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Efficiency and input substitutability in English higher education 1996/97 to 2008/09

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Abstract

This paper explores the issue of efficiency and input substitutability in English higher education. Data envelopment analysis and stochastic frontier analysis are used to estimate an output distance function (which incorporates measures of both quantity and quality of teaching and research inputs and outputs) over a thirteen-year period. This paper makes a number of contributions to the literature. The comparison of the efficiency rankings derived from parametric and non-parametric estimation methods demonstrates that the methods provide substantially different estimates of the *level of efficiency* in the English higher education sector and of the *efficiency rankings* of the individual institutions. The length of the study under consideration allows a preliminary investigation of the effects on efficiency and input substitutability of merger activity. There is some evidence that merging has historically had a positive effect on efficiency. But there is also evidence that merging institutions differ in characteristics from non-merging ones: not only do they have different input and output portfolios, they also appear to be generally more flexible in terms of potential for input substitution.

JEL Classification: I23, C01, C33, D24

Keywords: higher education; efficiency; distance functions ; stochastic frontier analysis; data envelopment analysis; Morishima elasticity; stochastic frontier analysis

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1. INTRODUCTION

Cuts in public funding to UK higher education make it imperative that universities utilize their funds efficiently. Estimates of technical efficiency for the UK higher education sector vary from 85% to 95% (Athanassopulos and Shale 1997; Flegg *et al.* 2004; Johnes 2006; Flegg and Allen 2007a; 2007b; Johnes 2008). Whether these estimates offer an accurate reflection of current efficiency is doubtful. First they are based on data covering periods prior to 2005. Second few of the studies include the expanded sector which we observe in English higher education today. Third the studies almost exclusively adopt a non-parametric estimation approach to the calculation of efficiencies, the disadvantages of which are well-known. An additional weakness of previous studies of efficiency is that they fail to investigate the effect of merging on efficiency. This is a serious omission as one suggestion for increasing efficiency is to merge institutions (Griffiths 2010). There have, moreover, been recent reports of English higher education institutions (HEIs) entering talks about possible collaboration, though whether or not these talks will ultimately lead to mergers is unclear at this stage (Morgan 2011c; 2011b; 2011a).

The efficiency of an organisation can be assessed by examining its observed production relative to best practice in the industry. This leads to the adoption of a distance function approach which has a number of advantages: it handles a production situation with multiple inputs and multiple outputs; it does not assume any particular optimizing behaviour on the part of the firms; it does not require a knowledge of prices of either inputs or outputs; and it does not require prices to be exogenous (Coelli and Perelman 1999; Coelli 2000; Baños-Pino *et al.* 2002; O'Donnell and Coelli 2003; Uri 2003a; 2003b; Rodríguez-Álvarez *et al.* 2004). But the actual estimation of the distance function in the multiple input multiple output context poses something of a problem. Parametric estimation has obvious advantages in that it allows for stochastic errors and the estimated parameters can provide potentially useful information on, for example, returns to scale and scope, and elasticities. Yet few studies have employed parametric methods to estimate a multi-output multi-input distance function because of the data demands. Non-parametric estimation of the distance function, in contrast, easily handles the multi-dimensional nature of production but has disadvantages in that it does not allow for stochastic errors (such as measurement errors and random shocks), it does not provide parameter estimates from which information on, for example, elasticities can be derived, and estimates of efficiency can be distorted by outliers or by the choice of inputs and outputs.

The purpose of this paper is to explore the issue of efficiency in English higher education by a) comparing parametric and non-parametric efficiency estimates across the entire English higher education sector using up-to-date data; b) investigating, using the parametric distance function, the degree of input substitutability in the sector in order to assess potential for maintaining output levels in the face of resource cuts which might affect the balance of inputs; c) examining both efficiency and input substitutability of merging compared with non-merging institutions. An empirical analysis of the estimated efficiency and input substitutability effects of merger in the context of higher education this in particular is new to the literature on higher education and is particularly relevant if mergers are likely in the wake of financial cuts. Indeed, results will be of interest to those involved in higher education in all countries.

This paper is in five sections of which this exordium is the first. Section 2 introduces the distance function methodology and presents the estimation issues. The model specification and data are discussed in section 3, while section 4 examines the results concerning both efficiency and input substitutability from the parametric and non-parametric output distance functions. Finally, conclusions are drawn in section 5.

2. DISTANCE FUNCTION METHODOLOGY AND ESTIMATION

HEIs produce multiple outputs from a variety of inputs. A commonly-made assumption of separate production simplifies the estimation since an individual production function can be estimated for each output; but it does not capture the obvious jointness of production observed in higher education, and therefore precludes an examination of substitutability (Chizmar and Zak 1983; Chizmar and McCarney 1984; Chizmar and Zak 1984; Gyimah-Brempong and Gyapong 1991). The joint production process can be formalised as follows. It is assumed that HEIs use a vector of inputs $x \in \mathbb{R}_{+}^{K}$ to produce a vector of outputs $y \in \mathbb{R}_{+}^{M}$. In the output-oriented context, output ratios are held constant so that inputs are the choice variables (Paul and Nehring 2005). One of the purposes of this paper is to look at potential for changing the balance of inputs, and so it is an output-oriented approach which is taken here. Thus the production technology of the HEI is defined as

$$P(x) = \{y \in \mathbb{R}_{+}^{M} : x \text{ can produce } y\} \quad (1)$$

The output distance function (Shephard 1970), $D(x, y)$, is non-decreasing, positively linearly homogeneous of degree +1 and is defined on the output set $P(x)$ as:

$$D(x, y) = min_{\theta}\{\theta : (y/\theta) \in P(x)\} \quad (2)$$

It follows that

$$D(x, y) \leq 1 \Leftrightarrow y \in P(x) \quad (3a)$$

$$D(x, y) = 1 \Leftrightarrow y \in \text{Bound}P(x) \quad (3b)$$

where $\text{Bound}P(x)$ is the frontier of the output set (see Coelli *et al.* 2005). If *y* is located on the boundary of the production possibility set, $D(x, y) = 1$ and this represents technical efficiency; if $D(x, y) < 1$, *y* lies inside the frontier and technical inefficiency exists. The output distance function can be used to derive useful information on shadow prices and substitution properties. Shadow prices (or marginal products) of inputs are defined as

$$\partial D(x, y)/\partial x_k \quad (4)$$

and the marginal rate of technical substitution ($MRTS_{kl}$), which reflects the slope of the isoquant, is given by the ratio of input shadow prices as follows:

$$MRTS_{kl} = \frac{\partial D(x,y)/\partial x_k}{\partial D(x,y)/\partial x_l} \quad (5)$$

This reflects the slope of the isoquant and is therefore a measure of substitutability between inputs *k* and *l*, but is affected by the units in which inputs are measured. Thus a normalized $MRTS_{kl}$ (defined as follows) provides a more satisfactory measure of input substitutability:

$$sub_{kl} = \frac{\partial D(x,y)/\partial x_k}{\partial D(x,y)/\partial x_l} . \frac{x_k}{x_l} \quad (6)$$

If $sub_{kl} > 1$ ($sub_{kl} < 1$) it is difficult (easy) to substitute out of input *k* into input *l* (Paul *et al*. 2002). In the case of just two inputs, this measure of substitutability captures the curvature of the (two dimensional) isoquant. But when the number of inputs exceeds two sub_{kl} can be an inadequate reflection of substitutability because there are many directions in which the curvature of the isoquant can be measured. It has been argued that the Morishima elasticity of substitution is an appropriate measure of substitutability in the multiple input case (Blackorby and Russell 1989). In the context of a distance function, the (indirect) Morishima elasticity of substitution is defined as (Paul *et al*. 2002):

$$M_{kl}(x,y) = -\frac{\mathrm{d}\ln[D_k(x,y)/D_l(x,y)]}{\mathrm{d}\ln[x_k/x_l]} = x_k \frac{D_{kl}(x,y)}{D_l(x,y)} - x_k \frac{D_{kk}(x,y)}{D_k(x,y)} \quad (7)$$

This represents the percentage change in the ratio of input shadow prices (or the percentage change in the slope of the MRTS) brought about by a percentage change in ratio of inputs. If x_k and x_l are highly substitutable values will be small (less than or equal to zero); the elasticity rises if substitutability possibilities between the inputs x_k and x_l are limited. The Morishima elasticity (unlike the Allen elasticity) is asymmetric such that $M_{kl}(x,y)$ will not normally equal $M_{lk}(x,y)$ (Grosskopf *et al.* 1995).

2.1 Parametric estimation

The parametric estimation approach assumes a functional form for the distance function, estimates of the parameters are provided, and the significance of these can be tested. The wrong choice of functional form, however, introduces problems of misspecification the consequences of which can be serious: parameter estimates will be biased and efficiency estimates may be incorrect. Multicollinearity and omission of relevant variable(s) may also cause problems.

The desirable properties of the functional form are that it should be i) flexible; ii) easy to estimate; and iii) permit the imposition of homogeneity (Coelli and Perelman 2000). The translog fulfils all three criteria and has been used to estimate distance functions in various contexts ranging from agriculture to telecommunications (Whiteman 1999; Paul *et al.* 2000; 2002; Uri 2003a; 2003b; Karagiannis *et al.* 2004; Tonini 2004; Paul and Nehring 2005; Balcombe *et al.* 2007). The translog distance function is defined below for *N* HEIs using inputs x_k (k = 1,...,K) to produce outputs y_m (m = 1,...,M):

$\ln D_{it}(x,y) =$

$$\alpha_0 + \sum_{m=1}^{M} \alpha_m \ln y_{mit} + \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{M} \alpha_{mm} \ln y_{mit} \ln y_{nit} + \sum_{k=1}^{K} \beta_k \ln x_{kit} +$$
$$\frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl} \ln x_{kit} \ln x_{lit} + \sum_{k=1}^{K}\sum_{m=1}^{M} \delta_{km} \ln x_{kit} \ln y_{mit} \qquad i = 1,2,\ldots,N \qquad (8)$$

where subscript *it* refers to the *i*th HEI in the *t*th time period. Distance function restrictions require the following conditions to hold:

a) Homogeneity of degree +1 in outputs

$$\sum_{m=1}^{M} \alpha_m = 1 \quad \text{and} \qquad (9a)$$
$$\sum_{n=1}^{M} \alpha_{mn} = 0 \quad m = 1,2,\ldots,M \quad \text{and} \qquad (9b)$$
$$\sum_{m=1}^{M} \delta_{km} = 0 \quad k = 1,2,\ldots,K \qquad (9c)$$

b) Symmetry:

$$\alpha_{mn} = \alpha_{nm} \quad m,n = 1,2,\ldots,M \quad \text{and} \qquad (10a)$$
$$\beta_{kl} = \beta_{lk} \quad k,l = 1,2,\ldots,K \qquad (10b)$$

By the homogeneity restriction $D(x,\omega y) = \omega D(x,y)$ and so one output can be chosen arbitrarily, for example the *M*th output, such that $\omega = 1/y_M$. Thus equation (8) can be written as:

$$-\ln y_{Mit} = \alpha_0 + \sum_{m=1}^{M-1} \alpha_m \ln\left(\frac{y_{mit}}{y_{Mit}}\right) + \frac{1}{2}\sum_{m=1}^{M-1}\sum_{n=1}^{M-1} \alpha_{mn} \ln\left(\frac{y_{mit}}{y_{Mit}}\right) \ln\left(\frac{y_{nit}}{y_{Mit}}\right) + \sum_{k=1}^{K} \beta_k \ln x_{kit} +$$
$$\frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl} \ln x_{kit} \ln x_{lit} + \sum_{k=1}^{K}\sum_{m=1}^{M-1} \delta_{km} \ln x_{kit} \ln\left(\frac{y_{mit}}{y_{Mit}}\right) + \varepsilon_{it} \qquad i = 1,2,\ldots,N \qquad (11)$$

where $\varepsilon_{it} = -\ln D_{it}(x,y)$

The quantity which is of interest here is the distance (or efficiency) $\ln D_{it}(x,y)$ which is measured by the error term in equation (11), and the choice of parametric estimation method depends on the assumptions made about this error term. Three alternative estimation methods will be used in the subsequent analysis, all of which assume that the error can be split into two components i.e. $\varepsilon_{it} = v_{it} - u_{it}$.

- Random effects (RE) estimation assumes v_{it} to represent statistical noise and $u_{it} = u_i$ (i.e. technical inefficiency) to be time-invariant, but it makes no distributional assumptions about u_i.
- A time-invariant (TI) stochastic frontier model (Aigner *et al.* 1977) assumes v_{it} and u_{it} are independently and identically distributed such that $v_{it} \sim N(0,\sigma_v^2)$, $u_{it} = u_i \sim N^+(\mu,\sigma^2)$ and N^+ represents a truncated-normal distribution truncated at 0. In the following analysis u_i is treated as a random variable (Coelli *et al.* 2005) and the TI stochastic frontier model of equation (11) is estimated using maximum likelihood methods.
- A time-varying decay (TVD) model assumes that v_{it} and u_{it} are independently and identically distributed such that $v_{it} \sim N(0,\sigma_v^2)$, $u_{it} = \{exp[-\eta(t - T_i)]\}u_i$ where T_i is the last period in the *i*th panel, η is a decay parameter to be estimated, and u_i is the base level of inefficiency which in this

case is the inefficiency for the last period observed for unit *i* (Battese and Coelli 1992). In what follows the TVD stochastic frontier model of equation (11) is estimated in a random effects framework by maximum likelihood methods.

It is worth considering the potential for simultaneous equations bias in equation (11) since both inputs and outputs appear on the right hand side. Under output-orientation, inputs are given and outputs are endogenous. But it is the normalised outputs (i.e. the output ratios) which appear in equation (11), and, since these are held constant (Cuesta and Orea 2002; Tonini 2004), there is no simultaneous equations bias.

2.2. Non-parametric estimation

The DEA approach does not require a functional form and allows for each firm to have different objectives. However, there are no parameter estimates (hence no significance tests), so there is no information about elasticities, and results can be severely affected by the presence of outliers. Given the diversity of the English higher education sector this could be a severe drawback. DEA makes no allowance for stochastic errors; while recent developments have introduced bootstrapping methods to the DEA methodology, such methods address issues of sampling variability rather than stochastic error (Coelli *et al.* 2005).

Taking a DEA approach, the technical efficiency of the firm or decision making unit (DMU) *i* at time *t* (TE_{it} = $D_{it}(x,y)$) is defined as (Charnes *et al* 1978; 1979):

$$TE_{it} = \frac{\sum_{m=1}^{M} a_{mt} y_{mit}}{\sum_{k=1}^{K} b_{kt} x_{kit}} \qquad (12)$$

where y_{mit} and x_{kit} are as already defined; a_{mt} is the weight applied to output *m* in time *t* and b_{kt} is the weight applied to input *k* in time *t*. For each DMU, weights are found by maximizing efficiency subject to the constraints that weights must be non-zero and universal. DEA can be applied in the context of constant returns to scale (CRS) or variable returns to scale (VRS) (see Coelli *et al.* 2005 for details). DMU *i* is efficient in time *t* if TE_{it} (= $D_{it}(x,y)$) is equal to 1.

Few studies have compared efficiency values derived using both parametric and non-parametric output distance functions, and fewer still in the context of higher education. In a comparison of parametric and non-parametric estimation of cost functions in the Canadian higher education sector there is a significant though not particularly high degree of correlation between the two methods (McMillan and Chan 2006). A higher correlation is found in the context of German universities, but the DEA and SFA models are not entirely comparable (Kempkes and Pohl 2010).

3. MODEL SPECIFICATION AND DATA

3.1 Inputs and outputs

The input and output variables used in this study are constructed from annual statistics for all HEIs in England published by the Higher Education Statistics Agency (HESA). HEIs can be seen as using raw materials, capital and labour to produce teaching and research outputs. Five measures of inputs are specified (see table 1 for detailed definitions).

- Undergraduate students (UGINPUT) are used to reflect the raw material input into undergraduate teaching. These vary by institution in terms of quality on entry. A quality adjusted measure of undergraduate student input (UGINQUAL) is obtained by weighting undergraduate students (UGINPUT) by average entry score (QUAL), as reflected by the average A level score of those students entering on the basis of A levels. This method of adjusting for undergraduate input quality is inexact because the average A level score is derived only from students entering each university with A level qualifications rather than from all students. Thus we assume that students entering on the basis of qualifications other than A levels will be similar in quality to those who enter on the basis of A levels, and that QUAL adequately reflects inter-university differences in undergraduate entry quality. An additional problem is that the units of measurement of the entry score data vary between two periods: A level points ranged from 2 to 10 for the top grade from 1996/97 to 2001/02 and A level tariff ranged from 40 to 120 from 2002/03 to 2008/09. To overcome this problem, the average entry scores for 1996/97 to 2001/02 have been converted to the tariff scale using an appropriate transformation reflecting the relationship between points and tariff[2]. Alternative specifications of the distance function are used in the subsequent analysis to assess the sensitivity of efficiency rankings to the quality adjustment of undergraduate input.
- Postgraduate students (PGINPUT) are used to reflect the raw material input to postgraduate teaching. These vary by institution in terms of quality on entry but, owing to data constraints, postgraduate inputs are not adjusted for quality. This is in line with previous comparable studies (Athanassopulos and Shale 1997; Glass *et al.* 2002; Flegg *et al.* 2004; Glass *et al.* 2006; Flegg and Allen 2007a; 2007b; Johnes 2008).
- The number of academic staff (STAFF) is used to reflect academic labour input.
- The expenditure on administration and central services (ADMIN) is used to reflect non-academic labour inputs[3].
- Capital inputs are measured by expenditure on library, computing and other learning resources (ACSERV).

Three measures of outputs are included in the model.

- Undergraduate teaching output is based on number of undergraduate first degree qualifications (UGOUTPUT). Measuring the quality of undergraduate teaching output is problematic. Approaches, such as using the number of 'good' degrees (Flegg *et al.* 2004; Flegg and Allen 2007a; 2007b) are

[2] Sensitivity of the results to this adjustment has been tested by producing additional results for the restricted period of 2002/03 to 2008/09. These results are reported elsewhere.

[3] Numbers of non-academic staff are not available for the whole period of the study.

inappropriate given the diversity of HEIs (and hence undergraduate qualifications) in the sample. But an unweighted count of all degree qualifications (Johnes 2008) disadvantages those HEIs producing higher quality. Thus an attempt to produce a quality-adjusted measure of undergraduate teaching output is made by including all undergraduate qualification types, but weighting by degree classification (see table 1) to produce the output variable UGOUTQUAL. Alternative specifications of the distance function are used in the subsequent analysis to assess the sensitivity of efficiency rankings to the quality adjustment of undergraduate output.

- Postgraduate teaching output is measured by number of postgraduate degree qualifications (PGOUTPUT). Owing to data constraints, this variable is not adjusted for quality which is in line with previous comparable studies (Athanassopulos and Shale 1997; Glass *et al.* 2002; Flegg *et al.* 2004; Glass *et al.* 2006; Flegg and Allen 2007a; 2007b; Johnes 2008).
- Income received for research purposes (RESEARCH) is included to reflect research output. This is a potentially controversial measure of research output. Alternatives, such as the ratings of university departments' research produced by the Research Assessment Exercise (RAE), which incorporate both quality and, if weighted by appropriate staff numbers, quantity (Glass *et al.* 2006) are unsatisfactory because they may be biased (Clerides *et al.* 2011) and are available only at intervals over the study period (1996, 2001 and 2008). Research income is easily available and is related to past research record; it therefore provides an up-to-date measure of both the quality and quantity of research (Abbott and Doucouliagos 2003; Flegg *et al.* 2004; Flegg and Allen 2007a; 2007b; Worthington and Lee 2008).

Table 1 here

Two further shortcomings should be considered. First outputs are not disaggregated by subject as to do so would cause degrees of freedom problems in the parametric model. Inter-university variations in subject mix, however, may be accounted for to some extent, first by the inclusion of HEI type dummies, and second by the estimation methods: RE allows for unobserved heterogeneity amongst the observations in the parametric context, and DEA calculates weights which are unique to each DMU in the data set in the non-parametric context. Seocnd, the outputs included here encompass only the teaching and research functions of HEIs. Universities also produce 'third mission' or social output such as the storage of knowledge, the provision of advice to business and comment on issues of public interest. In line with most previous studies, no attempt is made here to find and include a measure of this output, and results may be biased as a consequence of the omission.

3.2 Efficiency over time

HEIs are likely to experience productivity change over a 13-year period. This might be due to changes in efficiency (movements in relation to the frontier) or to changes in technology (shifts in the frontier).

Previous studies examining English higher education over earlier periods suggest positive but small annual average increases in total factor productivity which are more a consequence of advances in technology than improvements in technical efficiency (Flegg *et al.* 2004; Johnes 2008). Changes over time are investigated here in a variety of ways: in the TI parametric model, technical efficiency changes are assumed to be zero while technology changes are investigated using a set of 12 year dummies. These year dummies are included in the TVD parametric model to capture technology change, while the inclusion of the parameter η allows for technical efficiency change. The DEA models are estimated first using the pooled data (thereby assuming a common frontier and hence zero technology change over the whole 13-year period) and second by taking a within-year approach to allow the frontier (and hence technology) to change over time.

3.3 HEI type

HEIs are divided into three different types in this study. Pre-1992 HEIs are traditional universities which had university status prior to the Further and Higher Education Act of 1992. They undertake teaching (undergraduate and postgraduate) and research in a whole range of subjects including medical and veterinary sciences. Post-1992 HEIs are former polytechnics which, by the provision of the Further and Higher Education Act of 1992 have been allowed to award their own degrees and use the title university. Finally, (former) colleges of higher education have been allowed to apply for university and degree-awarding status since 2003. They are often (but not always) specialist institutions concentrating on a particular discipline. Previous research suggests that technical efficiency is highest amongst the former colleges of higher education, followed by the post- and pre-1992 HEIs (Johnes 2008).

3.4 Model

The precise specification of the parametric distance function to be estimated is:

$$-\ln y_{3it} = \alpha_0 + \sum_{m=1}^{2} \alpha_m \ln\left(\frac{y_{mit}}{y_{3it}}\right) + \frac{1}{2}\sum_{m=1}^{2}\sum_{n=1}^{2} \alpha_{mn} \ln\left(\frac{y_{mit}}{y_{3it}}\right)\ln\left(\frac{y_{nit}}{y_{3it}}\right) + \sum_{k=1}^{5} \beta_k \ln x_{kit} + \frac{1}{2}\sum_{k=1}^{5}\sum_{l=1}^{5} \beta_{kl} \ln x_{kit} \ln x_{lit} + \sum_{k=1}^{5}\sum_{m=1}^{2} \delta_{km} \ln(x_{kit}) \ln\left(\frac{y_{mit}}{y_{3it}}\right) + \sum_{t=2}^{13} \tau_t t_{it} + \omega_{1i} T_{1i} + \omega_{2i} T_{2i} + v_{it} - u_{it} \qquad i = 1,2,\dots,N \qquad (13)$$

where t_{it} are time dummies (where the first year of the sample is the base year) included to capture changes in productivity over time; T_{1i} and T_{2i} are dummy variables to reflect (former) colleges of higher education and post-1992 HEIs respectively. The numeraire is y_3 (the measure of undergraduate teaching output). In order to check the sensitivity of the results to this choice of numeraire, results presented in this paper have also been generated using respectively y_1 (the measure of postgraduate teaching output) and y_2 (the measure of research output) as numeraire. In line with previous research (Coelli and Perelman 2000; Paul and Nehring 2005), results are remarkably insensitive to choice of numeraire and all conclusions remain the same.

Three variants of this parametric model are estimated in the sequel: the error u_{it} is estimated using, respectively, a) TI RE, b) TI SFA and c) TVD SFA. All input and output variables are mean-corrected (Cuesta and Orea 2002; Cuesta and Zofío 2005). In the context of DEA, estimation is performed on the assumption of a) CRS and b) VRS (output-oriented), and each of these variants is estimated on i) the pooled sample and ii) within year. In the case of both estimation approaches, two models are specified: model 1 makes no adjustment for the quality of undergraduate teaching input and output (x_2 is UGINPUT and y_3 is UGOUTPUT); model 2 makes an adjustment for quality of both undergraduate teaching input and output (x_2 is UGINQUAL and y_3 is UGOUTQUAL). In total there are therefore 6 sets of parametric efficiency estimates and 8 sets of non-parametric efficiency estimates.

3.5 Data

The analysis is based on a panel of data covering 13 years from 1996/97 to 2008/09. The sample is unbalanced for a number of reasons. First, some HEIs merged during the study period. When this happened the merged institution was treated as a different entity from the HEIs which merged to form it (this approach is similar to Cuesta and Orea 2002). Second, some HEIs entered the higher education sector during the period. Third, HEIs which produced a zero amount of any output or used a zero amount of any input during a given year were removed from the sample in that year. Finally, four HEIs were removed entirely from the sample: Open University was removed because of its large size and unique nature of teaching provision; the University of London (Institutes and activities) was also excluded on the grounds that the composition of the component HEIs recorded under this umbrella changed over time; University of Buckingham was deleted because it is not publicly funded; and Heythrop College because it only became publicly funded during the time period under consideration. The number of HEIs included in each year therefore varies from 108 to 113, and the panel includes 1444 observations in total.

Descriptive statistics are provided in table 2 for all variables across the pooled sample. The typical HEI produces just over 1000 graduates from postgraduate degrees and over 2500 graduates from undergraduate degrees. In addition, it receives over £72 million in research grants. This variable has a particularly large spread suggesting that some universities at the extremes are involved in very little or an extremely large amount of research activity. The inputs used by the average HEI are nearly 2000 postgraduate students, 7000 undergraduate students, and just over 900 academic staff. In addition it spends over £9 million on academic services and nearly £17 million on administration. Examination of the inputs and outputs over time (not shown here) suggests that there has been an upward trend in all inputs over the entire period; outputs have risen until the final year when there has been a slight fall.

Table 2 here

The averages across the sector conceal considerable differences between the different types of HEIs. Former colleges of higher education are considerably smaller in terms of both inputs used and outputs produced than either of the other two groups of HEIs (see figures 1a and 1b). The emphasis on the different production activities also varies by type. Research activity is dominant in pre-1992 universities where the value of research income is typically twice that in post-1992 HEIs and 6 times that in former colleges of higher education. Undergraduate teaching, on the other hand is predominantly in the post-1992 HEIs (both before and after adjusting for quality), and postgraduate outputs are produced almost equally by both pre- and post-1992 HEIs at around 3 times the volume of former colleges of higher education. Postgraduate inputs are higher in pre- than post-1992 HEIs, as are staff, administrative and capital inputs. The relative size of undergraduate input varies according to whether quality is taken into account: the volume of undergraduate inputs is smaller in pre- than post-1992 HEIs, but this is reversed when quality is incorporated into the measure.

Figures 1a and 1b here

4. RESULTS

The estimated parameters of models 1 and 2 are presented in table 3. All elasticities have the expected signs at the sample means and the evidence regarding returns to scale (evaluated at the mean value of inputs and outputs) is that returns are decreasing. This contrasts with the finding of (ray) economies of scale in English higher education calculated from an estimated cost function for the period 2000/01 to 2002/03 (Johnes *et al.* 2005). The discrepancy may arise because of the difference between the studies in the estimation approach (output distance function versus cost function), the definitions of outputs, the incorporation here of quality of undergraduate teaching, and the considerably longer time period covered by this study.

Table 3 here

4.1 Efficiency scores

Statistics summarizing estimated efficiencies are shown in table 3 for the parametric models and in table 4 for the non-parametric models. The presence of technical inefficiency in the TI SFA (TVD SFA) model can be assessed using the test of H_0: $\sigma_u^2 = 0$ (H_0: $\mu = 0$) (Coelli *et al.* 2005). H_0 is rejected in both cases, and for both models 1 and 2, and so inefficiency is significant.

Table 4 here

The first main result regards the levels of efficiency estimated for the English higher education sector. While many institutions are operating reasonably efficiently, there is considerable scope at the lower end for some institutions to improve their efficiency: all estimation methods indicate that minimum efficiency is at or below 60%.

Second, the methods of estimation differ in terms of estimates of mean efficiency: the parametric estimates of mean efficiency are at the bottom end (at around 70% to 80%), the VRS non-parametric estimates are at the top end (at around 82% to 95%), and the CRS non-parametric estimates lie somewhere in the middle (at around 74% to 90%). These non-parametric estimates of efficiency are broadly in line with those derived from previous non-parametric results (Athanassopulos and Shale 1997; Glass *et al.* 2002; Flegg *et al.* 2004; Glass *et al.* 2006; Flegg and Allen 2007a; 2007b; Johnes 2008). The fact that parametric and non-parametric efficiency results differ should not come as a surprise: the parametric methods used here, in contrast to DEA, do not allow individual institutions to vary in their objectives, but instead apply the same parameters of the distance function to all HEIs. Given the diversity of the HEIs in this data set, perhaps a random parameter distance function might be a more appropriate approach, but this makes considerable demands on the data and is beyond the scope of the present paper.

Policy-makers should be aware that estimates of the *level of* efficiency (and hence estimates of scope for efficiency savings) vary considerably by method of estimation. This is less of a problem, however, if both methods provide the same ranking. Rank order correlation coefficients, presented in tables 5a and 5b, suggest that whilst rankings for all pairs of efficiency scores are significantly positively correlated, the level of correlation is low ranging from 0.259 to 0.461. Closer scrutiny reveals that while each method identifies broadly the same small groups of high- and low-performing HEIs, there are vast differences in rankings in the middle. Policy-makers should therefore be aware that choice of methodological approach may well affect conclusions regarding *relative* efficiency of HEIs.

Tables 5a and 5b here

The final point to note from the efficiency results is the sensitivity of the results to whether or not undergraduate input and output measures are adjusted for quality. In the parametric models, the incorporation of quality appears to provide higher estimates of mean (and minimum efficiency) at least in the cases of the two SFA estimation methods. There is little difference in the DEA models, however. This may once again be a consequence of SFA applying the same parameters of the distance function to all HEIs in contrast to DEA which does not. It should be noted that rank correlations between pairs of efficiencies which differ only in whether or not undergraduate teaching input and output have been adjusted for quality are 0.85 or above. The discussion of results in the remainder of this section is therefore in the context of the results from model 2 which adjusts undergraduate teaching input and output for quality.

4.2 Efficiency over time

An understanding of the patterns of change in efficiency over time is important here to provide a context for the examination of the comparison of efficiency in merging and non-merging HEIs. The SFA TVD model, the only one to allow for both technical efficiency and technology change, suggests that there has been no significant technology change while technical efficiency has been decreasing by 1.4% per annum over the period 1996/97 to 2008/09. Given that there is no significant change in the frontier over the period, this implies that the inefficient institutions are becoming relatively more inefficient compared to the frontier HEIs over time.

There are clearly similar trends over time in mean efficiency (see figure 2) between the SFA TVD results and the pooled DEA results (particularly those estimated on the assumption of CRS). This is perhaps not surprising since the former found no significant technology change and the latter models do not allow for technology change. The within-group DEA models, however, show a more random pattern of mean efficiency over time, and there is no obvious trend. Technology change cannot be established from the DEA models because of the unbalanced panel nature of the data set.

Figure 2 here

4.3 Efficiency by HEI type

The parametric frontier models of estimation provide evidence that the former colleges of higher education are significantly more efficient than pre-1992 universities. The DEA efficiencies (see table 6) suggest that both former colleges of higher education and post-1992 HEIs are, on average, more efficient than their pre-1992 counterparts. It is therefore clear that the differences in the input and output characteristics of these different types of institutions, both measured (see figures 1a and 1b) and unmeasured (eg. differences in subject mix) feed through into differences in efficiency. The poorer performance of the pre-1992 HEIs may be a consequence of many of these HEIs being involved in teaching medical and veterinary sciences which are resource intensive and involve undergraduates in longer than average courses. Thus attempts to measure efficiency in this diverse sector need explicitly to take into account inter-institutional differences in provision.

Table 6 here

4.4 Efficiencies by merger activity

A merger is defined as the union of two or more institutions to form an entirely new entity. Included in the sample data are 19 instances of (horizontal) merger and this enables us to examine the effects on efficiency of merger. Of the 19 instances of merger, 4 occurred between pairs of pre-1992 HEIs, 4 between pairs of former colleges of higher education, 8 between pre-1992 HEIs and former colleges of higher education, 2 between post-1992 HEIs and former colleges of higher education, and 1 between pre- and post1992 HEIs. Historically, mergers have not been popular in the higher education sector (Berriman and Jacobs 2010). Despite this, a merger may have efficiency benefits which accrue from returns to scale, as a consequence of increased administrative, economic and academic efficiency (Skodvin 1999; Harman 2000), or returns to scope if the merging institutions have complementary activities (Skodvin 1999).

A comparison of the mean efficiency of three types of HEIs (pre-, post- and non-merging HEIs) in table 7 shows that, with the exception of the pooled CRS DEA model, average efficiency is considerably higher amongst post- than pre- and non-merging institutions. The null hypothesis of identical means in the three groups is rejected in all cases. This finding also holds when the investigation is carried out by year (detailed results not reported). These results should be accompanied by a strong caveat, however: whether the difference in efficiency is a consequence of the merger or of some other underlying characteristic(s) – and merging and non-merging HEIs are very different in terms of their characteristics – is unknown.

Table 7 here

4.5 Elasticities of input substitution

An advantage of the parametric distance function is that it can provide measures of elasticities of substitution between the inputs (as defined in section 2). The normalized MRTS and the Morishima elasticities (calculated as the mean across values for all and subgroups of universities) are displayed in table 8[4]. The normalized MRTS (sub_{12}) in column 1 suggests that it is easier to substitute out of x_1 (postgraduate input) into x_2 (undergraduate input) than the other way around. The Morishima elasticities suggest, in contrast, that substitution between these raw material inputs in either direction is difficult. All elasticties suggest that substitutability becomes easier post-merger (see columns 2 to 4), but the differences in substitutability between pre- post- and non-merging HEIs is not significant.

Tables 8a and 8b here

The normalized MRTS for capital and labour inputs (sub_{34} and sub_{35}) indicate that it is harder to substitute out of academic staff into either of the other two inputs (capital and administration) than the other way around. The value of sub_{45} suggests that it is easier to substitute out of capital into administrative input than vice versa; moreover, this is significantly easier in pre-merging HEIs and significantly harder in post-merging HEIs (than in non-merging HEIs). The Morishima elasticities point to academic and administrative inputs being the pair of inputs with lowest substitution possibilities (since the value of the elasticity is highly positive), while academic staff and capital are the inputs with the greatest potential for substitution.

There are some interesting (and significant) differences in capital and labour input substitutability between pre- and post-merging HEIs. For example, substitution out of capital into administrative input is 4 times harder than switching from administrative input into capital in post-merger HEIs, compared to being only 1.5 times harder in pre-merger HEIs. In addition, substitution out of academic staff into administrative input is 3 times harder than switching from administrative input into academic staff in post-merger HEIs, compared to being only half as difficult in pre-merger HEIs. Merger activity seems to lead to administrative input becoming an abundant input relative to both capital and academic labour. Similarly academic labour becomes abundant relative to capital following merger.

[4] Note that only the results for model 2 estimated using the SFA TI estimation method are shown. These results are generally representative of those from other estimating methods; the restriction of the results to just one model is to make the interpretation easier.

5. CONCLUSIONS

HEIs are likely to face tight fiscal constraints over the coming years. There has been some suggestion that cuts can be absorbed by increased efficiency which in turn may be effected by merging some HEIs. The purpose of this study is to estimate a multi-input multi-output distance function in order to provide a better understanding of potential for efficiency improvements in the sector. The results are derived from an unbalanced panel data set of English HEIs over a period from 1996/97 to 2008/09. This is a period of rapid change both in terms of expansion of all inputs and outputs and in terms of considerable merger activity. This study differs in a number of ways from previous ones which have examined efficiency in the English higher education sector. First, it uses both parametric and non-parametric estimation techniques. Second, quality of undergraduate teaching input and output is incorporated into the models. Third, the potential for substitution between inputs is estimated. Fourth, it presents an exploratory analysis of the effect (in terms of efficiency and substitutability between inputs) of merger activity.

The first main finding from the study is that the level of average efficiency in the English university sector varies considerably by estimation method with parametric methods generally providing the lowest estimates of efficiency and parametric methods the highest. The extent to which cuts can be offset by increased efficiency is therefore unclear. Moreover, the rank correlations between parametric and non-parametric efficiencies are significantly positive but low (0.259 to 0.461). Both methods identify the same set of best- and worst-performing HEIs, but differ in particular for HEIs in the middle. Policy-makers should be aware that the choice of methodology could affect their conclusions regarding both the *level of efficiency* in the sector as a whole, and the *relative efficiency* of individual HEIs.

There is some evidence of a slight decline in technical efficiency over time combined with no change in technology. This suggests that inefficient HEIs are becoming more inefficient relative to the frontier institutions over the sample period. Thus the rapid expansion observed over the period has had a more detrimental effect on the HEIs which were already inefficient than on those institutions operating on the frontier.

The second main result concerns the efficiency of different types of HEI. Former colleges of higher education and post-1992 HEIs appear to be more efficient, on average, than pre-1992 universities. There are clear differences in the portfolio of (measured) outputs produced by the different types of HEIs (post-1992 institutions and former colleges of higher education have a higher concentration of teaching outputs relative to research than pre-1992 HEIs), as well as differences in subject mix (which is not measured). Policy-makers should therefore be aware that such differences may result in differential efficiencies.

A third major finding concerns the effect of merger activity on efficiency. The typical pre-merger HEI has efficiency which is similar to (or slightly higher than) the average non-merging HEI. Thus merger activity in English higher education has not, historically, been a reaction to a crisis in efficiency in the HEIs proposing to merge. Of particular interest to institutions considering merger or collaboration activities is the result that the typical merged HEI is significantly more efficient than either pre-merger or non-merging HEIs, suggesting that, on average, merging is a positive activity. But these results should be interpreted with extreme care as the characteristics of the three types of institutions (pre-, post- and non-merging HEIs) differ considerably and so the efficiency differences may be a consequence of something other than the merger.

Finally the analysis provides results regarding input substitutability. With respect to the raw material inputs of postgraduate and undergraduates (the latter being weighted for quality), the normalized MRTS value suggests that it is easier to substitute from postgraduates into undergraduates (than the other way around), and that this ease of substitution increases in post-merger compared to pre- and non-merging institutions. The Morishima elasticities suggest that substitution is difficult in both directions, but that it becomes slightly easier to substitute out of postgraduates into undergraduates post-merger. These results are of particular interest in the present context of increasing undergraduate fees in English universities which may in turn have an effect which that might have on the balance of postgraduates and undergraduates.

In the context of capital and labour inputs, we find that there is least scope for substitution between academic staff and administrative inputs and greatest scope for substitution between academic staff and capital inputs. When we examine input substitutability by merger activity we find that, generally, pre-merger HEIs experience the most flexibility. Thus, in the past, institutions which have entered into mergers have been no less efficient than their non-merging counterparts, and have also experienced considerably more flexibility in terms of input substitutability. While there is some preliminary evidence here of greater efficiency in merged HEIs, there is also evidence that institutions which have merged in the past have had favourable characteristics (i.e. increased flexibility in input substitution) which were likely to lead to a successful merger. Policy-makers should be aware that benefits may not accrue to mergers in which the participants do not display these characteristics.

This work should be seen as an illustration of the uses of a parametric multi-input multi-output distance function. Whilst it has presented some interesting results concerning efficiency, substitutability and merger activity, it has perhaps raised more questions than it has answered. In particular the model needs to be refined in order to look at, for example, subject mix and the balance of home/EU and overseas students. The results regarding mergers have provided sufficient evidence of the need for a more rigorous analysis of the effects of merger. Such an analysis would construct a matched sample (or a control group) of non-merging HEIs with similar characteristics to those of the merging HEIs with which to make comparisons. Thus the results here should be seen as a signal of the need for further empirical investigation.

REFERENCES

Abbott, M. and H. Doucouliagos (2003). 'The efficiency of Australian universities: a data envelopment analysis.' *Economics of Education Review* 22: 89-97.

Aigner, D., C. A. K. Lovell and P. Schmidt (1977). 'Formulation and estimation of stochastic frontier production models.' *Journal of Econometrics* 6: 21-37.

Athanassopulos, A. and E. A. Shale (1997). 'Assessing the comparative efficiency of higher education institutions in the UK by means of data envelopment analysis.' *Education Economics* 5(2): 117-135.

Balcombe, K., H. Doucouliagos and I. Fraser (2007). 'Input usage, output mix and industry deregulation: an analysis of the Australian dairy manufacturing industry.' *The Australian Journal of Agricultural and Resource Economics* 51(2): 137-156.

Baños-Pino, J., V. Fernández-Blanco and A. Rodríguez-Álvarez (2002). 'The allocative efficiency measure by means of a distance function: the case of Spanish railways.' *European Journal of Operational Research* 137(1): 191-205.

Battese, G. E. and T. J. Coelli (1992). 'Frontier production functions, technical efficiency and panel data: with application to paddy farmers in India.' *Journal of Productivity Analysis* 3: 153-169.

Blackorby, C. and R. Russell (1989). 'Will the real elasticity of substitution please stand up? (A comparison of Allen/Uzawa and Morishima elasticities).' *American Economic Review* 79: 882-888.

Chizmar, J. F. and B. J. McCarney (1984). 'An evaluatio of 'trade-offs' implementation using canonical estimation of joint educational production functions.' *Journal of Economic Education* 15(1): 11-20.

Chizmar, J. F. and T. A. Zak (1983). 'Modeling multiple outputs in educational production functions.' *American Economic Review* 73(2): 18-22.

Chizmar, J. F. and T. A. Zak (1984). 'Canonical estimation of joint educational production functions.' *Economics of Education Review* 3(1): 37-43.

Clerides, S., P. Pashardes and A. Polycarpou (2011). 'Peer review vs metric-based assessment: testing for bias in the RAE ratings of UK Economics departments.' *Economica* 78(311): 565-583.

Coelli, T. J. (2000). 'On the econometric estimation of the distance function representation of a production technology.' *Working Paper* 2000/042.

Coelli, T. J. and S. Perelman (1999). 'A comparison of parametric and non-parametric distance functions: with application to European railways.' *European Journal of Operational Research* 117: 326-339.

Coelli, T. J. and S. Perelman (2000). 'Technical efficiency of European railways: a distance function approach.' *Applied Economics* 32: 1967-1976.

Coelli, T. J., D. S. P. Rao, C. J. O'Donnell and G. E. Battese (2005). *An Introduction to Efficiency and Productivity Analysis*. New York, Springer.

Cuesta, R. A. and L. Orea (2002). 'Mergers and technical efficiency in Spanish savings banks: a stochastic distance function approach.' *Journal of Banking and Finance* 26(12): 2231-2247.

Cuesta, R. A. and J. Zofío (2005). 'Hyperbolic efficiency and parametric distance functions:with application to Spanish savings banks.' *Journal of Productivity Analysis* 24: 31-48.

Flegg, T. and D. Allen (2007a). 'Does expansion cause congestion? The case of the older British universities, 1994-2004.' *Education Economics* 15(1): 75-102.

Flegg, T. and D. Allen (2007b). 'Using Cooper's approach to explore the extent of congestion in the New British universities.' *Economics Issues* 12(2): 47-81.

Flegg, T., D. Allen, K. Field and T. W. Thurlow (2004). 'Measuring the efficiency of British universities: a multi-period data envelopment analysis.' *Education Economics* 12(3): 231-249.

Glass, J. C., G. McCallion, D. G. McKillop, S. Rasaratnam and K. S. Stringer (2006). 'Implications of variant efficiency measures for policy evaluation in UK higher education.' *Socio-Economic Planning Sciences* 40: 119-142.

Glass, J. C., D. G. McKillop and G. O'Rourke (2002). 'Evaluating the productive performance of UK universities as cost-constrained revenue maximizers: an empirical analysis.' *Applied Economics* 34: 1097-1108.

Griffiths, S. (2010). 'Be afraid, parents'. *The Sunday TImes*. London Retrieved from http://www.timesonline.co.uk/tol/life_and_style/education/article6990896.ece accessed 25th February 2010.

Grosskopf, S., K. J. Hayes and J. G. Hirschberg (1995). 'Fiscal stress and the production of public safety: a distance function approach.' *Journal of Public Economics* 57: 277-296.

Gyimah-Brempong, K. and A. O. Gyapong (1991). 'Characteristics of education production functions: An application of canonical regression analysis.' *Economics of Education Review* 10(1): 7-17.

Harman, G. (2000). 'Institutional mergers in Australian higher education since 1960.' *Higher Education Quarterly* 54(4): 343-366.

HESA (1994/95a). *Resources of Higher Education Institutions*. Cheltenham, http://www.hesa.ac.uk/index.php/content/view/831/251/.

HESA (1994/95b). *Students in Higher Education Institutions*. Cheltenham, http://www.hesa.ac.uk/index.php/content/view/830/251/.

HESA (1995/96a). *Resources in Higher Education Institutions*. Cheltenham, http://www.hesa.ac.uk/index.php/content/view/827/251/.

HESA (1995/96b). *Students in Higher Education Institutions*. Cheltenham, http://www.hesa.ac.uk/index.php/content/view/826/251/.

HESA (1996/97a). *Resources in Higher Education Institutions*. Cheltenham, http://www.hesa.ac.uk/index.php/content/view/823/251/.

HESA (1996/97b). *Students in Higher Education Institutions*. Cheltenham, http://www.hesa.ac.uk/index.php/content/view/822/251/.

HESA (1997/98a). *Resources in Higher Education Institutions*. Cheltenham, http://www.hesa.ac.uk/index.php/content/view/819/251/.

HESA (1997/98b). *Students in Higher Education Institutions*. Cheltenham, http://www.hesa.ac.uk/index.php/content/view/818/251/.

HESA (1998/99a). *Resources in Higher Education Institutions*. Cheltenham, http://www.hesa.ac.uk/index.php/content/view/815/251/.

HESA (1998/99b). *Students in Higher Education Institutions*. Cheltenham, http://www.hesa.ac.uk/index.php/content/view/814/251/.

HESA (1999/00a). *Resources in Higher Education Institutions*. Cheltenham, http://www.hesa.ac.uk/index.php/content/view/811/251/.

HESA (1999/00b). *Students in Higher Education Institutions*. Cheltenham, http://www.hesa.ac.uk/index.php/content/view/810/251/.

HESA (2000/01a). *Resources in Higher Education Institutions*. Cheltenham, http://www.hesa.ac.uk/index.php/content/view/807/251/.

HESA (2000/01b). *Students in Higher Education Institutions*. Cheltenham, http://www.hesa.ac.uk/index.php/content/view/802/251/.

HESA (2001/02a). *Resources in Higher Education Institutions*. Cheltenham, http://www.hesa.ac.uk/index.php/content/view/1551/251/.

HESA (2001/02b). *Students in Higher Education Institutions*. Cheltenham, http://www.hesa.ac.uk/index.php/content/view/1549/251/.

HESA (2002/03a). *Resources in Higher Education Institutions*. Cheltenham, http://www.hesa.ac.uk/index.php/content/view/1555/251/.

HESA (2002/03b). *Students in Higher Education Institutions*. Cheltenham, http://www.hesa.ac.uk/index.php/content/view/1554/251/.
HESA (2003/04a). *Resources in Higher Education Institutions*. Cheltenham.
HESA (2003/04b). *Students in Higher Education Institutions*. Cheltenham.
HESA (2004/05a). *Resources in Higher Education Institutions*. Cheltenham.
HESA (2004/05b). *Students in Higher Education Institutions*. Cheltenham.
HESA (2005/06a). *Resources in Higher Education Institutions*. Cheltenham.
HESA (2005/06b). *Students in Higher Education Institutions*. Cheltenham.
HESA (2006/07a). *Resources in Higher Education Institutions*. Cheltenham.
HESA (2006/07b). *Students in Higher Education Institutions*. Cheltenham.
HESA (2007/08a). *Resources in Higher Education Institutions*. Cheltenham.
HESA (2007/08b). *Students in Higher Education Institutions*. Cheltenham.
HESA (2008/09a). *Resources in Higher Education Institutions*. Cheltenham.
HESA (2008/09b). *Students in Higher Education Institutions*. Cheltenham.
Johnes, G., J. Johnes, E. Thanassoulis, P. Lenton and A. Emrouznejad (2005). *An Exploratory Analysis of the Cost Structure of Higher Education in England*. London, Department for Education and Skills.
Johnes, J. (2006). 'DEA and its application to the measurement of efficiency in higher education.' *Economics of Education Review* 25(3): 273-288.
Johnes, J. (2008). 'Efficiency and productivity change in the English higher education sector from 1996/97 to 2004/05.' *The Manchester School* 76(6): 653-674.
Karagiannis, G., P. Midmore and V. Tzouvelekas (2004). 'Parametric decomposition of output growth using a stochastic input distance function.' *American Journal of Agricultural Economics* 86(4): 1044-1057.
Kempkes, G. and C. Pohl (2010). 'The efficiency of German universities - some evidence from nonparametric and parametric methods.' *Applied Economics* 42(16): 2063-2079.
McMillan, M. L. and W. H. Chan (2006). 'University efficiency: A comparison and consolidation of results from stochastic and non-stochastic methods.' *Education Economics* 14(1): 1-30.
Morgan, J. (2011a). 'Lancaster and Liverpool aim to strengthen global hand with 'federal structure' collaboration'. *Times Higher Education*. 29th September 2011
Morgan, J. (2011b). 'Mersey-Lancs links spark fears'. *Times Higher Education*. 4th August 2011
Morgan, J. (2011c). 'Midlands mutality breaks new ground'. *Times Higher Education*. 3rd February 2011
O'Donnell, C. J. and T. Coelli (2003). 'A Bayesian approach to imposing curvature on distance functions.' *Centre for Efficiency and Productivity Analysis* Working paper No. 03/2003.
Paul, C. J. M., W. E. Johnston and G. A. G. Frengley (2000). 'Efficiency in New Zealand sheep and beef farming: the impacts of regulatory reform.' *Review of Economics and Statistics* 82(2): 325-337.
Paul, C. J. M., W. E. Johnston and G. A. G. Frengley (2002). 'Post-reform substitution and cost efficiency in the New Zealand agricultural sector.' *International Journal of Business and Economics* 1(2): 135-146.
Paul, C. J. M. and R. Nehring (2005). 'Product diversification, production systems, and economic performance in US agricultural production.' *Journal of Econometrics* 126: 525-548.
Rodríguez-Álvarez, A., V. Fernández-Blanco and C. A. K. Lovell (2004). 'Allocative inefficiency and its cost: the case of Spanish public hospitals.' *International Journal of Production Economics* 92: 99-111.
Shephard, R. W. (1970). *Theory of Cost and Production Frontiers*. Princeton, NJ, Princeton University Press.
Skodvin, O.-J. (1999). 'Mergers in higher education - success or failure?' *Tertiary Education and Management* 5(1): 65-80.

Tonini, A. (2004). 'A distance function approach for the Polish agricultural sector using generalised maximum entropy with linear inequality restrictions.' *Working paper*.

Uri, N. D. (2003a). 'The adoption of incentive regulation and its effect on technical efficiency in telecommunications in the United States.' *International Journal of Production Economics* 86: 21-34.

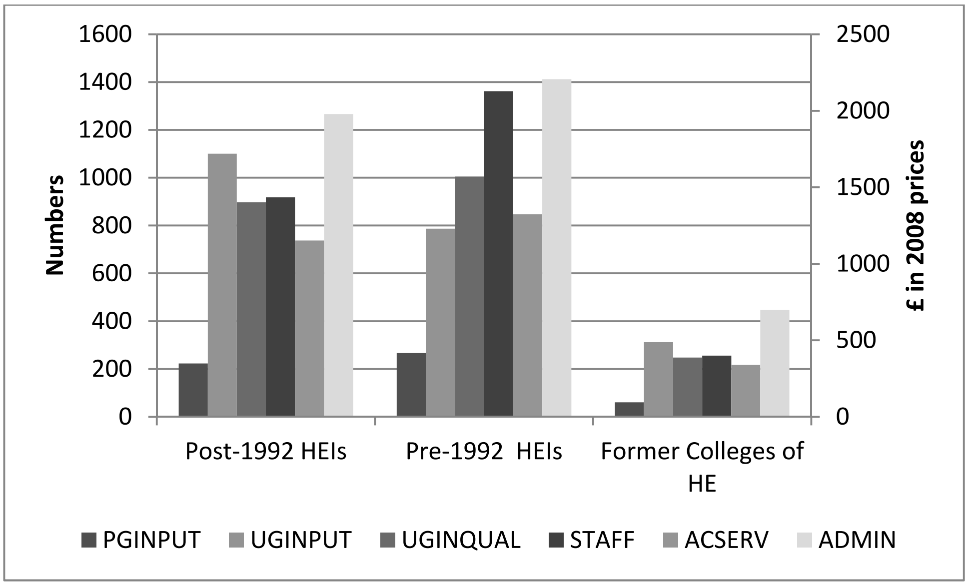
Uri, N. D. (2003b). 'Technical efficiency in telecommunications in the United States and the impact of incentive regulation.' *Applied Mathematical Modelling* 27: 53-67.

Whiteman, J. L. (1999). 'The measurement of efficiency where there are multiple outputs.' *Centre of Policy Studies/IMPACT Centre Working Papers*.

Worthington, A. C. and B. L. Lee (2008). 'Efficiency, technology and productivity change in Australian universities 1998-2003.' *Economics of Education Review* 27(3): 285-298.

Figure 1: Mean outputs and inputs by type of HEI

a) **Inputs**



b) **Outputs**

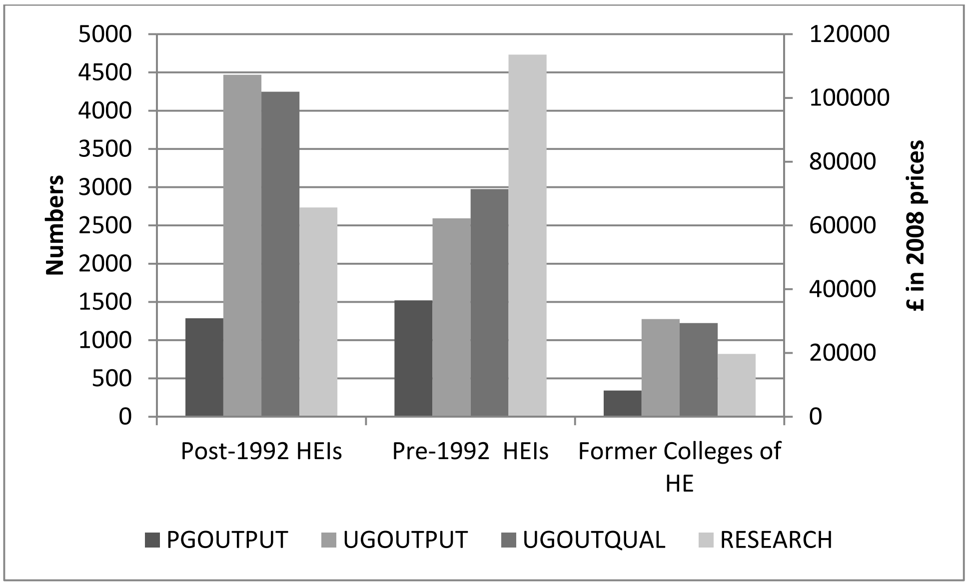


Figure 2: Mean efficiency over time estimated using parametric and non-parametric models

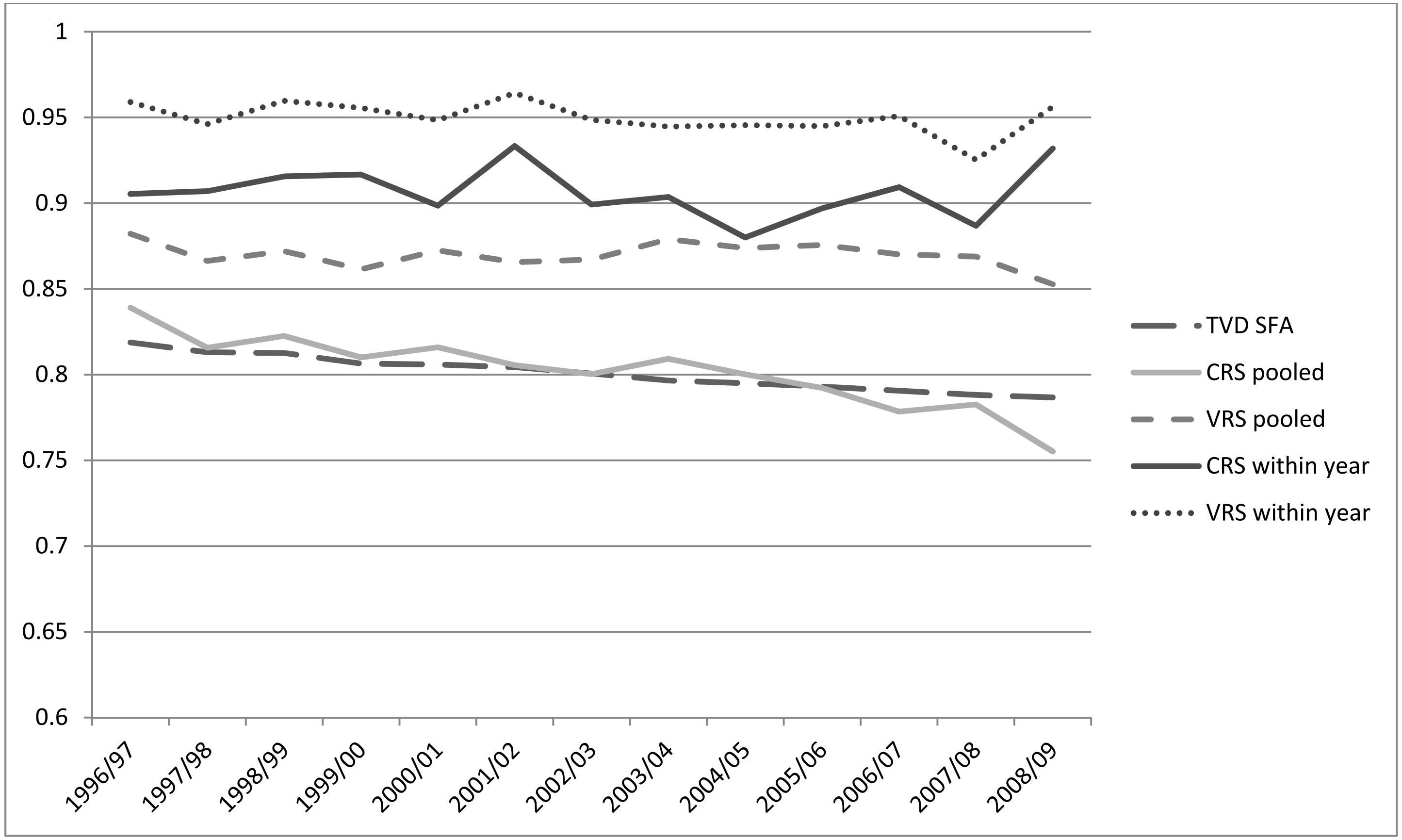


Table 1: Definitions of inputs and outputs

Variable name		Definition
Inputs:		
PGINPUT	x_1	**The total number of FTE postgraduate students (i.e. students on programmes of study leading to higher degrees, diplomas and certificates, including Postgraduate Certificate of Education (PGCE) and professional qualifications)**
UGINPUT	x_2 Model 1	**The total number of FTE first degree and other undergraduates. The 'other undergraduates' category includes qualification aims below degree level such as Foundation Degrees and Higher National Diploma (HND)[2]**
QUAL		**1996/97-2001/02: Average A-level points of full-time, first year, first degree students at English HEIs converted to the tariff scale using an appropriate transformation reflecting the relationship between points and tariff; 2002/03-2008/09: Average A-level tariff scores of full-time, first year, first degree students at English HEIs**
UGINQUAL	x_2 Model 2	**UGINPUT*QUAL/mean(QUAL)**
STAFF	x_3	**The number of full-time academic staff plus 0.5 times the number of part-time academic staff**
ACSERV[1]	x_4	**Expenditure incurred on centralised academic services such as the library and learning resource centres, central computer and computer networks, centrally run museums, galleries and observatories, and any other general academic services (in £000s)**
ADMIN[1]	x_5	**Expenditure on total administration and central services including expenditure on staff and student facilities (including, for example, Careers Advisory Service, all grants to student societies, emoluments to wardens of halls of residence, accommodation office, athletic and sporting facilities, excluding maintenance, and the institution's health service) and general educational expenditure (in £000s)**
Outputs		
PGOUTPUT	y_1	**The number of higher degrees plus total other postgraduate qualifications awarded (including doctorate, other higher degrees, PGCEs and other postgraduate qualifications)**
RESEARCH[1]	y_2	**Income received in funding council grants plus income received in research grants and contracts (in £000s)**
UGOUTPUT	y_3 Model 1	**The number of first degree and other undergraduate degrees awarded (see definition of UG)**
UGOUTQUAL	y_3 Model 2	UGOUTPUT *WEIGHT/mean(WEIGHT) where WEIGHT is: first class=30; upper second class=25; lower second class=20; third class=15; unclassified=10; other undergraduate qualification=5.

Notes:

1. These variables are deflated to July 2008 values using the higher education pay and prices index (http://www.universitiesuk.ac.uk/statistics/heppi/default.asp).

2. A full description of students included in these categories can be found in the HESA data documentation.

Degree classification weightings are: first class=30; upper second class=25; lower second class=20; third class=15; unclassified=10; other undergraduate qualification=5

3. Source of entry score data: HESA Student Record 1996/97-2008/09. Copyright Higher Education Statistics Agency Limited 2010. HESA cannot accept responsibility for any inferences or conclusions derived from the data by third parties.

4. Source of all other data:(HESA 1994/95a; 1994/95b; 1995/96a; 1995/96b; 1996/97a; 1996/97b; 1997/98a; 1997/98b; 1998/99a; 1998/99b; 1999/00a; 1999/00b; 2000/01a; 2000/01b; 2001/02a; 2001/02b; 2002/03a; 2002/03b; 2003/04a; 2003/04b; 2004/05a; 2004/05b; 2005/06a; 2005/06b; 2006/07a; 2006/07b; 2007/08a; 2007/08b; 2008/09a; 2008/09b).

Table 2: Descriptive statistics

	1996/97-2008/09 N=1444	
Variable	Mean	SD
Outputs:		
PGOUTPUT	1096.63	913.41
UGOUTPUT	2673.78	1850.53
UGOUTQUAL	2765.97	1834.94
RESEARCH	72192.86	79655.38
Inputs:		
PGINPUT	1919.13	1517.81
UGINPUT	7219.74	4749.82
QUAL	285.92	81.15
UGINQUAL	7437.14	5852.08
STAFF	905.91	867.01
ACSERV	9757.03	8539.87
ADMIN	16827.69	12617.76

Notes:

1. See Table 1 for variable definitions.

Table 3: Parameter estimates of the translog output distance function 1996/97–2008/09

		MODEL 1: NO QUALITY						MODEL 2: QUALITY					
		a) RE		b)TI		c) TVD		a) RE		b) TI		b) TVD	
		coeff	P-value	coeff	P-value	coeff	P-value	coeff	P-value	coeff	P-value	coeff	P-value
CONSTANT		0.031	0.000	-0.359	0.000	-0.335	0.000	0.038	0.015	-0.210	0.000	-0.203	0.000
PGOUTPUT	α_1	0.080	0.000	0.075	0.000	0.056	0.000	0.079	0.000	0.070	0.000	0.066	0.000
UGOUTQUAL	α_2	0.619	0.000	0.662	0.000	0.689	0.000	0.557	0.000	0.585	0.000	0.600	0.000
RESEARCH[1]	α_3	0.301		0.263		0.255		0.364		0.346		0.334	
PGOUTPUT*PGOUTPUT	α_{11}	0.097	0.000	0.094	0.000	0.082	0.000	0.108	0.000	0.097	0.000	0.095	0.000
UGOUTQUAL*UGOUTQUAL	α_{22}	-0.108	0.004	-0.117	0.001	-0.090	0.018	0.041	0.172	0.043	0.145	0.052	0.077
RESEARCH*RESEARCH	α_{33}	-0.318		-0.289		-0.256		0.071		0.067		0.085	
PGOUTPUT*UGOUTQUAL	α_{12}	-0.153	0.000	-0.133	0.000	-0.124	0.000	-0.039	0.015	-0.036	0.019	-0.032	0.043
PGOUTPUT*RESEARCH[1]	α_{13}	0.057		0.039		0.042		-0.069		-0.060		-0.064	
UGOUTQUAL*RESEARCH[1]	α_{23}	0.261		0.250		0.214		-0.001		-0.007		-0.021	
PGINPUT	β_1	-0.145	0.000	-0.145	0.000	-0.133	0.000	-0.140	0.000	-0.139	0.000	-0.135	0.000
UGINQUAL	β_2	-0.327	0.000	-0.287	0.000	-0.307	0.000	-0.319	0.000	-0.285	0.000	-0.274	0.000
STAFF	β_3	-0.262	0.000	-0.228	0.000	-0.241	0.000	-0.222	0.000	-0.199	0.000	-0.212	0.000
ACSERV	β_4	-0.133	0.000	-0.131	0.000	-0.141	0.000	-0.131	0.000	-0.131	0.000	-0.136	0.000
ADMIN	β_5	-0.125	0.000	-0.141	0.000	-0.141	0.000	-0.148	0.000	-0.150	0.000	-0.153	0.000
PGINPUT*PGINPUT	β_{11}	0.033	0.069	0.029	0.089	0.035	0.034	0.019	0.283	0.017	0.305	0.017	0.294
UGINQUAL*UGINQUAL	β_{22}	-0.197	0.005	-0.182	0.006	-0.245	0.000	-0.074	0.184	-0.086	0.102	-0.075	0.155
STAFF*STAFF	β_{33}	-0.148	0.007	-0.140	0.007	-0.187	0.000	0.027	0.660	-0.014	0.804	-0.015	0.789
ACSERV*ACSERV	β_{44}	-0.001	0.962	0.005	0.835	0.012	0.593	-0.012	0.598	-0.009	0.677	-0.006	0.768
ADMIN*ADMIN	β_{55}	-0.150	0.008	-0.124	0.021	-0.156	0.002	-0.128	0.012	-0.110	0.022	-0.115	0.015
PGINPUT*UGINQUAL	β_{12}	0.083	0.021	0.067	0.048	0.060	0.072	0.002	0.952	-0.003	0.920	-0.005	0.852
PGINPUT*STAFF	β_{13}	-0.114	0.000	-0.091	0.001	-0.103	0.000	-0.019	0.513	-0.012	0.671	-0.013	0.636
PGINPUT*ACSERV	β_{14}	0.003	0.879	0.001	0.936	0.011	0.516	0.031	0.063	0.032	0.044	0.036	0.026
PGINPUT*ADMIN	β_{15}	-0.002	0.938	-0.004	0.881	-0.002	0.953	-0.028	0.301	-0.035	0.173	-0.035	0.170
UGINQUAL*STAFF	β_{23}	0.144	0.001	0.153	0.000	0.219	0.000	-0.022	0.619	0.014	0.741	0.019	0.653

UGINQUAL*ACSERV	β_{24}	-0.076	0.013	-0.095	0.001	-0.113	0.000	-0.036	0.177	-0.060	0.020	-0.068	0.009
UGINQUAL*SADMIN	β_{25}	0.111	0.025	0.144	0.002	0.131	0.006	0.257	0.000	0.264	0.000	0.255	0.000
STAFF*ACSERV	β_{34}	0.064	0.012	0.070	0.004	0.058	0.016	0.034	0.183	0.048	0.049	0.044	0.073
STAFF*ADMIN	β_{35}	0.028	0.514	-0.023	0.582	-0.001	0.982	-0.098	0.025	-0.109	0.008	-0.104	0.011
ACSERV*ADMIN	β_{45}	-0.016	0.569	-0.007	0.808	0.003	0.911	-0.034	0.180	-0.026	0.289	-0.019	0.439
PGINPUT*PGOUTPUT	δ_{11}	-0.075	0.000	-0.067	0.000	-0.066	0.000	-0.070	0.000	-0.062	0.000	-0.062	0.000
PGINPUT*UGOUTQUAL	δ_{12}	0.085	0.000	0.072	0.001	0.070	0.002	-0.052	0.008	-0.058	0.002	-0.055	0.003
PGINPUT*RESEARCH[1]	δ_{13}	-0.010		-0.005		-0.004		0.122		0.120		0.116	
UGINQUAL*PGOUTPUT	δ_{21}	-0.182	0.000	-0.151	0.000	-0.145	0.000	-0.074	0.002	-0.068	0.002	-0.062	0.006
UGINQUAL*UGOUTPUT	δ_{22}	-0.055	0.207	-0.073	0.080	-0.071	0.093	0.058	0.078	0.049	0.117	0.060	0.056
UGINQUAL*RESEARCH[1]	δ_{23}	0.236		0.224		0.216		0.015		0.019		0.001	
STAFF*PGOUTPUT	δ_{31}	0.169	0.000	0.155	0.000	0.158	0.000	0.074	0.001	0.077	0.000	0.070	0.001
STAFF*UGOUTQUAL	δ_{32}	0.015	0.684	0.036	0.297	0.040	0.250	-0.105	0.002	-0.083	0.012	-0.092	0.006
STAFF*RESEARCH[1]	δ_{33}	-0.184		-0.191		-0.198		0.031		0.006		0.022	
ACSERV*PGOUTPUT	δ_{41}	0.014	0.271	0.007	0.535	0.004	0.731	-0.009	0.439	-0.010	0.347	-0.011	0.325
ACSERV*UGOUTPUT	δ_{42}	-0.061	0.005	-0.059	0.004	-0.055	0.007	0.022	0.195	0.021	0.198	0.023	0.165
ACSERV*RESEARCH[1]	δ_{43}	0.047		0.051		0.051		-0.013		-0.011		-0.012	
ADMIN*PGOUTPUT	δ_{51}	0.048	0.055	0.029	0.204	0.016	0.468	0.060	0.007	0.042	0.043	0.043	0.038
ADMIN*UGOUTQUAL	δ_{52}	0.027	0.390	0.036	0.226	0.042	0.167	0.085	0.001	0.085	0.001	0.084	0.001
ADMIN*RESEARCH[1]	δ_{53}	-0.075		-0.065		-0.058		-0.145		-0.127		-0.126	
COLLHE		0.114	0.000	0.192	0.000	0.274	0.000	0.028	0.242	0.097	0.001	0.112	0.000
POST1992		0.057	0.008	0.099	0.003	0.145	0.000	-0.047	0.029	0.019	0.593	0.024	0.501
YEAR DUMMIES:	τ_t												
1997/98		0.043	0.042	0.044	0.021	-0.041	0.173	0.017	0.078	0.017	0.057	0.015	0.101
1998/99		-0.001	0.888	0.000	0.987	-0.022	0.025	-0.005	0.623	-0.004	0.692	-0.010	0.279
1999/00		0.045	0.046	0.046	0.017	-0.067	0.293	0.013	0.194	0.013	0.149	0.004	0.676
2000/01		0.028	0.009	0.030	0.002	-0.016	0.182	0.017	0.083	0.018	0.052	0.006	0.574
2001/02		0.053	0.000	0.055	0.000	-0.091	0.302	0.025	0.011	0.027	0.003	0.012	0.265
2002/03		0.035	0.001	0.037	0.000	-0.035	0.018	0.013	0.188	0.015	0.100	-0.003	0.755
2003/04		0.000	0.000	0.000	0.000	0.000	0.014	0.013	0.195	0.014	0.117	-0.007	0.562

2004/05	0.035	0.001	0.036	0.000	-0.062	0.001	0.010	0.326	0.011	0.231	-0.013	0.293
2005/06	0.057	0.000	0.099	0.000	0.145	0.002	0.020	0.052	0.021	0.026	-0.007	0.596
2006/07	0.042	0.000	0.044	0.000	-0.085	0.000	0.028	0.006	0.028	0.002	-0.004	0.810
2007/08	0.000	0.000	0.000	0.000	0.000	0.001	0.027	0.007	0.028	0.003	-0.007	0.645
2008/09	0.051	0.000	0.053	0.000	-0.108	0.000	0.026	0.010	0.026	0.006	-0.013	0.449
σ^2			0.023	0.000	0.037	0.000			0.031	0.000	0.034	0.000
σ_u^2			0.019	0.000	0.033	0.000			0.027	0.001	0.030	0.000
σ_v^2			0.005	0.000	0.004	0.000			0.004	0.000	0.004	0.000
μ			0.352	0.000	0.424	0.000			0.182	0.001	0.196	0.000
η					-0.034	0.000					-0.014	0.004
Mean Technical Efficiency	0.748		0.700		0.689		0.747		0.803		0.801	
SD Technical Efficiency	0.073		0.089		0.097		0.073		0.097		0.097	
Min Technical Efficiency	0.589		0.484		0.365		0.520		0.515		0.479	
Log Likelihood			1557.78		1573.72				1644.15		1648.32	
N	1444		1444		1444		1444		1444		1444	
No. of groups	155		155		155		155		155		155	
Returns to scale[3]	0.991		0.765		1.103		0.960		0.824		0.921	

Notes:

1. RE=random effects estimation model; TI=time-invariant SFA model; TVD=time-varying decay SFA model
2. Estimated parameters without P-values are calculated using the homogeneity conditions (see equations (9a) to (9c)) and symmetry conditions (see equations (10a) to (10b)).
3. Returns to scale are evaluated at the mean of inputs (and outputs).
4. See section 3 and Table 1 for definitions of the variables and models.

Table 4: Descriptive statistics for efficiency scores derived from various DEA models

		MODEL 1				Model 2			
DEA efficiency model		mean	SD	Min	Max	mean	SD	Min	Max
a) CRS	i) pooled	0.736	0.128	0.428	1.000	0.802	0.109	0.375	1.000
a) CRS	ii) within year	0.870	0.115	0.504	1.000	0.906	0.094	0.438	1.000
b) VRS	i) pooled	0.819	0.125	0.434	1.000	0.870	0.102	0.452	1.000
b) VRS	ii) within year	0.924	0.091	0.598	1.000	0.950	0.071	0.557	1.000

Note:
See section 4 and Table 1 for definitions of the models.

Table 5a: Spearman's correlations between efficiency scores derived using parametric and non-parametric approaches, 1996/97-2008/09 (MODEL 1)

			Parametric			Non-parametric		
	Model 1		1a	1b	1c	1ai	1aii	1bi
Parametric	1b		0.944					
	1c		0.799	0.853				
Non-parametric	1a) CRS	i) pooled	0.409	0.420	0.424			
	1a) CRS	ii) within year	0.315	0.304	0.385	0.844		
	1b) VRS	i) pooled	0.429	0.461	0.324	0.856	0.711	
	1b) VRS	ii) within year	0.347	0.370	0.379	0.789	0.853	0.816

Table 5b: Spearman's correlations between efficiency scores derived using parametric and non-parametric approaches, 1996/97-2008/09 (MODEL 2)

			Parametric			Non-parametric		
	Model 2		2a	2b	2c	2ai	2aii	2bi
Parametric	2b		0.935					
	2c		0.938	0.987				
Non-parametric	2a) CRS	i) pooled	0.414	0.362	0.415			
	2a) CRS	ii) within year	0.327	0.259	0.297	0.865		
	2b) VRS	i) pooled	0.435	0.430	0.450	0.831	0.757	
	2b) VRS	ii) within year	0.342	0.330	0.360	0.764	0.830	0.832

Table 6: Mean DEA efficiency by HEI type

		MODEL 2			
		Post-1992 HEIs	Pre-1992 HEIs	Colleges of higher education	F-statistic
		n = 375	n = 624	n = 445	df=2,1441
DEA	**a)CRS i) pooled**	0.821	0.768	0.833	4.76
	a) CRS ii) within year	0.923	0.874	0.938	10.08
	b) VRS i) pooled	0.889	0.859	0.869	15.81
	b) VRS ii) within year	0.966	0.935	0.957	1.63

Note: The F-statistic tests the null hypothesis that all means are identical.

Table 7: Mean efficiency by merger activity

		Model 2			
		Pre-merger	Post-merger	Non-merging	F-statistic
		n = 142	n = 133	n = 1169	df=2,1441
Parametric	**a) TI RE**	0.744	0.794	0.742	31.53
	b) TI SFA	0.797	0.890	0.793	64.46
	c) TVD SFA	0.806	0.882	0.791	57.87
Non-parametric	**a)CRS i) pooled**	0.832	0.826	0.796	10.98
	a) CRS ii) grouped	0.919	0.937	0.901	10.08
	b) VRS i) pooled	0.890	0.928	0.861	30.20
	b) VRS ii) grouped	0.963	0.975	0.945	13.52

Table 8a: Mean substitutability between raw material inputs evaluated from individual universities: SFA TI Model 2

	All	Pre-Merger	Post-Merger	Non-merging
sub_{12}	0.213#	0.451	-2.323	0.472
	(8.616)	(0.440)	(28.319)	(0.505)
M_{12}	1.329#	1.175	1.105	1.373
	(6.537)	(0.429)	(0.314)	(7.263)
M_{21}	0.810#	0.705	1.607	0.732
	(2.943)	(0.215)	(8.968)	(1.236)

Table 8b: Mean substitutability between capital and labour inputs evaluated from individual universities: SFA TI Model 2

	All	Pre-Merger	Post-Merger	Non-merging	
sub_{34}	1.287#	1.397	2.095	1.182	*
	(1.149)	(1.735)	(1.101)	(1.022)	
sub_{35}	1.081##	0.804	2.002	1.010	*
	(1.873)	(2.724)	(1.520)	(1.751)	
sub_{45}	0.875#	0.553	1.152	0.882	**
	(1.587)	(3.235)	(1.468)	(1.259)	
M_{34}	0.540#	0.367	0.545	0.560	**
	(0.614)	(1.085)	(0.100)	(0.564)	
M_{43}	0.536#	0.063	0.708	0.574	*
	(1.933)	(3.504)	(0.089)	(1.761)	
M_{35}	1.523#	1.229	1.849	1.521	*
	(1.478)	(2.035)	(0.910)	(1.443)	
M_{53}	1.266#	2.481	0.583	1.196	*
	(4.646)	(8.103)	(0.936)	(4.290)	
M_{45}	1.089#	1.045	1.144	1.087	*
	(0.318)	(0.416)	(0.219)	(0.313)	
M_{54}	0.539#	0.714	0.291	0.546	*
	(1.346)	(1.770)	(0.925)	(1.324)	

Notes: Standard deviations are in parentheses.
(##) indicates that the null hypothesis that the mean is equal to *a* can be rejected at the 5% (10%) significance level; where *a*=1 in the case of sub values and *a*=0 in the case of Morishima elastictities.
* (**) indicates that the null hypothesis that the means across groups are equal can be rejected at the 5% (10%) significance level.