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Efficiency in English higher education institutions revisited: a network approach

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Abstract

The efficiency of English higher education institutions is evaluated using a traditional 'black-box' data envelopment analysis (DEA) and using an alternative method, namely network DEA. The alternative method is seen to provide considerable additional information, and suggests that institutions could increase their efficiency by focusing attention on employability issues.

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1. Introduction

The efficiency with which services are provided is a perennial matter of interest both to economists and policy-makers. One area where the availability of data has encouraged a proliferation of studies is that of higher education. Interest in this area has redoubled recently owing both to changes in funding mechanisms that have focused attention on the question of whether institutions are delivering value for money and to methodological developments.

In England the higher education system has undergone considerable change in recent years, much of this being directed at fostering a more competitive environment. In a variety of respects, however, the market remains highly imperfect; while prices are more flexible, information remains opaque.[1] In this context, where reform has improved competition along some dimensions and not along others, it is instructive to ascertain the extent (and source) of inefficiency that remains.

The methodological developments include sophisticated refinements to the standard tools whereby efficiency is traditionally evaluated. One such refinement forms the focus of attention in this note – namely the ability to model each institution as a network of interconnected nodes, each of which is responsible for converting inputs into outputs, and where the outputs of one node might be intermediate in the sense that it subsequently becomes an input into another node.

The focus of attention in this note is the teaching and learning function of universities. It is recognised that institutions of higher education have a multiplicity of goals that include also research and knowledge transfer, but here we concentrate on the way in which these institutions convert their inputs into outputs that matter for students – namely satisfaction, employability, and (as an intermediate output) degree results.

The remainder of the note is divided into four sections. First, conceptual issues are discussed. This is followed by a discussion of the model structure and data. Results are then presented and analysed. The note ends with a discussion and conclusion.

2. Conceptual issues

The use of data envelopment analysis (DEA) as a means of evaluating performance in the higher education sector has been common over the last two decades (Johnes and Johnes, 1993; Athanassopoulos and Shale, 1997, Johnes, 2004, 2006a, 2006b). DEA involves a refinement to the analysis of ratios of outputs to inputs (Farrell, 1957) such that a multiplicity of outputs and inputs can be compared. This is achieved, using the method of Charnes et al. (1977), by employing linear programming techniques that allow each decision-making unit to be assigned input and output weights that maximise its measured efficiency relative to linear combinations of the most efficient units.[2] Since it does not impose a single set of weights or

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[1] For example, the maximum level of tuition fee for undergraduate students has been increased substantially, to £9000. This is accompanied by a package of loans, repayment of which is income-contingent, underwritten by the government. Loans that are not repaid within 30 years of graduation are written off. This means that prospective students do not know how much their education will cost them; moreover they do not know how much more or less it will cost them at one university as opposed to another.

[2] Färe and Grosskopf (2000) argue that DEA is tantamount to activity analysis which was developed by von Neumann (1945).

prices on the inputs and outputs of the production process that must apply across all producers, this method is non-parametric; the absence of a single point estimate for these weights that applies across all decision-making units furthermore means that the tools of statistical inference are not available to researchers in this context.

The simple DEA model treats the production process as a 'black box'. Inputs are converted into outputs, but there is no modelling of how this is done. Where decision-making units are known to comprise several inter-related components, this knowledge is typically not accounted for in the modelling procedure. Either each component is evaluated in isolation from the others, or the analysis is conducted on the aggregate without any consideration whatsoever of the way in which the component parts interact. Useful information is lost as a consequence.

An alternative method, pioneered by Färe (1991) and by Färe and Grosskopf (1996) and recently refined by Tone and Tsutsui (2009), is to construct a network of 'divisions' or 'nodes' that, when viewed together, comprise the decision-making unit. Each node converts inputs into outputs, some of which may themselves be inputs into or outputs from the activities of other nodes. The efficiency of each node can then be assessed (by comparing it with the corresponding node in other decision-making units) on the supposition that the inputs that it uses are themselves efficiently produced. The efficiency score of the whole decision-making unit is then evaluated as the efficiency of the final node (or, if there are multiple final outputs produced by different nodes, by an appropriately weighted sum).[3]

When evaluating efficiencies under the assumption of constant returns to scale, it is possible that the efficiency scores obtained by some (but not all) nodes are all lower than unity. This represents a point of contrast between network DEA models and traditional ('black-box') DEA models.

Following Tone and Tsutsui (2009), the technology assumed within the network model is given by

$$\begin{aligned}
&\mathbf{x}^k \geq \Sigma_j\, \mathbf{x}_j^k \lambda_j^k, \quad \forall k \\
&\mathbf{y}^k \leq \Sigma_j\, \mathbf{y}_j^k \lambda_j^k, \quad \forall k \\
&\mathbf{z}^{k,h} = \Sigma_j\, \mathbf{x}_j^{k,h} \lambda_j^k, \qquad \forall k,h \text{ as outputs from node k} \\
&\mathbf{z}^{k,h} = \Sigma_j\, \mathbf{x}_j^{k,h} \lambda_j^h, \qquad \forall k,h \text{ as inputs into node h} \qquad (1)
\end{aligned}$$

where x is the vector of inputs, y the vector of outputs and z a vector of intermediate products that are outputs from one node and inputs into another. The λ terms represent intensity vectors that are specific to the superscripted node. The summations are across all decision-making units. The linking activities are assumed to be determined so that $\mathbf{Z}^{k,h}\lambda^h = \mathbf{Z}^{k,h}\lambda^k$ where $\mathbf{Z}^{k,h} = (\mathbf{z}_1^{k,h}, \ldots, \mathbf{z}_n^{k,h})$. Hence decision-making units are free to decide upon the levels of the intermediate outputs that will be produced.

Subject to this restriction and to (1), the linear program

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[3] In the empirical work that follows, we assume that the intermediate outputs are all 'free' in the sense that they may be chosen by the decision-making unit. We also assume that the intensity vector is free to vary across units. The weights attached to the nodes are assumed equal, thereby simplifying equation (2) in the discussion that follows.

$$\theta^* = \min_{\lambda^k,\, s^{k-}} \Sigma_k \left[1 - \left(\sum_{i=1}^{mk} s_i^{k-}/x_i^{k}\right)/m_k\right] \quad (2)$$

is solved simultaneously for each decision-making unit to evaluate the overall efficiency scores θ*. Here m_k denotes the the number of inputs to the kth node and s is a slack. Note that, as an alternative to the input minimising formulation given in (2), it is also possible to express the problem as one of output maximisation; the former formulation is used in the empirical analysis that follows. The overall efficiency score can be broken down into node-specific scores

$$\theta_k = 1 - \left(\sum_{i=1}^{mk} s_i^{k-}/x_i^{k}\right)/m_k \quad \forall k \quad (3)$$

The overall efficiency of the network is thus essentially constructed to be the mean of the node-specific efficiencies. Note that, since this averages into the calculation the efficiency of nodes that produce outputs relatively inefficiently alongside that of nodes that produce outputs efficiently, the overall efficiencies that emerge from a network DEA are in general equal to or lower than those that are obtained from a corresponding ‘black-box’ model. This feature of the network DEA offers the advantage of highlighting areas (nodes) where efficiency can be substantially improved even in situations where overall performance appears to be strong.

3. Data and model structure

To illustrate the operation of a network DEA in the context of higher education, we consider the case of decision-making units within which there are two nodes. The decision-making units are English higher education institutions. The inputs into the first node are the mean entry tariff (based on scores achieved by the entry cohort at A level and similar qualifications[4]), student:staff ratio, and per student spend. Outputs from this node are student satisfaction (as measured by the overall satisfaction score on the National Student Survey) and the proportion of bachelor degrees awarded at first and upper second class level (reported in the Higher Education Statistical Agency publication, *Students in Higher Education Institutions*). The latter also serves as an input to the second node. A further input into the second node is a measure of the reputation of the producer, proxied by the average research assessment exercise score (reported in the Times Higher Education Table of Excellence - http://bit.ly/19PWR7A). The output of the second node is the rate of graduate employment. This network is illustrated in Figure 1. Where not otherwise noted, data come from the Guardian University Guide. The data used all refer to the 2011-12 year. We exclude from the analysis any institution for which we do not have a complete set of data.

4. Results

Results for the network DEA model are reported in the first three columns of Table 1, and may be compared with those obtained for the standard DEA model, reported in the final

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[4] An A* grade at A level (the most common type of national examination used as a university entrance qualification in England) amounts to 140 tariff points, with each lower grade amounting to 20 fewer points. Tariff points are also earned for a wide range of other qualifications, including the International Baccalaureate and Business Technology Education Council awards.

column.[5] The standard DEA (which, like all models considered here, assumes constant returns to scale) suggests that the unweighted average of efficiency scores across all universities is high, at 0.91. Some 17 institutions achieve efficiency scores of 1, and the lowest score is 0.747. The network DEA results suggest that production at node 1 exhibits a high degree of efficiency, the unweighted average across all universities again being 0.91. Production at node 2 is less efficient, however, with an unweighted average score of 0.65. Consequently the overall efficiency, as measured by the network DEA, is somewhat lower than is the case for the standard DEA model.

Several universities achieve an efficiency score of unity at node 1. Only one achieves this at node 2, namely Cumbria. This is the institution that has the second lowest research score in our sample, and its high efficiency score for this node reflects the fact that its graduates enjoy high rates of employment in spite of this input into the node being low. The results overall suggest that universities in general might most easily achieve efficiency gains by focusing on node 2 (employability) activities.

5. Discussion and conclusions

Institutions of higher education are complex organisations that use a multiplicity of inputs to produce a multiplicity of outputs. In this respect, DEA models are ideally suited to analysis of this sector. Network models based on DEA offer a richer analysis that is capable of opening up the ‘black box’ of production, providing insight into precisely which aspects of an organisation might be performing relatively well or poorly. By shining a light on the interior workings of this black box, the present paper represents a significant advance on earlier analyses.

The design of a network inevitably involves a measure of subjectivity. Inputs may, for example, be argued to enter the network at different nodes; outputs, likewise, may be deemed to be final outputs or intermediate. Yet the disaggregation of a single ‘black box’ system into parts likely yields information that is managerially useful.

The teaching and learning function is, of course, only one aspect of a university’s activity. It might be argued that the overall efficiency of an institution depends also on how efficiently it converts inputs (spending, say) into research (which would then become an intermediate or a final output rather than, as here, an exogenous input). The design of a network for analysis will inevitably vary with the aims of the analysis. Here the aim has been to highlight areas of the typical institution in which efficiency could be increased as a means of improving outcomes for students.

In so doing, we have identified the process with which institutions facilitate the transition of their graduates into the labour market as being an area where efficiency gains could be made. Broadly speaking, universities are efficient in ensuring that, for a given expenditure of resources and a given quality of student intake, they produce graduates with good degree results. While graduates of some institutions are successful in converting this into good labour market performance, marked differences between institutions remain in this dimension. Institutions with low scores in this area might usefully examine their peers.

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[5] The programming is conducted using MaxDEA. The standard DEA has entry tariff, student:staff ratio, per student spend, and research assessment score as inputs, and graduate employment, student satisfaction and degree results as outputs.

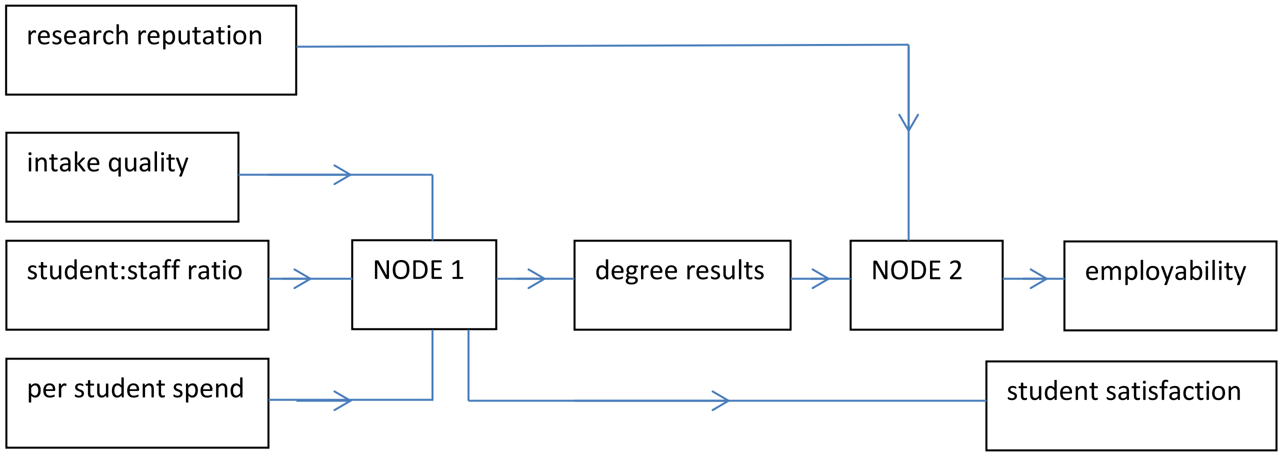

Figure 1 The DEA network

Table 1 Network DEA and DEA results

University	**Network DEA**			**DEA**
	overall	**node 1**	**node 2**	
Anglia Ruskin	0.837	0.983	0.690	0.988
Aston	0.796	0.848	0.745	0.889
Bath	0.769	0.857	0.680	0.854
Bath Spa	0.731	0.812	0.650	0.803
Bedfordshire	0.849	1.000	0.698	1.000
Birmingham	0.783	0.890	0.677	0.885
Birmingham City	0.725	0.801	0.649	0.806
Bolton	0.704	0.887	0.521	0.878
Bournemouth	0.698	0.751	0.645	0.754
Bradford	0.756	0.830	0.682	0.896
Brighton	0.710	0.846	0.574	0.849
Bristol	0.813	0.939	0.688	0.954
Brunel	0.675	0.812	0.538	0.812
Bucks New University	0.779	0.891	0.668	0.902
Cambridge	0.791	0.959	0.623	0.980
Canterbury Christ Church	0.845	0.987	0.703	0.967
Cardiff	0.776	0.922	0.629	0.912
Central Lancashire	0.760	0.916	0.605	0.899
Chester	0.913	0.981	0.845	0.973
Chichester	0.757	0.941	0.573	0.932
City	0.733	0.776	0.691	0.800
Coventry	0.942	1.000	0.884	1.000
Cumbria	1.000	1.000	1.000	1.000
De Montfort	0.720	0.885	0.555	0.892
Derby	0.739	0.929	0.549	0.928
Durham	0.793	0.920	0.666	0.913
East London	0.659	0.925	0.394	0.925
Edge Hill	0.961	0.938	0.984	1.000
Essex	0.652	0.852	0.451	0.850
Exeter	0.719	0.799	0.638	0.797
Gloucestershire	0.804	0.892	0.715	0.874
Goldsmiths	0.671	0.879	0.463	0.879
Greenwich	0.777	0.919	0.636	0.893
Hertfordshire	0.702	0.877	0.527	0.856
Huddersfield	0.838	0.940	0.736	0.928
Hull	0.745	0.849	0.642	0.838
Imperial College	0.816	0.964	0.669	0.970
Keele	0.881	1.000	0.762	1.000
Kent	0.786	0.986	0.585	0.969
King's College London	0.867	0.999	0.736	1.000
Kingston	0.710	0.823	0.597	0.797
Lancaster	0.757	0.889	0.625	0.880
Leeds	0.694	0.815	0.572	0.807
Leeds Met	0.766	0.954	0.579	0.937
Leeds Trinity	0.972	1.000	0.944	1.000
Leicester	0.825	1.000	0.650	1.000
Lincoln	0.855	0.870	0.840	0.918

University	**Network DEA**			**DEA**
	overall	**node 1**	**node 2**	
Liverpool	0.788	0.973	0.603	0.952
Liverpool John Moores	0.705	0.827	0.583	0.799
London Met	0.811	1.000	0.621	1.000
London School of Economics	0.821	1.000	0.642	1.000
London South Bank	0.794	0.960	0.627	1.000
Loughborough	0.738	0.850	0.626	0.841
Manchester	0.707	0.851	0.563	0.834
Manchester Met	0.710	0.840	0.581	0.870
Middlesex	0.711	0.855	0.568	0.858
Newcastle	0.795	0.911	0.678	0.908
Newman University	0.851	0.964	0.737	0.975
Northampton	0.860	0.935	0.784	0.914
Northumbria	0.754	0.878	0.629	0.870
Nottingham	0.760	0.937	0.583	0.928
Nottingham Trent	0.726	0.836	0.615	0.815
Oxford	0.782	0.987	0.577	1.000
Oxford Brookes	0.754	0.831	0.676	0.833
Plymouth	0.781	0.939	0.624	0.939
Portsmouth	0.768	0.894	0.643	0.894
Queen Mary	0.857	1.000	0.714	1.000
Reading	0.757	0.911	0.603	0.900
Roehampton	0.754	0.943	0.566	0.947
Royal Holloway	0.730	0.912	0.549	0.911
Salford	0.716	0.886	0.546	0.886
Sheffield	0.782	0.948	0.615	0.945
Sheffield Hallam	0.723	0.856	0.589	0.834
SOAS	0.781	0.997	0.566	0.987
Southampton	0.746	0.959	0.533	0.952
Southampton Solent	0.757	0.865	0.649	0.865
St Mark and St John	0.960	1.000	0.920	1.000
St Mary's UC, Twickenham	0.837	0.925	0.750	0.931
Staffordshire	0.827	1.000	0.653	1.000
Sunderland	0.755	1.000	0.510	0.959
Surrey	0.740	0.876	0.605	0.863
Sussex	0.660	0.856	0.464	0.856
Teesside	0.713	0.864	0.563	0.863
UCL	0.842	1.000	0.683	1.000
UEA	0.781	0.993	0.570	0.980
UWE Bristol	0.764	0.836	0.693	0.883
Warwick	0.723	0.849	0.596	0.848
West London	0.833	0.972	0.693	0.974
Westminster	0.659	0.761	0.557	0.747
Winchester	0.776	1.000	0.551	1.000
Worcester	0.866	0.875	0.858	0.908
York	0.707	0.873	0.541	0.862
York St John	0.836	0.872	0.800	0.889

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