Measuring the Efficiency and Productivity of British Universities: An Application of DEA and the Malmquist Approach

A.T. FLEGG, D.O. ALLEN, K. FIELD & T.W. THURLOW[1]

ABSTRACT

This paper uses data envelopment analysis to examine the technical efficiency (TE) of 45 British universities in the period 1980/81 to 1992/93. This period was chosen primarily because it was characterized by major changes in public funding and in student : staff ratios. To shed light on the causes of variations in efficiency, TE is decomposed into pure technical efficiency (PTE), congestion efficiency (CE) and scale efficiency (SE). The analysis indicates that there was a substantial rise in the weighted geometric mean TE score during the study period, although this rise was most noticeable between 1987/88 and 1990/91. The rising TE scores are attributed largely to the gains in PTE and CE, with SE playing a minor role. The Malmquist approach is then used to distinguish between changes in technical efficiency and intertemporal shifts in the efficiency frontier. The results reveal that total factor productivity rose by 51.5% between 1980/81 and 1992/93, and that most of this increase was due to a substantial outward shift in the efficiency frontier during this period.

Introduction

In the early 1980s, over 80% of the recurrent income of universities in the UK was obtained from the Treasury (Johnes & Taylor, 1990, p. 38) and, as a result of this dependency on public funding, universities came under scrutiny. Although they are now substantially less dependent on public funds, the efficiency of British universities continues to be the subject of political and economic debate.

In 1984, the Committee of Vice-Chancellors and Principals responded to the government's wish for an efficiency study of universities by setting up the Jarratt Committee. This committee recommended wide-ranging changes in the management of universities and, *inter alia*, the introduction of appropriate performance indicators (Cave *et al.*, 1997, p. 4). Furthermore, a White Paper in 1987 proposed radical new arrangements for the distribution of public funds to universities (*ibid.*, p. 6). Instead of obtaining grants to cover their costs, universities would need to enter into contracts with the Universities Funding Council to provide specific academic outputs in return for the resources granted to them (*ibid.*). The government urged higher education to provide wider access to its services, and be more responsive to the needs of industry and commerce, less dependent on public funding and more cost-conscious in managing its resources (Johnes & Taylor, 1990, p. 12). With the aim of making universities more responsive to students' demand for higher education, and to encourage them to exploit any spare capacity, an increasing proportion of public funds would henceforth be provided in the form of fee income rather than as block grants (*ibid.*, pp. 42–47).

Given these calls for greater efficiency, it is of considerable interest to examine how well universities responded to the increased pressure put upon them. This study uses data envelopment analysis (DEA) to measure the relative efficiency of 45 universities in the UK over the period 1980/81 to 1992/93.[2] This approach makes it possible to measure the degree of variation in efficiency across the sector as a whole, and to identify possible sources of inefficiency. An important feature of the variant of DEA employed in this paper is its ability to identify ‘congestion’ inefficiency, which is inefficiency arising from negative marginal productivity of inputs.[3] More specifically, one of the hypotheses to be examined here is whether British universities' efficiency was impaired by the exceptionally rapid expansion in the number of students that began in the late 1980s.

The focus of most DEA studies of UK universities has been on the relative performance of individual departments in a given discipline.[4] A notable exception to this is the interesting study by Athanassopoulos and Shale (1997), who apply DEA at the institutional level. However, their study of 45 institutions pertains to a single academic year, 1992/93. By contrast, the primary aim here is to examine trends in efficiency over time, along with the underlying causal factors. The period 1980/81 to 1992/93 was chosen because it was characterized by major changes in public funding and in student : staff ratios. In addition, *University Statistics* has a consistent set of data for this period on the key variables required. A final point is that the exclusion of any new universities created after 1992 means that the sample employed here is relatively homogeneous.

The standard DEA approach has the disadvantage that it cannot distinguish between changes in relative efficiency brought about by movements towards or away from the efficiency frontier in a given year and shifts in this frontier over time. To capture these two sources of change in efficiency, Malmquist indices are computed.

In the next section, the theory underlying the measurement of technical efficiency is examined. This is followed by a discussion of the variables used. The DEA and Malmquist results are then presented and considered in detail. Finally, the findings are summarized and conclusions are drawn.

Measuring the Relative Efficiency of British Universities

One approach to the evaluation of universities' relative efficiency would be to use econometric techniques to fit a stochastic cost frontier to data for a cross-section of universities in a given year. This has been done by Izadi *et al.* (2002), who estimated a model of the form:

$$E_i = \alpha + (\delta_1 A_i^{\beta 1} + \delta_2 S_i^{\beta 2} + \delta_3 P_i^{\beta 3} + \delta_4 R_i^{\beta 4})^{\rho} + \varepsilon_i \qquad (1)$$

where E_i is the total expenditure of university i, A_i is its undergraduate student load in arts subjects, S_i is its undergraduate student load in the sciences, P_i is its postgraduate student load, and R_i is the value of research grants and contracts received. The error term, ε_i, has two statistically independent components, such that $\varepsilon_i = \eta_i + \omega_i$. The role of η_i is to capture measurement errors, random influences, etc., whereas ω_i is there to measure technical inefficiency. ω_i is constrained to be non-negative; a fully efficient university would have $\omega_i = 0$, whereas $\omega_i > 0$ would indicate inefficiency.

A big advantage of the above formulation is that it yields useful information concerning the returns to scale and scope in higher education; what is more, the information relating to returns to scale is provided separately for each explanatory variable. It is also possible to estimate the technical inefficiency of each university.[5] However, whilst the approach taken by Izadi *et al.* is attractive in many ways, it requires fairly complex computations that cannot be performed using standard software packages. In addition, it is not possible to decompose the estimates of ω_i so as to shed light on the possible causes of inefficiency. For these reasons, an alternative approach – data envelopment analysis (DEA) – is pursued here.[6]

DEA makes use of a linear programming algorithm to construct an ‘efficiency frontier’, with the most efficient organizations within a group being used to define the standard against which the performance of the other organizations is evaluated. The concept of efficiency is thus relative rather than absolute. According to Nunamaker (1985, p. 51), the principal strength of DEA “lies in its ability to combine multiple inputs and outputs into a single summary measure of efficiency without requiring specification of any *a priori* weights”. However, a disadvantage of DEA is that the distribution of efficiency scores is typically highly skewed, with an unknown theoretical distribution, which creates problems when attempting to test hypotheses concerning the relative efficiency of different groups or the changes in efficiency over time.[7]

DEA allows us to determine the technical efficiency (TE) of each university for each academic year in the sample period. TE is defined as the ratio of the weighted sum of outputs to the weighted sum of inputs, as in the following expression for university i:

$$TE_i = \frac{\sum_r u_{ri} Q_{ri}}{\sum_s v_{si} X_{si}} \qquad (2)$$

where Q_{ri} is the quantity of output r and X_{si} is the quantity of input s. With DEA, the weights u_{ri} and v_{si} are determined in such a way that the efficiency of each university is maximized, subject to the following constraints:

$$\frac{\sum_r u_{ri} Q_{rj}}{\sum_s v_{si} X_{sj}} \leq 1 \quad \text{for } j = 1, 2, \ldots, n \qquad (3)$$

$$u_{ri}, v_{si} \geq \varepsilon \quad \text{for all r and s} \qquad (4)$$

where ε is a small positive number (e.g. 10^{-6}). The first set of constraints dictates that no other university j should be able to obtain a TE score in excess of unity by adopting the same set of weights as university i, whereas the second set specifies that all weights must be positive.[8]

It is worth noting that DEA deems *any* deviation from the efficiency frontier to be the result of technical inefficiency. Hence measurement errors, as well as random influences on a university's output, are ignored. Whilst the deterministic nature of the DEA frontier is clearly a disadvantage, this shortcoming of DEA is – in the authors' opinion – outweighed by its ease of use and capacity to handle the multiple inputs and outputs employed in this study.

Output Variables

It seems reasonable to argue that a university's output should be defined primarily according to the services it provides in terms of teaching, research, consultancy and other educational services. These aspects of a university's activities are captured here via the following output variables:

- income from research and consultancy;
- the number of undergraduate degrees awarded, adjusted for quality;
- the number of postgraduate degrees awarded.

Research and Consultancy

Research is clearly an important aspect of output in its own right. It may also indirectly influence the quality of teaching output by affecting a university's physical resources and the focus of its staff.

Since universities sell their services to government and industry, the income received can be used to estimate the value of the output produced. However, the use of *research* income as a measure of output is problematic, since such income may be considered to be an input into the research process rather than an output (Johnes & Johnes, 1993, p. 338). Research income may also be distorted by differences in research costs across academic disciplines. On the other hand, research income is likely to reflect the perceived quality, as well as quantity, of research output and it should provide a more up-to-date picture of such output than, for example, publications or citations, for which there is bound to be a considerable time lag. Moreover, the necessary information is readily available. Indeed, in a study of this nature, one has little option but to use research income as a proxy for research output since data for most alternative variables are not available on an annual basis.[9] For instance, whilst research ratings might be a better measure than research income, such ratings appear too infrequently to be of use here. With regard to consultancy income, it should be noted that some disciplines offer more scope for lucrative consultancies than do others, so that a university's discipline mix may well affect this source of income.

Undergraduate Degrees

The number of undergraduate degrees awarded is clearly an important measure of the output of any university. However, an obvious shortcoming of this measure is that it fails to take any account of the *quality* of the degrees awarded.

One way of taking quality into account would be to use the graduate unemployment rate, standardized by subject and gender mix, as an index of the quality of degrees awarded. However, whilst this is an intrinsically attractive measure, Johnes *et al.* (1987) note some serious problems regarding the comparability of such rates. It is also a measure that is strongly biased in favour of Oxford, Cambridge and Durham (*ibid.*, pp. 701–702).

An alternative approach would be to multiply the number of degrees awarded by the proportion of students gaining ‘good’ degrees, defined in some way. This approach is an attractive one inasmuch as the quality of teaching should be reflected in students' achievements and hence in the class distribution of degrees awarded. Nonetheless, it must be recognized that students' achievements depend not only on the quality of teaching but also on the ability of the students and their initial qualifications. Another potential problem with the use of degree results is the possible variation, both across institutions and intertemporally, in the implicit standards set for particular classes of degree and also in the models of assessment used (e.g., the mix of coursework and examinations).

With degree results, there is a choice, at least in principle, between a fairly narrow definition of quality – the proportion of first-class honours degrees awarded to undergraduate students – and a broader definition comprising both firsts and upper seconds. However, the existence of undivided seconds at Oxford and several Scottish universities (Johnes *et al.*, 1987, p. 703) creates a problem in using a broader definition. A more serious obstacle is the fact that, while *University Statistics* has annual data on the number of first-class degrees awarded, it has no data on the number of upper seconds. For these reasons, the proportion of firsts will be used here to adjust for the quality of undergraduate degrees awarded. This means that the output variable becomes the *number* of firsts awarded. The sensitivity of the results to the use of this variable is considered later in the paper.

Postgraduate Degrees

For simplicity, and in order to avoid artificially boosting the efficiency scores, masters degrees and doctorates were aggregated into a single variable.[10] A disadvantage of this is, of course, that variations across universities in the ratio of masters degrees to doctorates are thereby ignored. This variable also fails to take account of possible differences in the quality of postgraduate degrees.

Input Variables

The following input variables are used in the DEA analysis:

- the number of staff;
- the number of undergraduate students;
- the number of postgraduate students;
- aggregate departmental expenditure.

Number of Staff. This variable includes both academic and academic-related staff. Part-time staff were given a weight of 0.5.

Number of Students. This refers to the full-time equivalent student load.

Aggregate Departmental Expenditure. This variable includes departmental expenditure on equipment, salaries and wages of non-academic staff, and so on. Expenditure on academic staff is not included. (See Appendix A for more detailed information concerning inputs.)

Trends in Labour Productivity

Before we consider the DEA results, it may be of interest to examine the trends in the three output variables over the period 1980/81 to 1992/93. Each variable has been expressed relative to the number of staff, to give an indication of labour productivity. The index of university costs (1985 = 100) was used to convert the income from research and consultancy into constant prices.

See Figure 1

A striking feature of Figure 1 is the fact that there is a clear upward trend in all three measures of labour productivity, although the pattern is somewhat different in each case. For higher degrees, there is a steady growth in productivity throughout the period under review, from 3438 higher degrees per 10,000 staff in 1980/81 to 5495 in 1992/93, an increase of 60%. The number of first-class degrees produced per 10,000 staff increases from 787 in 1980/81 to 1182 in 1992/93, a rise of 50%. Even so, there is a marked dip in the graph in 1986/87. From Appendix A, Table 6, we can see that the aggregate student : staff ratio reached a minimum in that year. With respect to real income from research and consultancy, there is a strong upward trend until 1986/87, but a more modest and uneven rise subsequently. Taking the period as a whole, real income per member of staff almost doubles, from £6134 in 1980/81 to £12,091 in 1992/93.

A note of caution is called for with regard to the rise in the output of first-class degrees per member of staff. For this to be deemed to be a genuine rise in productivity, we would need to assume that the strong upward trend in the proportion of firsts awarded was a consequence of more effective teaching and learning rather than a decline in the threshold standard required to gain a first or an improvement in the initial qualifications of students.[11]

Initial DEA Results

See Table 1 and Figure 2

Table 1 displays results that, in different ways, capture trends in the relative performance of the 45 universities. First let us consider the unweighted arithmetic mean TE scores, which are also plotted in Figure 2 (see the graph labelled UAM). Two distinct periods stand out. The first period, from 1980/81 to 1986/87, was characterized by fairly large fluctuations in the mean scores, with no obvious trend. By contrast, a strong upward trend is evident from 1986/87 onwards, although this was interrupted briefly, albeit sharply, in 1989/90.[12] These results indicate a reduction in the amount of *variation* in performance across the university sector. The impression of greater homogeneity is bolstered by the rising minimum scores shown in the last column of Table 1. We can see, for instance, that the least efficient university in 1986/87 was producing only 56.4% of its potential output, when measured relative to the observed 'best practice' for that year.[13] By 1992/93, the minimum TE score had increased to 0.742. Table 1 also shows that the standard deviation of the TE scores was much lower in 1992/93 than in 1986/87. It is evident that the gap in TE between the frontier and non-frontier universities was shrinking during this period.

The mean TE scores considered thus far take no account of differences in the number of students in each university. For instance, London had over 13% of the total number of UK university students in 1992/93, whereas Essex had only 1%. Therefore, in order to gain a more accurate picture of the performance of the sector as a whole, each university's TE score was weighted by its relative share of students, to obtain a weighted arithmetic mean (WAM). The results are presented in Table 1 and illustrated in Figure 2.

Figure 2 reveals that, in most cases, the weighting has no discernible impact, although this is clearly not the case in first four years.[14] These exceptions suggest that there may be some association between a university's size and its TE score. However, for each of the first four years, only a very weak positive correlation was found between universities' TE scores and their size, when measured in terms of students.[15] For the final two years, the correlations were negative but again close to zero. It is worth noting that the use of weighted scores has not fundamentally altered the earlier finding of a strong upward trend in mean TE from 1986/87 onwards, with a sharp dip in 1989/90.

See Figure 3

Let us now consider the impact of using the weighted geometric mean (WGM) as the measure of central tendency. This statistic is more appropriate than the weighted arithmetic mean (WAM) because it can be decomposed in a straightforward way into component indices. From Table 1 and Figure 3, we can see that the WGM is invariably lower than the WAM, but follows the same pattern. Towards the end of the period, the two measures get closer. This is to be expected, given the rise in the raw scores and the fact that both measures have a maximum value of unity.

Decomposition of Technical Efficiency

In order to shed some light on the possible causes of the intertemporal fluctuations and trends in TE identified earlier, it is useful to break down TE into three multiplicative components, such that:

$$\mathrm{TE} \equiv \mathrm{PTE} \times \mathrm{CE} \times \mathrm{SE} \qquad (5)$$

where PTE denotes 'pure' technical efficiency, CE denotes congestion efficiency and SE denotes scale efficiency. Each component of identity (5) is constrained to lie in the interval [0, 1]. The particular decomposition discussed here mirrors that of Byrnes *et al.* (1984) and Färe *et al.* (1985a), who built upon the pioneering work of Farrell (1957). Scale efficiency will be examined first.

See Figure 4

Figure 4 illustrates the situation facing a number of hypothetical universities. The diagram shows the inputs each university requires to produce one unit of output.[16] Universities I, E and F are operating under constant returns to scale and are fully efficient in other respects too (TE = 1).[17] They are assumed to be in long-run equilibrium. Now consider university G. Whilst this university is technically efficient *given* its scale, this scale is not optimal. In terms of identity (5), PTE = CE = 1 but SE < 1. It is presumed that, by adjusting its scale, university G could operate more efficiently and thereby reduce the inputs it needs to produce each unit of output. To become fully efficient, it would need to reduce its inputs to the levels currently achieved by university F. This adjustment could only be achieved in the long run (cf. Färe *et al.*, 1985a, p. 95). The performance of university G in terms of scale efficiency can be measured by the ratio SE = OF/OG, which is below the optimum of SE = 1. Universities E and H can be compared in the same way.

'Congestion' occurs when a productive input is overused to such an extent that its marginal product becomes negative.[18] This gives rise to an isoquant that, beyond a point, slopes upwards from left to right. The segment HM′ of isoquant M′M in Figure 4 illustrates congestion.[19] Essentially what has occurred here is that the number of students has increased to the point where the enrolment of an additional student, with the number of staff held constant, would *reduce* the output of a university such as K, i.e. the marginal productivity of students has become negative! Conversely, a decrease in the number of students, with the number of staff held constant, would raise output. Clearly, university K is suffering from serious congestion. It could move from point K to point J, reducing both inputs proportionally, without experiencing a fall in output. Following Färe *et al.* (1985a, pp. 94–95), we measure congestion in terms of the distance between a point on the existing (upward-sloping) isoquant to a point on the nearest congestion-free (vertical) isoquant. Hence the congestion efficiency of university K can be measured by the ratio CE = OJ/OK, which falls short of the optimum of CE = 1.

University L in Figure 4 is in the unfortunate situation of experiencing all three types of inefficiency.

Its scale efficiency ratio of SE = OI/OJ is below unity, as is its congestion efficiency ratio of CE = OJ/OK. It also suffers from 'pure' technical inefficiency as it is operating to the right of isoquant M′M; its score here is given by the ratio PTE = OK/OL, which again is below one. Finally, its technical efficiency, as defined by the ratio TE = OI/OL, is well below unity. Identity (5) can now easily be verified by substituting in the relevant ratios for university L.

Since $TE \equiv PTE \times CE \times SE$, its intertemporal variation can be explained by considering the behaviour of its three component ratios. These ratios were computed for each university for each year in the period 1980/81 to 1992/93, by solving a series of linear programming problems (see Appendix B). The weighted geometric means of TE, PTE, CE and SE are displayed in Table 2 and graphed in Figure 5.[20] These are denoted hereafter as WGM_{te}, WGM_{pte}, WGM_{ce} and WGM_{se}.

See Table 2 and Figure 5

For the period as a whole, WGM_{te} rose from 0.859 to 0.916. However, even though all its components increased, they did so by differing amounts: WGM_{pte} from 0.954 to 0.984, WGM_{ce} from 0.942 to 0.967 and WGM_{se} from 0.955 to 0.963. It is evident, therefore, that the rise in TE was largely due to the gains in PTE and CE, with SE playing a minor role. The rising PTE and CE scores show that, by cutting down on any unnecessary inputs, universities were getting closer to a congestion-free isoquant. This process corresponds to a movement from, say, point L towards point J in Figure 4.

Table 2 also gives information concerning returns to scale. The results suggest that, in 1992/93, 21 universities were too large, 9 were too small and 15 were of optimal size.[21] By contrast, in 1980/81, there were roughly equal numbers of universities in the three categories. However, we need to bear in mind that the departures from constant returns were modest in most cases; the fact that WGM_{se} is so high in both years provides little scope for dispersion in returns to scale.

Figure 5 sheds some new light on the behaviour of the TE scores. During the subperiod 1980/81 to 1983/84, WGM_{te} first rose and then fell. Here the shape of the TE graph is largely determined by the changes in SE. In contrast, between 1983/84 and 1986/87, WGM_{te} was relatively stable. However, this stability masks some substantial, and largely offsetting, changes in CE and SE.

A strong upward trend in WGM_{te} began in 1986/87, although this was interrupted briefly, albeit sharply, in 1989/90. This interruption was almost entirely due to a temporary decline in WGM_{ce}. Figure 5 shows a large rise in WGM_{te} in 1990/91 because the rebound in WGM_{ce} was reinforced by a rise in both WGM_{pte} and WGM_{se}. If we ignore these aberrations, we can see that the impressive rise in

WGM_{te} between 1986/87 and 1990/91 was the result of an improvement in all three types of efficiency, although the rise in WGM_{pte} was much smaller than that in WGM_{ce} and WGM_{se}. This can be explained by the fact that WGM_{pte} was much higher to start with.

The behaviour of congestion efficiency is interesting. WGM_{ce} rose strongly between 1984/85 and 1988/89, yet this period was followed by a succession of ups and downs about a slight upward trend. It would seem that, during the first period, universities were able to reduce congestion because there was only a moderate growth in student numbers and no rise in the student : staff ratio (see Appendix A, Table 6). By contrast, the second period was characterized by a sharply rising ratio, which made it very difficult to achieve any further gains in CE. Indeed, it is remarkable that WGM_{ce} is slightly higher in 1992/93 than in 1988/89. As for the ups and downs in this statistic, these may be due to lags in universities' adjustments to rising student : staff ratios.

Nevertheless, it might be objected that any rise in the student : staff ratio could be accommodated by a sufficient improvement in the frontier technology and thus not lead to greater congestion. However, whilst this argument may be true in the long run, it is less compelling in the short run, especially in situations where the rise in the ratio is both rapid and unforeseen.

A Malmquist Analysis

From the analysis thus far, it is evident that British universities became more similar in terms of their TE scores during the period under review. This convergence in performance is important in the sense that the sector as a whole cannot attain its maximum potential output if relative inefficiency continues to exist. However, a rise in the mean TE score from one year to the next does not necessarily indicate improved performance, as it may merely reflect an inward shift of the efficiency frontier. Malmquist indices, as explained below, provide a useful way of distinguishing between changes in technical efficiency and shifts in the efficiency frontier over time.[22]

Malmquist Total Factor Productivity (TFP) Indices

A TFP index measures the change in total output relative to the change in the usage of all inputs. The change in a TFP index can be decomposed into two components:

- the change in technical efficiency (universities getting closer to or further away from the efficiency frontier).
- the change in technology (shifts in the efficiency frontier).

A *Malmquist TFP index* is defined using distance functions. It is the geometric mean of two TFP indices, one evaluated with respect to the technology (efficiency frontier) in the current period *t* and the other with respect to the technology in the base period *s* (see Coelli *et al.*, 1998, pp. 222–226). With a Malmquist TFP index, the change in TE for university i is measured by the ratio $TE_{i,t}/TE_{i,s}$.

See Table 3

Now consider the findings displayed in Table 3. The third column shows the results of using geometric means to aggregate the ratios $TE_{i,t}/TE_{i,s}$ for the 45 universities. The numbers in the subsequent three columns were computed in like fashion. The results indicate, for example, that TE improved by 0.9% between 1981/82 and 1982/83. This was the net outcome of a simultaneous rise of 1.3% in PTE and fall of 0.4% in CE, with no change in SE. Rounding apart, the numbers in the third column are the product of those in the next three columns.

The DEAP program (see Coelli *et al.*, 1998, pp. 226–232) was used to generate the first two columns of Table 3. Again, rounding apart, the figures in the first column are the product of those in the next two columns. The results indicate, for example, that TFP improved by 4.7% between 1982/83 and 1983/84. This was the net outcome of a simultaneous improvement of 6.3% in technology (an outward shift in the efficiency frontier) but deterioration of 1.5% in TE (universities moving away from the frontier).

However, whilst Table 3 is useful in highlighting annual changes, it is not easy to see the cumulative effects of changes in efficiency. The chained indices presented in Table 4 provide a way of quantifying these cumulative effects.[23]

See Table 4

Table 4 reveals that there was a large rise of 51.5% in TFP between 1980/81 and 1992/93. What is interesting about this rise in productivity is that it was brought about predominantly by an outward shift in the efficiency frontier rather than by enhanced technical efficiency: the results show that frontier technology improved by 39.1% whereas TE rose by only 8.8%. It is worth noting that this modest rise in TE was largely due to the gains in PTE (4.1%) and CE (2.9%). By contrast, the rise in SE over the twelve-year period was a mere 1.5%.

See Figure 6

The trends in TFP, frontier technology and technical efficiency are illustrated in Figure 6 by the graphs labelled TFP, TECH and TE. What is most striking about this figure is the way in which the growth in TFP tracks that in frontier technology up to 1987/88, but diverges sharply thereafter as a result of the flattening out of the TECH graph. For the next two years, TFP mimics the rise and fall of TE. There is a curious ‘bowl’ shape to the TECH graph in the final three years, which indicates that the efficiency frontier shifted inwards and then outwards again. It is interesting to see how the rise in TE between 1989/90 and 1990/91 more than compensated for the inward shift of the efficiency frontier, thereby causing TFP to rise. Also, notwithstanding a large outward shift in the efficiency frontier between 1991/92 and 1992/93, universities' technical efficiency did not suffer and, in fact, slightly improved. This strong performance led to a very large rise in TFP.

In view of the importance of technical efficiency in explaining the shape of the TFP graph from 1987/88 onwards, it may be worthwhile to look briefly at the factors underlying the TE graph. From Table 3 we can see that SE was the driving force behind the rise in TE between 1987/88 and 1988/89, whereas CE was the main factor behind its fall the following year. The large rise in TE between 1989/90 and 1990/91 was the outcome of substantial gains in both PTE and CE. Finally, the slight upward tilt of the TE graph in the last two years hides the fact that this period was characterized by largely offsetting movements in all three components of the TE index.

The financial and other aspects of the environment facing universities changed considerably during the thirteen academic years under examination here. The possible consequences of this changing environment will now be considered.

The Changing Environment

The severe financial pressures which British universities experienced during the 1970s were reinforced by the change of government in May 1979. Notwithstanding a warning by the University Grants Committee that any cuts in Treasury funding in excess of 2.5% in real terms would seriously impair efficiency, real funding was, in fact, cut by 8.7% between 1980/81 and 1984/85 (Johnes & Taylor, 1990, pp. 33–35). What is more, the cuts were applied highly selectively (*ibid.*). To see whether these cuts had a significant impact on universities' technical efficiency, the change in each university's TE score between 1980/81 and 1984/85 was correlated with the percentage change in real Treasury funding. This produced a correlation coefficient of –0.303, which is significant at the 5% level (using a two-tailed test).[24] This result suggests, somewhat surprisingly, that those universities suffering the greatest cuts improved their relative performance the most. However, on closer analysis, this result was found to be spurious – a consequence of the inclusion of Salford in the calculations.[25] When Salford was excluded, a positive, but non-significant, correlation of 0.146 was obtained. The weakness of this correlation may be due to the fact that many universities were able to offset the cuts in Treasury funding with increased income from elsewhere, e.g. from overseas students (cf. Johnes & Taylor, 1990, p. 35). Another possibility is that those universities worst affected by the cuts made the most effort to enhance efficiency.[26]

Table 4 shows that the TE index rose by only 1.3% between 1980/81 and 1984/85. The modest size of this gain can also be confirmed by examining the TE graph in Figure 6. This evidence suggests, therefore, that the cuts had little impact on universities' technical efficiency. Furthermore, Figure 6 reveals that TFP was not affected in any obvious way. The TFP graph is, in fact, virtually a straight line over this period.

The financial pressure on universities continued unabated throughout the 1980s. One measure of this pressure is the proportion of recurrent income received from the Treasury; this fell fairly steadily from 83.0% in 1982/83 to 71.1% in 1988/89, before dropping sharply to 61.4% in 1989/90. The Treasury's share then declined gradually for three years, reaching 59.3% in 1992/93.[27] The abrupt cut in Treasury funding in 1989/90 provides a possible explanation of the sharp fall in the TE index in that year, which brought the prolonged rising trend in the TFP index to a sudden end.

Whilst the cuts in Treasury funding were regrettable in one sense, they did give universities greater financial independence and hence flexibility. Furthermore, a switch in the balance of public funding from block grants towards fee income was announced in April 1989. As a consequence, the proportion of recurrent income received from home students' fees increased sharply from 1990/91 onwards.[28] The aim of this policy was to give universities an incentive to admit more students. Also worth noting is the introduction in 1991/92 of competitive tendering for students (see Johnes & Taylor, 1990, pp. 42–47).

The switch to a more decentralized funding regime, along with improvements in the management of universities following the Jarratt Committee's report (1985), can probably explain the rise in the technical efficiency of universities from 1987/88 onwards, as illustrated in Figure 6. However, how can we explain the curious ‘spoon’ shape of the TECH graph from 1987/88 onwards? The answer probably lies in the rapid and highly unbalanced expansion of universities, which caused a sharp rise in the student : staff ratio from 1988/89 onwards. When combined with inadequate funding, it is hardly surprising that this overexpansion in the number of students should cause the potential output of universities to stall and then drop sharply. By 1992/93, however, universities appear to have adjusted to their new and harsher environment.[29]

Sensitivity Analysis

As an extremal method, DEA is known to be highly sensitive to erroneous data and unusual observations (Sexton *et al.*, 1986, pp. 73–87; Wilson, 1995). The efficiency scores also tend to be affected by changes in the set of variables used in the analysis. Here we shall investigate the impact of replacing the number of first-class degrees with a broader output variable, the number of firsts and upper seconds. Comparative data were available only for the first eight years of the study period,[30] and the existence of undivided seconds at Oxford, Edinburgh and Glasgow meant that these universities could not be included in the analysis. In addition, Cambridge was excluded because of an upward bias in its recorded numbers of firsts and upper seconds.[31]

Although leaving out these four universities is unfortunate in one sense, it does afford an opportunity to assess the impact of altering the composition of the sample. Cambridge is a manifestly atypical university in terms of its output of first-class degrees and it is, therefore, invariably on the efficiency frontier. Whilst Oxford is less of an extreme case than Cambridge, it nonetheless has a TE score of unity in twelve years out of thirteen. By contrast, Edinburgh is fully efficient in seven years out of thirteen and Glasgow achieves this distinction only in the last two years. (The frontier universities are identified in Appendix C, Table 7.)

See Table 5

The effects of excluding the four universities mentioned above plus Ulster are shown in Table 5. Ulster was excluded because it is atypical in certain respects.[32] One can see that the mean scores are invariably higher than before, which is in line with expectations. However, the differences between the two sets of scores are much larger in the period up to 1987/88 than they are in the subsequent five years. A possible explanation of this phenomenon is the fact that, by 1988/89, the differences between Cambridge and most other universities had diminished substantially in terms of the recorded number of first-class degrees awarded per member of staff.[33]

Table 5 also shows that the use of a broader output variable, the number of firsts and upper seconds, yields much higher mean TE scores. This is in line with expectations: most universities should be able to achieve an enhanced TE score when judged in terms of this less stringent criterion. There is also much less variation across universities in the number of firsts plus upper seconds than there is in the number of firsts. This greater degree of similarity should likewise contribute towards higher mean scores.

It is worth noting too that, when we use the number of firsts as the output variable, there is no evidence of an improvement in TE between 1980/81 and 1987/88. This is true for both N = 45 and N = 40. By contrast, not only does the use of a broader output variable raise the mean TE scores, but it also results in a marked rise in these scores over time. A plausible explanation of these better scores is that universities were becoming more similar in terms of their propensity to award a first or upper second. However, while both the number, v, and the proportion, π, of students awarded a first or upper second rose steadily between 1980/81 and 1987/88, the coefficients of variation of v and π remained remarkably stable over this period. Hence some other factor must lie behind the upward trend in the mean scores shown in the last column of Table 5.

See Figure 7

Figure 7 illustrates the consequences of excluding the five universities. One can see that, in terms of their general shape, the three graphs are remarkably similar to those in Figure 6. In fact, the only real difference is in the shape of the TECH graph between 1987/88 and 1989/90. This difference can readily be explained, however, in terms of the change in the composition of the set of efficient universities: when Cambridge is dropped from the sample, a pronounced peak occurs in the output of first-class degrees in 1988/89, which is clearly visible in Figure 7 in the form of a 'hump' in the TECH graph.[34] Apart from this minor aberration, it seems fair to conclude that the results are not very sensitive to changes in the composition of the sample. What is more, the TFP graphs end up at almost exactly the same spot in 1992/93, reflecting a growth over the study period of 51.5% in the full sample and 49.9% in the subsample.

The DEA software used in this study has an output orientation and it is well known that the orientation employed affects the results in terms of returns to scale (Seiford & Zhu, 1999, pp. 3–4; Färe & Grosskopf, 1994). As the final part of this sensitivity analysis, the DEAP program was used to re-examine the question of returns to scale. DEAP generated exactly the same TE scores as our own program but slightly different SE scores. Using an output-orientated approach, DEAP calculated a rise of 1.6% in scale efficiency between 1980/81 and 1992/93. This is very close to the 1.5% indicated in Table 4. However, when an input-orientated approach was employed, DEAP calculated a somewhat larger rise of 2.8% in scale efficiency. Thus the orientation adopted does make some difference to the results.

Conclusion

This study has used data envelopment analysis (DEA) and Malmquist indices to assess the performance of 45 British universities over the period 1980/81 to 1992/93. Unlike most earlier studies of the efficiency of universities, the focus here has been on measuring changes in performance over time rather than on assessing relative efficiency in a single academic year. As a first step, a technical efficiency (TE) score was computed for each university for each academic year. These scores were then aggregated by calculating the weighted geometric mean. The WGM_{te} rose from 0.859 in 1980/81 to 0.916 in 1992/93.

The Malmquist analysis revealed a rise of 51.5% in total factor productivity (TFP) over the study period. What is interesting about this growth in TFP is that it was brought about predominantly by a marked outward shift in the efficiency frontier rather than by enhanced technical efficiency (TE): whereas frontier technology improved by 39.1%, TE rose by only 8.8%. Whilst this rise in TE may seem unimpressive, one needs to remember that the DEA efficiency scores were, in most cases, very high at the outset. As regards the causes of this rise in TE, the results indicated a 4.1% rise in pure technical efficiency, a 2.9% rise in congestion efficiency and a 1.5% rise in scale efficiency.

Given the rapid rise in the average size of British universities from 1988/89 onwards, it is not surprising to find that only nine universities were still subject to increasing returns to scale in 1992/93, whereas twenty-one were experiencing decreasing returns. However, these deviations from constant returns were not typically very large. Indeed, scale efficiency remained high throughout the period 1980/81 to 1992/93 and in no year was a significant correlation found between universities' TE scores and their size, as proxied by the number of students.

Other authors have likewise failed to detect any pronounced scale effects. For instance, using DEA and data for 1992/93, Athanassopoulos and Shale (1997) found that the imposition of constant returns caused only a slight fall in the mean efficiency scores.[35] Similarly, the results obtained by Izadi *et al.* (2002), using data for 1994/95 and the stochastic cost model discussed earlier, provide no grounds for rejecting the hypothesis of constant returns.[36] This conclusion is not, however, supported by the findings of Glass *et al.* (1995a,b), who found evidence of increasing returns.[37] It is also worth noting that, when the results of cost studies are disaggregated, strongly increasing returns emerge for postgraduate tuition, but the findings are more mixed with regard to undergraduate tuition and research.[38]

During the 1980s, British universities were under severe financial and political pressure to raise efficiency. In view of the 51.5% rise in TFP, it is evident that an impressive rise in productivity did indeed occur. What is more, the DEA results show a large improvement in TE as well, particularly from 1987/88 onwards. It is clear that the typical university was getting closer to the 'best practice' exemplified by the frontier universities. This is important in the sense that the sector as a whole cannot attain its full potential if technical inefficiency continues to exist.[39] Whilst the financial and managerial reforms introduced in the 1980s were probably not the sole cause of the enhanced efficiency of British universities, it does seem likely that they were the driving force. Even so, one might argue that the cuts in Treasury funding could have been introduced in a less disruptive way, especially in the early 1980s. This factor probably delayed the improvement in TE.

An unusual facet of the present study is its examination of the role of congestion efficiency (CE) and some comments on this are warranted. WGM_{ce} rose steadily between 1984/85 and 1988/89, but fluctuated markedly thereafter. It would seem that, during this first period, universities were able to reduce congestion because there was only a moderate growth in student numbers and no rise in the student : staff ratio. By contrast, the second period was characterized by a sharply rising student : staff ratio, which made it very difficult to achieve any further gains in CE. Indeed, it is remarkable that the rapid expansion in the number of students from 1988/89 onwards did not cause a pronounced *fall* in CE. Taking the study period as a whole, $WGM_{\mathbf{ce}}$ rose from 0.942 to 0.967.

Notwithstanding the fluctuations in WGM_{ce}, the number of universities exhibiting congestion remained high throughout the study period; this number fluctuated in the range 19 to 26. What this finding suggests is that a large proportion of universities were experiencing negative marginal productivity in terms of one or more of their inputs. In other words, they could have produced a larger output by reducing the quantity used of any congested input. An excessive number of undergraduate students is the most likely cause of this congestion.

Still, one should be cautious when considering these findings. For instance, Coelli *et al.* (1998, p. 175) warn that "... unless one has a strong reason for suspecting congestion one should not go looking for it because one will often find it whether or not it actually exists". This is because the so-called congestion may merely reflect the paucity of data in the extremities of the isoquants. However, given the relatively large sample used in this study, along with the strong *a priori* grounds for suspecting congestion, there is no good reason to believe that the findings obtained here are spurious.

Another caveat concerns the procedure used to identify and measure congestion. In common with most earlier studies of congestion, this one has followed the procedure developed by Färe, Grosskopf and Lovell (FGL) and their associates. This approach has been criticized by Cooper *et al.* (2001a), who use hypothetical examples to demonstrate that the FGL approach can (i) find congestion where it does not exist and (ii) fail to find congestion where it does exist. Cooper *et al.* (CGL) also criticize the axiomatic approach taken by Färe *et al.* and their disregard of slacks. However, CGL's first example of apparent failure of the FGL approach probably reflects the peculiarities of the particular data set employed rather than an absence of congestion.[40] Their second example refers to a rather unusual situation in which both factors of production have negative marginal products. Here CGL claim that FGL would wrongly attribute the technical inefficiency to PTE rather than to CE.[41]

Although it is possible to raise valid objections to the FGL approach, it seems unlikely that these would invalidate the findings of this study. For instance, it is improbable that one would encounter cases where universities were suffering from negative marginal productivity with respect to more than one input. What is more relevant is whether the two approaches would differ substantially in terms of the calculated amount of congestion. Here we should note the observation by Färe and Grosskopf (2000, pp. 32–33) that their approach would generally measure a smaller amount of congestion.[42]

In addition to a re-examination of congestion using the CGL approach, there are several ways in which this study could be refined and extended. For instance, since the most able students tend to obtain places at the more prestigious universities, an output variable such as the number of first-class degrees automatically gives certain universities an undue advantage. This problem might be addressed in future research by including a variable reflecting students' ability on intake, so that we could measure the ‘value added’ by each university. The most obvious measure here is ‘A’ level scores or their equivalent, although their use as a measure of the quality of a university's student intake has attracted criticism.[43]

The use of earnings from research and consultancy as a measure of output can also be criticized and it would be interesting to see, as a sensitivity analysis, what difference it would make if we were to measure research output using scores from the research assessment exercises of 1989 and 1992.[44] Another potentially fruitful area for investigation is the impact of time lags in the response of outputs to inputs. These lags are likely to be especially important where there has been a large and sudden change in the intake of undergraduate students.

The last year examined here, 1992/93, coincided with the creation of a large number of new universities from the former polytechnics and colleges. Therefore, by extending the sample period, it might be possible to see what effect competition from these newer universities has had on the efficiency of the older ones. It would also be interesting to test whether significant differences exist between the efficiency of new and traditional universities.

Notes

1. School of Economics, University of the West of England, Bristol. We would particularly like to thank Peter Taylor and Chris Webber for some very helpful suggestions. We have also benefited from discussions with Richard O'Doherty and John Sloman. Correspondence address: Mr Tony Flegg, School of Economics, University of the West of England, Coldharbour Lane, Bristol BS16 1QY. e-mail: tony.flegg@uwe.ac.uk. Telephone: 0117 328 2261. Facsimile: 0117 328 2295. A shorter version of this paper is forthcoming in *Education Economics*.

2. Our study was inspired by the work of Al-Naji (1995).

3. See Byrnes *et al.* (1984), Färe *et al.* (1985a) and Field (1990) for earlier applications of this approach.

4. See, for example, Tomkins & Green (1988), Beasley (1990), Johnes & Johnes (1993), Johnes (1995) and Beasley (1995).

5. Izadi *et al.* use UK data for 1994/95 to derive estimates of technical inefficiency for 99 separate institutions. To achieve this, they employ a method proposed by Jondrow *et al.* (1982) to separate out the two components of the error term in model (1).

6. Silkman (1986) and Boussofiane *et al.* (1991) provide excellent non-technical introductions to DEA. A comprehensive and up-to-date introduction to DEA and its applications is given in Cooper *et al.* (2000a). See also Coelli *et al.* (1998, chapters 6 & 7).

7. There are several possible ways of dealing with these problems; see, for example, Atkinson & Wilson (1995), Cooper *et al.* (2000a, pp. 200–205) and Färe *et al.* (1985a).

8. It is worth mentioning that, for computational purposes, the problem would need to be set out in a different way; see, for example, Boussofiane *et al.* (1991, pp. 1–2). However, such computational details need not detain us here.

9. For a detailed discussion of possible ways of measuring research performance, see Johnes and Taylor (1990, chapter 9).

10. With DEA, efficiency scores tend to rise (and can never fall) as the number of inputs or outputs increases (Nunamaker, 1985; Sexton *et al.*, 1986, pp. 82–87). Having too many variables reduces the discriminatory power of the technique. This point is well illustrated by the study by Athanassopoulos and Shale (1997), who use nine variables and get a mean efficiency score of 0.9716.

11. 9.3% of undergraduates in UK universities gained first-class degrees in 1992/93, compared with 7.5% in 1986/87 and 6.1% in 1980/81.

12. A conventional test for difference in means indicates that there is no significant difference between the mean TE scores in 1980/81 and 1986/87 ($z = 0.11$), yet a highly significant difference emerges when 1986/87 is compared with 1992/93 ($z = 2.80$). Although an appeal to the central limit theorem is not unreasonable in this case, given N = 45, the 'bootstrapping' method might have been used instead of a conventional test (Atkinson & Wilson, 1995). However, it seems unlikely that the two procedures would have generated noticeably different outcomes.

13. It is worth noting that the observed 'best practice' captured in a DEA frontier differs from the concept of efficiency embodied in an isoquant, *viz* the *minimum* requirements for producing a given level of output. However, in a large sample, the DEA frontier is likely to be a close approximation to an isoquant (see Banker, 1993, on this point).

14. A slight distortion is introduced in 1984/85 as a result of the merger between Ulster University and Ulster Polytechnic, which had the effect of raising Ulster's weight from 0.0077 to 0.0297.

15. The correlation coefficients were 0.072, 0.117, 0.091 and 0.079. Even the largest of these is significant only at $p = 0.445$.

16. A similar diagram is employed by Färe *et al.* (1985a, p. 95), although it is worth noting that the efficiency of their frontier firm B can be called into question, given the existence of non-zero slack in one of the inputs.

17. Under constant returns to scale, a rise (fall) of x% in both inputs would raise (reduce) output by exactly x%. Universities operating under constant returns are necessarily fully efficient.

18. More formally, the productive technology is free from ‘congestion’ if an increase in any input, with all other inputs held constant, does not reduce output. In this situation, the inputs are said to be strongly (or freely) disposable. Cf. Byrnes *et al.*, 1984, p. 672.

19. The gradient along any segment of an isoquant can be derived from the equation $dQ = (\partial Q/\partial X_1)dX_1 + (\partial Q/\partial X_2)dX_2 = 0$, where the partial derivatives represent marginal products. The gradient, dX_2/dX_1, can thus be expressed as $-MP_1/MP_2$. Along segment HM′ of isoquant M′M, $MP_1 > 0$ and $MP_2 < 0$, so that $dX_2/dX_1 > 0$. Here a rise in the number of students would have to be accompanied by a rise in the number of staff, otherwise output would fall. In contrast, along the broken vertical section HM″, a rise in the number of students, with the number of staff held constant, would not reduce output. This is because there is no congestion and MP_2 is zero rather than negative. Of course, congestion may apply to both students and staff. However, this possibility need not be pursued here; for an exhaustive discussion of possible cases, see Färe *et al.* (1994a).

20. Notice that, rounding apart, the TE column in Table 2 is the product of the next three columns. This is a property of geometric means.

21. Note that the number of fully efficient universities is identical to the number experiencing constant returns to scale. The irs group in 1992/93 comprised Bath (0.9959), Bristol (0.9935), Brunel (0.9861), Essex (0.9399), Keele (0.8846), Kent (0.9903), UMIST (1.0000), Surrey (0.9975) and Dundee (0.9509). (Rounded SE scores are given in brackets.) The method of distinguishing between increasing and decreasing returns to scale is explained in Appendix B. See also Byrnes *et al.* (1984, pp. 673–675).

22. Examples of this approach include Färe *et al.* (1992, 1994b) and Burgess & Wilson (1995).

23. The numbers in the first two columns of Table 4 are not, in fact, correct to three decimal places as they had to be calculated using the rounded data in Table 3.

24. The figures for the percentage change in Treasury funding were obtained from Johnes and Taylor (1990, Table 3.1). N = 43 because Wales and Ulster had to be left out.

25. Salford suffered a cut in real Treasury funding of 36.4%, yet its TE score rose from 0.488 in 1980/81 to unity in 1984/85. This university is clearly an outlier.

26. It must also be recognized that Treasury funding is likely to be positively correlated with aggregate departmental expenditure, which is one of the inputs in the DEA model. This would tend to weaken any correlation between TE scores and changes in funding.

27. Sources: *University Statistics*, vol. 3, Table 1 and its various disaggregations; Johnes & Taylor (1990, Table 3.2).

28. In 1989/90, home students' fees constituted only 6.4% of universities' recurrent income. However, this proportion increased to 12.9% in 1990/91 and to 17.0% in 1991/92. Source: *University Statistics*, vol. 3, Table 1 and its various disaggregations.

29. In an effort to shed some light on the curious shape of the TECH graph, the maximum values of the twelve productivity ratios (output 1/input 1, output 1/input 2, etc.) were plotted over time. This analysis revealed a high degree of volatility over the period 1987/88 to 1992/93. Furthermore, the ratios frequently moved in opposite directions and no coherent pattern was evident. The analysis suggested, for instance, that the decline in the TECH graph between 1989/90 and 1990/91 was due to a sharp drop in the output of postgraduate awards, which was reinforced by lower earnings from research and consultancy but partially offset by a higher output of first-class degrees. By contrast, the flatness of the graph between 1987/88 and 1989/90 was the result of offsetting movements in the three output variables. It is also worth noting that, by the end of this turbulent five-year period, the most productive university was producing 24.6% more postgraduate awards per member of staff, 13.5% higher earnings from research and consultancy but 7.7% fewer first-class degrees.

30. Johnes and Taylor (1990, Table 7.1) give figures for the proportion of graduates awarded a first or an upper second. These proportions were then multiplied by the number of first degrees awarded.

31. See *University Statistics*, vol. 3, 1993/94, p. 93.

32. This university merged with Ulster Polytechnic in October 1984 and, as a result, it became the fifth largest university (out of 41) instead of the smallest. Ulster's TE score fell from 0.549 in 1983/84 to 0.468 in 1984/85 and this decline was accentuated by its increased weighting. Ulster was responsible for a large fall in the weighted mean TE score in 1984/85, although its presence was less marked in subsequent years.

33. The recorded number of first-class degrees per member of staff in Cambridge fell from 0.367 in 1980/81 to 0.263 in 1992/93. By contrast, the output of firsts in the most productive university in the subsample of N = 40 rose from 0.111 to 0.177. The smallest gap in productivity was in 1988/89.

34. The output of first-class degrees per member of staff in Cambridge rose from 0.285 to 0.290 (+1.8%) between 1987/88 and 1988/89 and then fell by 8.6% to 0.265 in 1989/90. By contrast, the output in the most productive university in the subsample rose from 0.143 to 0.225 (+57.3%) between 1987/88 and 1988/89 but then fell by 20% to 0.180 in 1989/90.

35. See the mean ‘outcome efficiency’ scores in Athanassopoulos and Shale (1997, Table 4).

36. See the figures for ‘ray returns to scale’ given in Izadi *et al.* (2002, Table 2). These results are based upon a sample comprising both new and traditional universities (N = 99).

37. It is worth noting that Glass *et al.* did not use a frontier approach in fitting their cost function.

38. See, for example, Izadi *et al.* (2002, Table 2), Johnes (1997, Table 2) and Glass *et al.* (1995a,b).

39. It is worth emphasizing that DEA measures efficiency relative to ‘best practice’ rather than ‘average practice’. It sets a tough standard and it would be naïve to believe that a unitary value of WGM_{te} could ever be achieved. For instance, some of the universities with high TE scores have special positions in the market (e.g. Cambridge and Oxford), enabling them to attract high-quality inputs (staff, students and other resources) and thus produce high-quality outputs. Other universities (e.g. Edinburgh and Bristol) enjoy attractive locations.

40. Cooper *et al.* (2001a) use a numerical example taken from Färe *et al.* (1985b, p. 76) to criticize the FGL approach. Seven DMUs are involved, all of which produce $y = 2$, using two inputs, x_1 and x_2. Using the FGL approach, DMUs 6 and 7 are found to suffer from congestion, yet Cooper *et al.* contend (p. 67) that there is no evidence of congestion because output has remained constant. However, if we were to recast this example slightly by raising the output of DMU_6 from 2 to 2.25 and relabelling the axes as x_2/y and x_1/y, it is easy to see that congestion (in accordance with their Definition 1, p. 62) would exist.

41. Cooper *et al.* (2001a, Fig. 2) construct an example in which a DMU G is clearly suffering from negative marginal productivity in both of its inputs. They claim that G is suffering from congestion. However, one must question the economic realism of this example. It would not, for instance, be consistent with the law of variable proportions. Under the FGL approach, such examples would be ruled out by the axiom of weak disposability.

42. The reason for this difference is that, unlike CGL, FGL "do not include a measure of the slack that exists when [their] measure signals congestion" (Färe & Grosskopf, 2000, p. 32). In fact, FGL treat slacks as akin to allocative inefficiency, whereas CGL regard slacks as a form of technical inefficiency. For a detailed comparison and contrast of the two approaches, see Brockett *et al.* (1998), Cherchye *et al.* (2001), Cooper *et al.* (2000b, 2001a,b) and Färe & Grosskopf (2000). It is worth noting that not all cases of upward-sloping isoquants would be treated as congestion under the FGL approach (see Färe & Grosskopf, 2000, p. 28, for examples).

43. Athanassopoulos and Shale (1997) use A-level entry scores averaged over the previous three years as a separate input variable in their DEA study. However, it might be more appropriate to construct a single input variable measuring both quality and quantity of undergraduates.

44. Athanassopoulos and Shale (1997) use weighted scores from the 1992 RAE as an output variable and research income as an input variable. See also Glass *et al.* (1995a,b) and Johnes & Taylor (1990, chapter 9).

Appendix A: Definitions of variables, sources of data and explanatory notes

Number of students. This refers to the 'full-time equivalent student load' of undergraduates and postgraduates. The latter include both research students and those on taught courses. The London and Manchester business schools (which have no undergraduates) were excluded from the analysis.

Number of staff. This comprises both academic and academic-related staff. Academic staff are those whose function is either teaching and research or solely research. Academic-related staff are those who do not have a main teaching or research function but are paid on national, or equivalent, academic or academic-related scales. Following a convention adopted by official statisticians, part-time staff were given a weight of 0.5.

Aggregate departmental expenditure. This is defined here as total departmental recurrent expenditure *other than* that on academic and academic-related staff *plus* departmental equipment expenditure, summed over all departments in a given university.

Income from research and consultancy. This comprises income from research grants and contracts plus income for other services rendered.

First-class degrees. This refers to the number of first-class honours degrees awarded to undergraduates. Degrees obtained at affiliated institutions are not included.

Higher degrees. This includes doctorates and other higher degrees.

Data for the variables listed above were obtained from *University Statistics*, vol. 3, various tables and years. It was noted that, in this publication, students and staff are enumerated as at 1 December, whereas qualifications obtained refer to a calendar year. Since undergraduate degrees are typically awarded in early summer, it was presumed that first-class degrees awarded in, say, 1986 related to the 1985/86 academic year. The situation was less clearcut with respect to higher degrees. Here it was decided to assign qualifications obtained in, say, 1986 to the 1986/87 academic year.

Aggregated data for the key variables are displayed in Table 6.

See Table 6

Appendix B: Constructing the reference technology

The aim of this appendix is to explain the method of calculating the four measures of efficiency used in this study. The analysis mirrors that of Byrnes *et al.* (1984) and Färe *et al.* (1985a), although the exposition has been simplified considerably in order to highlight and clarify the salient points. It should be noted that the linear programming (LP) problems are formulated here in terms of maximizing output for given inputs, unlike the discussion in the text where, for expositional reasons, the problem was couched in terms of minimizing inputs for a given output (as in an isoquant analysis). These approaches are equivalent only in the case of constant returns.

Suppose that there are three universities, R, U and T, and that each uses one input, X, to produce a single output, Q. If the technology is well behaved and satisfies the assumptions of constant returns to scale and non-congestion, then the best-practice technology can be constructed by solving the following LP problem for each university i (i = r, u, t):

$$\text{Maximize } \omega_i \tag{1}$$

subject to:

$$Q_rZ_r + Q_uZ_u + Q_tZ_t - Q_i\omega_i \geq 0 \tag{2}$$

$$X_rZ_r + X_uZ_u + X_tZ_t - X_i \leq 0 \tag{3}$$

$$Z_r, Z_u, Z_t \geq 0 \tag{4}$$

where $Z = (Z_r, Z_u, Z_t)$ is a set of weights to be determined. By taking the reciprocal of the optimal value of ω_i, one can obtain the technical efficiency (TE) score of university i.

See Figure 8

Best practice is depicted in Figure 8 by the ray OZ, which represents maximum average productivity. Clearly, university R is inefficient in the sense that its observed output, Q_r, falls short of its potential output, Q_r^*, so that $TE_r = Q_r/Q_r^* < 1$. The same is true for university T. Only university U is fully efficient.

In order to decompose TE into its components, the assumptions of constant returns to scale and non-congestion need to be relaxed. Let us first relax the assumption of constant returns. The best-practice technology can then be constructed by solving the following LP problem:

$$\text{Maximize } \theta_i \tag{5}$$

subject to:

$$Q_rZ_r + Q_uZ_u + Q_tZ_t - Q_i\theta_i \geq 0 \tag{6}$$

$$X_rZ_r + X_uZ_u + X_tZ_t - X_i \leq 0 \qquad (7)$$

$$Z_r + Z_u + Z_t = 1 \qquad (8)$$

$$Z_r, Z_u, Z_t \geq 0 \qquad (9)$$

The new constraint $Z_r + Z_u + Z_t = 1$ yields a solution that, in Figure 8, corresponds to the modified best-practice technology bounded by the X-axis starting at X_r, the broken line X_rRUT, and its horizontal extension from T. Any university located on this boundary would be deemed to be efficient in terms of the modified technology and would have a modified technical efficiency (MTE) score of unity. It should be noted that $MTE_i = 1/\theta_i$.

To measure *scale* efficiency, consider the optimal ray OZ in Figure 8, which depicts constant returns to scale. Only university U is scale efficient ($SE_i = 1$). University R is inefficient in the sense that it is experiencing increasing returns to scale and is thus too small. Its scale efficiency can be measured by the ratio $SE_r = Q_r/Q_r^*$, which is well below unity. The proportion of potential output lost as a consequence of this university's failure to operate at the correct scale can be measured by $(1 - SE_r)$. By contrast, university T has become too large and is experiencing diseconomies of scale. Its scale efficiency can be measured in a similar way.

Scale efficiency is captured by the ratio $SE_i = TE_i/MTE_i$. For universities R and T, $MTE_i = 1$, so that $TE_i = SE_i$. Thus, for these universities, the sole source of technical inefficiency is an inappropriate scale. However, university S is suffering from two sources of inefficiency: it is too large *and* it is operating beneath the frontier depicting best-practice technology, so that $TE_s = SE_s \times MTE_s$, where SE_s and MTE_s are both below unity.

To determine whether the deviation from the optimal scale is due to increasing or decreasing returns to scale, we need to reformulate the LP problem as:

$$\text{Maximize } \theta_i^* \qquad (10)$$

subject to:

$$Q_rZ_r + Q_uZ_u + Q_tZ_t - Q_i\theta_i^* \geq 0 \qquad (11)$$

$$X_rZ_r + X_uZ_u + X_tZ_t - X_i \leq 0 \qquad (12)$$

$$Z_r + Z_u + Z_t \leq 1 \qquad (13)$$

$$Z_r, Z_u, Z_t \geq 0 \qquad (14)$$

Again referring to Figure 8, the new constraint $Z_r + Z_u + Z_t \leq 1$ restricts the solution to a technology bounded by the X-axis, OUT, and the line emanating from T parallel to the X-axis. This modified technology rules out *increasing* returns. Thus, if there is scale inefficiency ($SE_i < 1$), it is due to decreasing returns if $\theta_i^* = \theta_i$ (the case of T) or to increasing returns if $\theta_i^* > \theta_i$ (the case of R). This is because university R becomes technically inefficient under the newly specified reference technology, whereas university T is unaffected.

To test for *congestion* inefficiency, we drop the assumption that all inputs have non-negative marginal products. The best-practice technology can now be constructed by solving the following LP problem:

$$\text{Maximize } \varphi_i \tag{15}$$

subject to:

$$Q_rZ_r + Q_uZ_u + Q_tZ_t - Q_i\varphi_i \geq 0 \tag{16}$$

$$X_rZ_r + X_uZ_u + X_tZ_t - X_i\psi_i = 0 \tag{17}$$

$$Z_r + Z_u + Z_t = 1 \tag{18}$$

$$Z_r, Z_u, Z_t \geq 0 \tag{19}$$

$$0 \leq \psi_i \leq 1 \tag{20}$$

where ψ_i is a parameter which has been introduced to effect a proportional scaling of the inputs; this allows for an isoquant with an upward-sloping segment such as HM′ in Figure 4. By taking the reciprocal of the optimal value of φ_i, one can obtain the ‘pure’ technical efficiency (PTE) score of university i. If PTE = 1, then a university is operating on an efficient isoquant, but may be experiencing scale or congestion inefficiency or possibly both.

To measure congestion, we need to determine the proportional reduction in inputs, if any, that is required to reach the closest congestion-free technology. Byrnes *et al.* (1984, p. 676) show that congestion efficiency can be measured by the ratio $CE_i = MTE_i/PTE_i$, so that $MTE_i = CE_i \times PTE_i$. If we recall that $TE_i = SE_i \times MTE_i$, then we can express technical efficiency as the product of its three component indices, to wit:

$$TE_i = SE_i \times CE_i \times PTE_i \tag{21}$$

Clearly, if the technology is non-congested and exhibits constant returns to scale, then $CE_i = 1$, $SE_i = 1$ and $TE_i = PTE_i$.

It should be noted that the treatment of scale efficiency, as discussed above, differs from that in Banker (1984), Banker *et al.* (1984), and Banker & Thrall (1992). These papers employ an input orientation and use a different procedure to measure scale efficiency. Congestion efficiency is not considered. For an application of this approach, see Johnes (1995). However, Banker *et al.* (1996) and Seiford & Zhu (1999) argue that the alternative methods of determining returns to scale in DEA differ more in terms of procedure than substance. See also Färe & Grosskopf (1994).

Appendix C: Results for individual universities

Table 7 identifies universities whose TE score fell in the top decile in a given academic year in the period 1982–93. The arithmetic mean TE score achieved in this period is given in the last column as a percentage. The following symbols are used:

*** denotes $TE_i = 1$ (these universities constitute the efficiency frontier)

** denotes $0.9500 \leq TE_i < 1$

* denotes $0.9000 \leq TE_i < 0.9500$

See Table 7

It should be noted that universities have been evaluated in terms of their degree of success in producing the following outputs from given inputs:

- income from research and consultancy
- first-class honours graduates
- successful postgraduate students

Clearly, other criteria would have generated somewhat different rankings. For this reason, the emphasis has been placed on discussing trends in the sector as a whole, rather than on examining the results for individual universities. Nonetheless, the scores are of some interest in their own right inasmuch as they indicate the sorts of results that can be generated by using the variables employed in this study. It is worth noting that Athanassopoulos and Shale (1997, Appendix B) present some very different results. A case in point is Ulster: this university is fully efficient across all of their specifications, yet our analysis yields a TE score of only 0.756 for Ulster in 1992/93.

References

Al-Naji, G. (1995) Relative efficiency measurement of UK universities: non-parametric approach within the framework of cybernetics, Ph.D. dissertation, University of Hull.

Athanassopoulos, A.D. & Shale, E. (1997) Assessing the comparative efficiency of higher education institutions in the UK by means of data envelopment analysis, *Education Economics*, 5, pp. 117–134.

Atkinson, S.E. & Wilson, P.W. (1995) Comparing mean efficiency and productivity scores from small samples: a bootstrap methodology, *Journal of Productivity Analysis*, 6, pp. 137–152.

Banker, R.D. (1984) Estimating most productive scale size using data envelopment analysis, *European Journal of Operational Research*, 17, pp. 35–44.

Banker, R.D. (1993) Maximum likelihood, consistency and data envelopment analysis: a statistical foundation, *Management Science*, 39, pp. 1265–1273.

Banker, R.D., Chang, H. & Cooper, W.W. (1996) Equivalence and implementation of alternative methods for determining returns to scale in data envelopment analysis, *European Journal of Operational Research*, 89, pp. 473–481.

Banker, R.D., Charnes, A. & Cooper, W.W. (1984) Some models for estimating technical and scale inefficiencies in data envelopment analysis, *Management Science*, 30, pp. 1078–1092.

Banker, R.D. & Thrall, R.M. (1992) Estimation of returns to scale using data envelopment analysis, *European Journal of Operational Research*, 62, pp. 74–84.

Beasley, J.E. (1990) Comparing university departments, *Omega*, 18, pp. 171–183.

Beasley, J.E. (1995) Determining teaching and research efficiencies, *Journal of the Operational Research Society*, 46, pp. 441–452.

Boussofiane, A., Dyson, R.G. & Thanassoulis, E. (1991) Applied data envelopment analysis, *European Journal of Operational Research*, 52, pp. 1–15.

Brockett, P.L., Cooper, W.W., Shin, H.C. & Wang, Y. (1998) Inefficiency and congestion in Chinese production before and after the 1978 economic reforms, *Socio-Economic Planning Sciences*, 32, pp. 1–20.

Burgess, J.F. & Wilson, P.W. (1995) Decomposing hospital productivity changes, 1985–1988: a nonparametric Malmquist approach, *Journal of Productivity Analysis*, 6, pp. 343–363.

Byrnes, P., Färe, R. & Grosskopf, S. (1984) Measuring productive efficiency: an application to Illinois strip mines, *Management Science*, 30, pp. 671–681.

Cave, M., Hanney, S., Henkel, M. & Kogan, M. (1997) *The Use of Performance Indicators in Higher Education: The Challenge of the Quality Movement*, 3rd edition (London, Jessica Kingsley).

Cherchye, L., Kuosmanen, T. & Post, T. (2001) Alternative treatments of congestion in DEA: a rejoinder to Cooper, Gu, and Li, *European Journal of Operational Research*, 132, pp. 75–80.

Coelli, T., Prasada Rao, D.S. & Battese, G.E. (1998) *An Introduction to Efficiency and Productivity Analysis* (Boston, Kluwer).

Cooper, W.W., Gu, B. & Li, S. (2001a) Comparisons and evaluations of alternative approaches to the treatment of congestion in DEA, *European Journal of Operational Research*, 132, pp. 62–74.

Cooper, W.W., Gu, B. & Li, S. (2001b) Note: Alternative treatments of congestion in DEA – a response to the Cherchye, Kuosmanen and Post critique, *European Journal of Operational Research*, 132, pp. 81–87.

Cooper, W.W., Seiford, L.M. & Tone, K. (2000a) *Data Envelopment Analysis* (Boston, Kluwer).

Cooper, W.W., Seiford, L.M. & Zhu, J. (2000b) A unified additive model approach for evaluating inefficiency and congestion with associated measures in DEA, *Socio-Economic Planning Sciences*, 34, pp. 1–25.

Färe, R. & Grosskopf, S. (1994) Estimation of returns to scale using data envelopment analysis: a comment, *European Journal of Operational Research*, 79, pp. 379–382.

Färe, R. & Grosskopf, S. (2000) Slacks and congestion: a comment, *Socio-Economic Planning Sciences*, 34, pp. 27–33.

Färe, R., Grosskopf, S., Lindgren, B. & Roos, P. (1992) Productivity changes in Swedish pharmacies 1980–1989: a non-parametric Malmquist approach, *Journal of Productivity Analysis*, 3, pp. 85–101.

Färe, R., Grosskopf, S. & Logan, J. (1985a) The relative performance of publicly-owned and privately-owned electric utilities, *Journal of Public Economics*, 26, pp. 89–106.

Färe, R., Grosskopf, S. & Lovell, C.A.K. (1985b) *The Measurement of Efficiency of Production* (Boston, Kluwer-Nijhoff)

Färe, R., Grosskopf, S. & Lovell, C.A.K. (1994a) *Production Frontiers* (Cambridge, Cambridge University Press).

Färe, R., Grosskopf, S., Norris, M. & Zhang, Z. (1994b) Productivity growth, technical progress, and efficiency change in industrialized countries, *American Economic Review*, 84, pp. 66–83.

Farrell, M.J. (1957) The measurement of productive efficiency, *Journal of the Royal Statistical Society*, Series A, General, 120, Part 3, pp. 253–281.

Field, K. (1990) Production efficiency of British building societies, *Applied Economics*, 22, pp. 415–426.

Glass, J.C., McKillop, D.G. & Hyndman, N.S. (1995a) Efficiency in the provision of university teaching and research: an empirical analysis of UK universities, *Journal of Applied Econometrics*, 10, pp. 61–72.

Glass, J.C., McKillop, D.G. & Hyndman, N.S. (1995b) The achievement of scale efficiency in UK universities: a multiple-input multiple-output analysis, *Education Economics*, 3, pp. 249–263.

Izadi, H., Johnes, G., Oskrochi, R. & Crouchley, R. (2002) Stochastic frontier estimation of a CES cost function: the case of higher education in Britain, *Economics of Education Review*, 21, pp. 63–71.

Jarratt Report (1985) *Report of the Steering Committee for Efficiency Studies in Universities* (London, Committee of Vice-Chancellors and Principals).

Johnes, G. (1995) Scale and technical efficiency in the production of economic research, *Applied Economics Letters*, 2, pp. 7–11.

Johnes, G. (1997) Costs and industrial structure in contemporary British higher education, *Economic Journal*, 107, pp. 727–737.

Johnes, G. & Johnes, J. (1993) Measuring the research performance of UK economics departments: an application of data envelopment analysis, *Oxford Economic Papers*, 45, pp. 322–347.

Johnes, G., Taylor, J. & Ferguson, G. (1987) The employability of new graduates: a study of differences between UK universities, *Applied Economics*, 19, pp. 695–710.

Johnes, J. & Taylor, J. (1990) *Performance Indicators in Higher Education: UK Universities* (Buckingham, SRHE and Open University Press).

Jondrow, J., Lovell, C.A.K., Materov, I.S. & Schmidt, P. (1982) On the estimation of technical efficiency in the stochastic frontier production function model, *Journal of Econometrics*, 19, pp. 233–238.

Nunamaker, T.R. (1985) Using data envelopment analysis to measure the efficiency of non-profit organizations: a critical evaluation, *Managerial and Decision Economics*, 6, pp. 50–58.

Seiford, L.M. & Zhu, J. (1999) An investigation of returns to scale in data envelopment analysis, *Omega*, 27, pp. 1–11.

Sexton, T.R., Silkman, R.H. & Hogan, A.J. (1986) Data envelopment analysis: critique and extensions, in: Silkman, R.H. (Ed.), chapter 4.

Silkman, R.H. (Ed.) (1986) *Measuring Efficiency: An Assessment of Data Envelopment Analysis* (San Francisco, Jossey-Bass).

Tomkins, C. & Green, R.H. (1988) An experiment in the use of data envelopment analysis for evaluating the efficiency of UK university departments of accounting, *Financial Accountability and Management*, 4, pp. 147–164.

University Statistics, various issues (Cheltenham, Universities' Statistical Record).

Wilson, P.W. (1995) Detecting influential observations in data envelopment analysis, *Journal of Productivity Analysis*, 6, pp. 27–45.

Table 1. Summary statistics: technical efficiency over time

Academic year	Unweighted arithmetic mean	Weighted arithmetic mean	Weighted geometric mean	Standard deviation	Minimum
1980/81	0.861	0.871	0.859	0.144	0.488
1981/82	0.863	0.878	0.868	0.132	0.596
1982/83	0.869	0.880	0.870	0.123	0.649
1983/84	0.858	0.868	0.857	0.131	0.549
1984/85	0.870	0.870	0.858	0.133	0.468
1985/86	0.871	0.866	0.853	0.135	0.501
1986/87	0.864	0.863	0.852	0.123	0.564
1987/88	0.873	0.872	0.860	0.128	0.575
1988/89	0.898	0.900	0.894	0.098	0.629
1989/90	0.883	0.882	0.874	0.113	0.587
1990/91	0.921	0.921	0.917	0.076	0.762
1991/92	0.923	0.920	0.916	0.084	0.708
1992/93	0.926	0.920	0.916	0.077	0.742

Table 2. Decomposition of technical efficiency (weighted geometric means) (N = 45)

Academic year	Technical efficiency	Pure technical efficiency	Congestion efficiency	Scale efficiency	Returns to scale		
					crs	drs	irs
1980/81	0.859	0.954	0.942	0.955	16	14	15
1981/82	0.868	0.950	0.947	0.964	14	15	16
1982/83	0.870	0.960	0.937	0.967	15	13	17
1983/84	0.857	0.965	0.945	0.940	11	19	15
1984/85	0.858	0.969	0.923	0.959	17	20	8
1985/86	0.853	0.963	0.935	0.948	13	19	13
1986/87	0.852	0.972	0.939	0.934	13	15	17
1987/88	0.860	0.974	0.946	0.933	12	19	14
1988/89	0.894	0.970	0.962	0.958	13	15	17
1989/90	0.874	0.968	0.941	0.959	16	12	17
1990/91	0.917	0.983	0.961	0.971	14	14	17
1991/92	0.916	0.990	0.951	0.973	17	18	10
1992/93	0.916	0.984	0.967	0.963	15	21	9

Note: The columns headed crs, drs and irs show the numbers of universities experiencing constant, decreasing or increasing returns to scale, respectively.

Table 3. Indices illustrating annual changes in TFP and its components (N = 45)

Comparison	Technical efficiency	Pure technical efficiency	Congestion efficiency	Scale efficiency	Frontier technology	Total factor productivity
1981/82 v. 1980/81	1.006	1.003	1.005	0.998	1.071	1.077
1982/83 v. 1981/82	1.009	1.013	0.996	1.000	1.043	1.052
1983/84 v. 1982/83	0.985	1.007	1.005	0.974	1.063	1.047
1984/85 v. 1983/84	1.013	1.002	0.976	1.037	1.031	1.045
1985/86 v. 1984/85	1.002	0.994	1.022	0.986	1.040	1.042
1986/87 v. 1985/86	0.994	1.008	1.000	0.986	1.043	1.037
1987/88 v. 1986/87	1.009	1.002	1.009	0.999	1.040	1.050
1988/89 v. 1987/88	1.034	0.996	1.009	1.029	1.000	1.035
1989/90 v. 1988/89	0.981	0.996	0.984	1.002	0.997	0.978
1990/91 v. 1989/90	1.048	1.021	1.019	1.007	0.965	1.011
1991/92 v. 1990/91	1.002	1.008	0.987	1.007	0.994	0.996
1992/93 v. 1991/90	1.004	0.993	1.018	0.993	1.053	1.057
Mean	1.007	1.003	1.003	1.001	1.028	1.036

Table 4. Indices showing the cumulative change in TFP and its components (N = 45)

Academic year	Total factor productivity	Frontier technology	Technical efficiency	Pure technical efficiency	Congestion efficiency	Scale efficiency
1980/81	1.000	1.000	1.000	1.000	1.000	1.000
1981/82	1.077	1.071	1.006	1.002	1.005	0.998
1982/83	1.133	1.117	1.015	1.015	1.002	0.998
1983/84	1.186	1.187	0.999	1.022	1.007	0.971
1984/85	1.240	1.224	1.013	1.024	0.982	1.007
1985/86	1.292	1.273	1.014	1.017	1.004	0.994
1986/87	1.340	1.328	1.008	1.026	1.004	0.979
1987/88	1.407	1.381	1.018	1.027	1.013	0.978
1988/89	1.456	1.381	1.053	1.024	1.022	1.007
1989/90	1.424	1.377	1.033	1.019	1.005	1.008
1990/91	1.439	1.329	1.082	1.040	1.024	1.016
1991/92	1.434	1.321	1.084	1.049	1.011	1.022
1992/93	1.515	1.391	1.088	1.041	1.029	1.015

Table 5. Sensitivity of technical efficiency (weighted geometric means)

Academic year	Using number of 1sts as output variable		Using 1sts plus 2.1s
	N = 45	N = 40	N = 40
1980/81	0.859	0.870	0.883
1981/82	0.868	0.882	0.897
1982/83	0.870	0.882	0.897
1983/84	0.857	0.880	0.903
1984/85	0.858	0.872	0.911
1985/86	0.853	0.870	0.897
1986/87	0.852	0.877	0.913
1987/88	0.860	0.870	0.914
1988/89	0.894	0.896	
1989/90	0.874	0.881	
1990/91	0.917	0.923	
1991/92	0.916	0.918	
1992/93	0.916	0.921	

Table 6. Aggregated data for key variables

Academic Year	Number of students	Annual change (%)	Number of staff	Annual change (%)	Student: staff ratio	Departmental Expenditure (£000)	Annual change (%)	Income from research and consultancy (£000)	Annual change (%)	First-class degrees	Annual change (%)	Higher degrees	Annual change (%)
1980/81	319,799	6.6	54,627	1.6	5.85	704,011		335,066		4,301	5.7	18,779	2.8
1981/82	321,688	0.6	54,537	–0.2	5.90	680,286	–3.4	354,571	5.8	4,427	2.9	19,388	3.2
1982/83	316,841	–1.5	53,720	–1.5	5.90	726,434	6.8	394,669	11.3	4,497	1.6	19,907	2.7
1983/84	313,520	–1.0	54,160	0.8	5.79	769,313	5.9	441,249	11.8	4,757	5.8	21,064	5.8
1984/85	319,892	2.0	55,870	3.2	5.73	824,986	7.2	489,019	10.8	5,069	6.6	21,367	1.4
1985/86	324,174	1.3	57,660	3.2	5.62	866,691	5.1	540,705	10.6	5,353	5.6	23,306	9.1
1986/87	330,013	1.8	59,310	2.9	5.56	937,259	8.1	617,001	14.1	5,375	0.4	24,329	4.4
1987/88	335,653	1.7	60,121	1.4	5.58	919,141	–1.9	625,685	1.4	5,754	7.1	26,289	8.1
1988/89	348,927	4.0	60,964	1.4	5.72	995,547	8.3	701,000	12.0	6,221	8.1	27,548	4.8
1989/90	370,666	6.2	63,119	3.5	5.87	1,052,434	5.7	714,585	1.9	6,725	8.1	29,916	8.6
1990/91	390,526	5.4	65,662	4.0	5.95	1,084,811	3.1	748,069	4.7	7,169	6.6	31,004	3.6
1991/92	425,550	9.0	68,055	3.6	6.25	1,108,441	2.2	761,484	1.8	7,819	9.1	34,162	13.9
1992/93	462,829	8.8	70,019	2.9	6.61	1,161,688	4.8	846,600	11.2	8,278	5.9	38,474	12.6

Note: The expenditure and income figures were deflated using the index of university costs (1985 = 100).

Table 7. Classification of universities in terms of technical efficiency: 1982/83 to 1992/93

	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	91/92	92/93	%
Aston	***	***	***	***	***	***	***	***	**	***	***	100
Bath				*	*			**	*	***	**	90
Birmingham	***	*	***	*	*	***	**					91
Bradford	***	**		*		*				*	*	90
Bristol	***	***	***	***	***	***	***	***	***	**	**	100
Brunel	**	***	***	*	*						*	91
Cambridge	***	***	***	***	***	***	***	***	***	***	***	100
City	***	***	**	***	***	***	***	***	***	***	***	100
Durham	*	*		*		*			*	*		90
East Anglia					*							81
Essex			***	***			**	**	*	***	*	92
Exeter									*	***		84
Hull				*		**	*	*	***		***	87
Keele												78
Kent						*	**	***	***	**	**	92
Lancaster	***	***	***	**	***	***	***	***	***	***	***	100
Leeds												74
Leicester												75
Liverpool									*			73
London	***	***	***	***	***	***	***	***	***	***	***	100
Loughborough	**	**	***	*	***	**	***	***	***		**	97
Manchester												79
UMIST	***	***	***	***	***	***	***	**	**	***	*	99
Newcastle									*	*		84
Nottingham									*			82
Oxford	***	***	***	***	***	**	***	***	***	***	***	100
Reading	*				***	**						86
Salford			***	***	***	***	***	***	**	***	***	95
Sheffield												74
Southampton	***	***	***	**		*	**	***	***	**	**	98
Surrey	*	**	***	***	***	***	***	*	**	***	*	97
Sussex	*	**	**		*	***		*		*		92
Warwick	***	**	*	***	***	***	***	***	***	***	*	98
York	***	*	***	***			**		**	**	***	92
Wales												76
Aberdeen	**			**								86
Dundee				*	*	***	***	***	*	**	**	93
Edinburgh	***	*	*	*	*	**	**	***	***	***	***	96
Glasgow							*	*	*	***	***	85
Heriot-Watt	***	***	***	***		*	*	***	***	***	***	97
St. Andrews			***	*			**	***		***	***	92
Stirling							**		***	*	***	84
Strathclyde											***	83
Belfast										**	*	76
Ulster												63

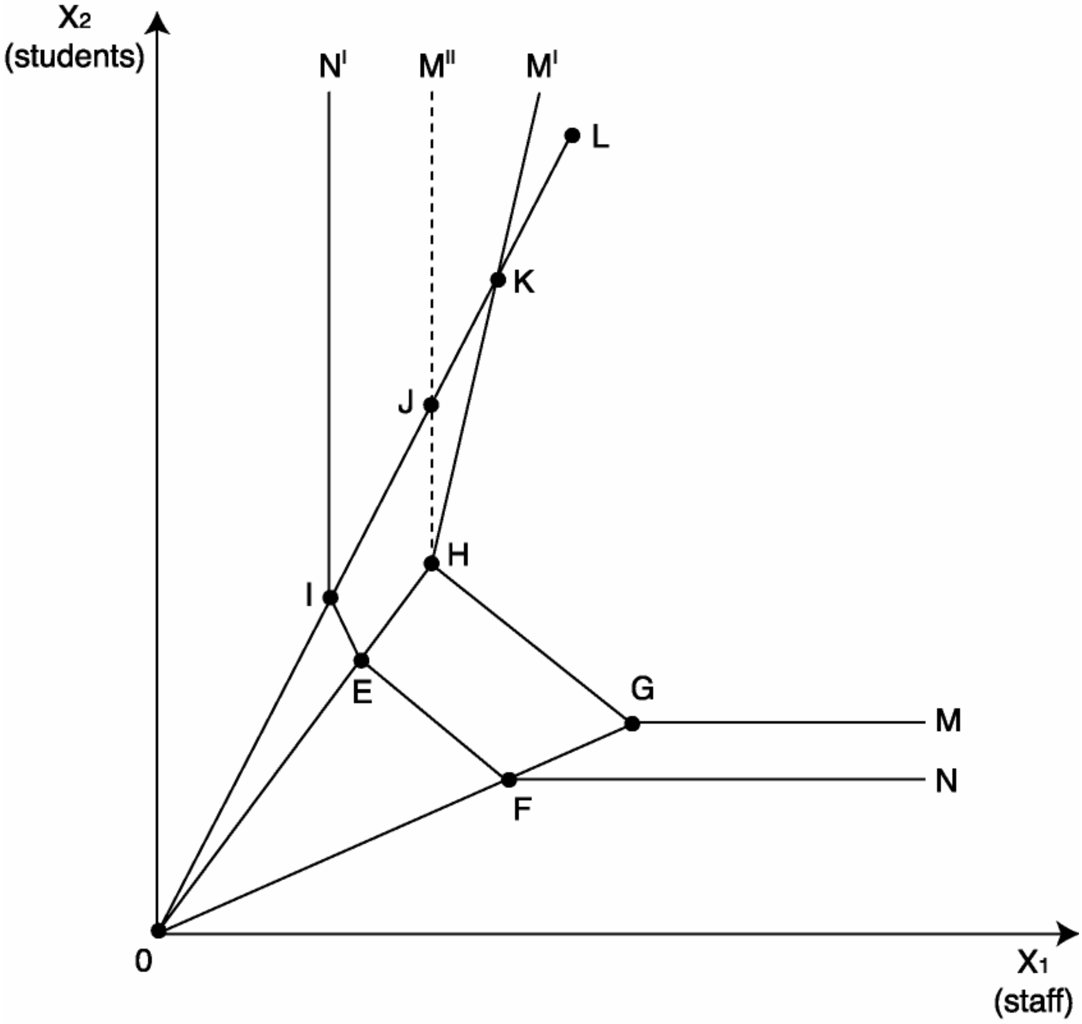

Figure 4. Decomposition of overall technical efficiency

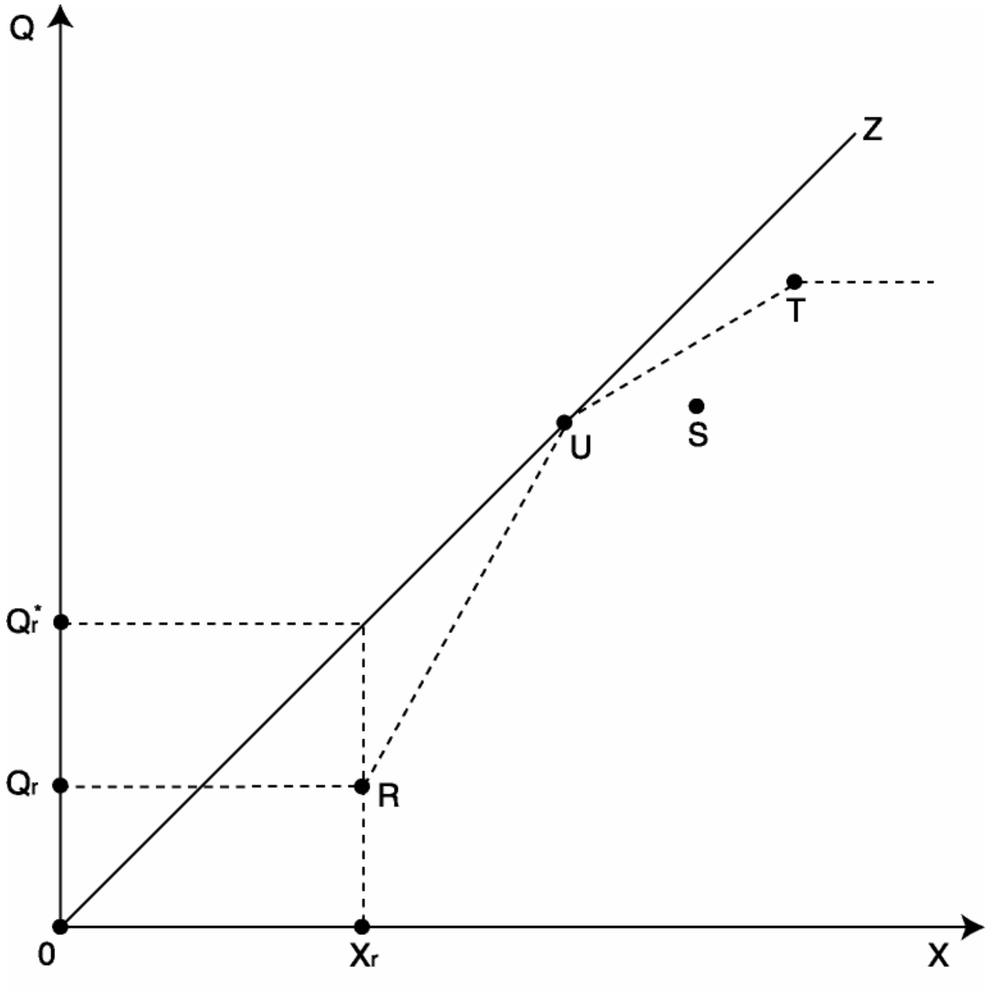

Figure 8. Returns to scale