labour productivity by contrast grew on average in both halves of our period, by 4.09 per cent per annum in 1954–73 and by

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Table 1.2. *Accounting for the growth of output per unit of labour (cross-industry averages)*

Period	Growth rates Y/L % p.a.	K/L % p.a.	X/L % p.a.	Input contribution %	of which (total = 100%): K/L %	X/L %
1954–73	4.09	4.58	4.36	78.5	23.4	76.6
1973–86	3.01	5.18	4.66	115.6	20.6	79.4
1954–86	3.66	4.80	4.47	90.4	22.0	78.0

Source: Table 4.7.

3.01 per cent in 1973–86 (table 1.2). For both kinds of productivity, there was considerable variation across industries, as evidenced by the standard deviations which are large in relation to the means. There was an even more striking contrast between the two halves of the period in the movements of output. Up to 1973, output grew rapidly, on average at 3.32 per cent per annum. Between 1973 and 1986, it fell at 1.17 per cent per annum (though growth resumed in the final sub-period, 1982–6). Labour input fell throughout the 32-year period and indeed in every sub-period, though much more rapidly after 1973; once again however there were large differences between industries. The growth rates of capital and of intermediate input also declined after 1973, but less sharply than that of labour. The result was that capital intensity (K/L) and intermediate input intensity (X/L), which both on average grew rapidly even before 1973, rose still more rapidly after that date.

Still considering cross-industry averages, we see from table 1.2 that the growth of inputs per unit of labour can account for much the greater part, some 79 per cent, of the growth of output per unit of labour up till 1973. For 1973–86, the contribution of total input to labour productivity growth exceeds 100 per cent, which simply reflects the fact that MFP growth is measured as negative over this period. Looking in more detail, it turns out that the major anomaly is the period 1973–82, and particularly 1973–6. For 1982–6, input growth explains 80 per cent of labour productivity growth. It turns out that even a generous allowance for accelerated scrapping of capital, much more generous than we have argued is reasonable, does not suffice to eliminate the puzzle of the 1973–82 period.

As was said above, the initial interest in MFP calculations arose because so little of output growth seemed to be due to input growth. So it is a little ironic that the UK seems to exhibit the opposite of this 'problem'. But it should be remembered that international comparisons

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