Sankhyā : The Indian Journal of Statistics
2016, Volume 78-B, Part 2, pp. 362-385

Statistical Auditing of Non-transparent Expert Assessments

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Abstract

A statistical model is developed for an audit of the assessments of a panel of experts when little information is made available beyond a final announcement of the individual assessed ratings given. The application is to the process for the research assessment exercise for UK universities. Based on the proportions of the publications a panel deems to be International standard, National standard or Unclassified, a department's research output is rated by the panel on a seven point scale. The expert panel's remit is carefully interpreted and the given ratings are modelled via an underlying trinomial random variable with a bivariate Normal approximation. A likelihood function is developed and maximised in order to obtain fitted ratings for all units of assessment. The model's fitted values for the given ratings explain outcomes remarkably well and there are few mis-classifications; but there are some surprising outliers that do still require some explanation. The procedure illustrates well how Statisticians, surprisingly, might be able to model and audit for consistency the work of experts even if little or no information is provided, beyond vague prior published guidelines for the assessments and the final ratings given.

AMS (2000) *subject classification.* Primary 62P99, 65C60, 62-07; Secondary 62F30, 74P99.
Keywords and phrases. Trinomial, Bivariate normal, Maximum likelihood estimation, MLE, Research assessment exercise, RAE

1 Introduction

The Research Assessment Exercise (RAE) in the UK produced expert evaluations of the quality of research undertaken in universities and other

Electronic supplementary material The online version of this article (doi:10.1007/s13571-016-0124-8) contains supplementary material, which is available to authorized users.

higher education establishments, and the assessments were used by the higher education funding bodies in allocating research monies to institutions. RAE2001 was the fifth such exercise and the subject panels assigned one of seven possible grades to each department included. The ratings were officially to be based on the proportions of research output that are deemed to fall into each of three *undefined* categories (International standard, National standard and Unclassified) in accordance with the criteria summarised in Table 1, Section 2; perhaps with some scope for adjustment in the light of other indicators of research activity. A large descriptive data set was published but apart from the eventual departmental ratings awarded, none of the underlying judgments by subject group panels, including their definitions of 'International standard' and 'National standard', were made public. Hence, the purpose of this paper is to carefully develop a realistic statistical model to explain the given ratings so as to audit, at least for consistency, the work of an expert panel. A likelihood function is developed and maximised in order to estimate the proportions of research output at the International, National and Unclassified levels; and fitted ratings for all departments in a subject group are thereby obtained. Adjustments to account for other measurable factors in departmental submissions are also derived in order to give full credit/benefit in the audit to any outliers that might appear to exist.

A number of prior statistical analyses of RAE outcomes have considered the research ratings that were awarded by subject panels. In the first comprehensive study (Johnes et al., 1993), a cumulative logit model was fitted to the RAE 1989 outcomes, with the predicted rating being treated in this case as an ordered categorical variable. With respect to the outcomes of RAE1992, Taylor (1995) employed a multiple linear regression, on the grounds that the estimated coefficients would be directly interpretable as the marginal contribution of each of the regressors. In that case, the rating was treated as continuous and, in order to allay concerns that this may be inappropriate, the author emphasised the consistency of the regression results with those from an ordered probit. Subsequently, a comparison between probit and linear regression fitted models has formed the basis of further published work that tested the significance of potential explanatory variables for RAE ratings; for instance in Business and Management for RAE1992 (Doyle et al., 1996), in Social Policy and Administration for RAE2001 (McKay, 2003), and in Business and Management, Economics and Econometrics, and Accounting and Finance for RAE2008 (Taylor, 2011). McKay (2003) found that around 80 % of the differences in the RAE2001 ratings of the particular subject group could be explained in this way. The key regressors used in these studies included: larger sizes of submissions, outputs in refereed

journals, higher research income, greater numbers of research students and studentships, whether an institution is an old rather than a new university, the halo effect of high ratings elsewhere in the same institution, regional location, and membership of the subject panel. Taylor (2011) supported the use of metrics in subsequent RAEs, essentially using the values of regressors that have been used in some of the studies. However, in comparison with all the published studies to date, which boast between 50 and 80 % explanatory power for the fitted ratings, this current paper presents a model giving at least 95 % fit to the data. Furthermore, the previous studies could not estimate the proportions of a submission deemed at International level or National level, a central issue, whereas the current paper automatically does this by the more precise and realistic modelling that considers all available published pieces of prior official guidance. The procedure gives a solution to a real statistical auditing problem without resort to mere regression fitting.

A second approach to the analysis of RAE data has concerned the perceived quality of the journals and books in which submitted research outputs have appeared, but again, basic correlation type of analysis was used. Initially, when Burkitt and Baimbridge (1995) examined the 1992 RAE ratings for Economics and Econometrics departments, they demonstrated how publication in a particular reputable journal (*The Economic Journal*) closely corresponds to departmental ratings. Likewise, Marston and Ayub (2000), who investigated the performance of Accountancy departments in RAE1996, showed that publication in three mainstream UK-based journals is positively associated with the RAE rating. More comprehensively, based on the RAE2001 data, Geary et al. (2004) ranked Business and Management journals by weighting each by the number of papers in the journal submitted by institutions of a particular grade. However, Easton and Easton (2003) point to the technical invalidity of using ranked categories in this way, as the linear weighting system makes assumptions about the intervals between ratings. In contrast, the current paper determines the expert panel's implied valuation of the quality of journals in satisfying the published assessment criteria.

2 The Statistical Model

The main focus of this paper is on modelling, precisely according to the prior published guidelines, the underlying decisions made by a subject panel, with their awarded ratings as data. Within each subject group, each department submits up to four pieces of work for each academic included in its submission. A panel of experts then rates the departmental submission as 1, 2, 3b, 3a, 4, 5 or 5* according to the proportions of the submitted work deemed to be of International Standard and of National Standard.

The problem and notation is developed as follows. Department k ($k = 1, 2,..., K$), rated R_k {either 7 (RAE 5*), 6 (RAE 5), 5 (RAE 4), 4 (RAE 3a), 3 (RAE 3b), 2 (RAE 2) or 1 (RAE 1)}, submitted N_{jk} papers published in journal j ($j = 1, 2,.... J$); where the word 'journal' is used to denote any type of publication outlet. It is required to determine the proportions of papers in each journal of category 1 standard (International), category 2 standard (National) and category 3 standard (lower than National standard). Let p_{ij} be the probability of a paper published in journal j being classified as category $i (i = 1, 2, 3)$ standard, and let $N_{jk} = N_{1jk} + N_{2jk} + N_{3jk}$ where N_{ijk} is the number of papers of department k published in journal j and classified as of category i standard ($i = 1, 2, 3$; $j = 1, 2, ..., J$). It follows that the bi-variate random vector, $\underline{N}_{jk} \equiv (N_{1jk}, N_{2jk})$, has a Trinomial distribution with parameters N_{jk}, p_{1j}, p_{2j}; and it is assumed that, for each k ($k = 1, 2, ..., K$), the J vectors $\{\underline{N}_{jk}\}$ are statistically independent.

Distribution Theory Consider the random vector $\left(\sum_{j=1}^{J} N_{1jk}, \sum_{j=1}^{J} N_{2jk}\right) = \sum_{j=1}^{J} (N_{1jk}, N_{2jk}) = \sum_{j=1}^{J} \underline{N}_{jk}$, which is the sum of independent Trinomial random vectors and hence has mean vector, $\underline{\mu}_k = \sum_{j=1}^{J} N_{jk}(p_{1j}, p_{2j})$ and variance-covariance matrix, $\underline{\Sigma}_k = \sum_{j=1}^{J} N_{jk} \begin{bmatrix} p_{1j}(1-p_{1j}) & -p_{1j}p_{2j} \\ -p_{1j}p_{2j} & p_{2j}(1-p_{2j}) \end{bmatrix}$. When the total $N_k \equiv \sum_{j=1}^{J} N_{jk}$ is large, $\left(\sum_{j=1}^{J} N_{1jk}, \sum_{j=1}^{J} N_{2jk}\right)$, suitably scaled by $1/\sqrt{N_k}$, will have approximately, a bi-variate normal distribution.

The Assessment Criteria The published criteria for the various ratings are given in Table 1 and more detailed guidance on the RAE assessment process specified the following:

(i) 'Virtually all' and 'virtually none' should be understood as within the top and bottom 10 per cent, respectively. 'Some' should be understood as around 10 %.

(ii) "Panels were permitted to form a view that the balance of quality justified the award of a particular grade even where the precise terms of the descriptions were not met. For example, a submission which considerably exceeded the required proportion of International excellence, but did not meet the requirement for National excellence in the

Table 1: Rating criteria for RAE 2001

5*	International excellence in more than half of the research activity submitted and National excellence in the remainder.
5	International excellence in up to half of the research activity submitted and National excellence in *virtually all* of the remainder.
4	National excellence in *virtually all* of the research activity submitted, showing *some* evidence of International excellence.
3a	National excellence in over two thirds of the research activity submitted, possibly showing evidence of International excellence.
3b	National excellence in more than half of the research activity submitted.
2	National excellence in up to half of the research activity submitted.
1	National excellence in none, or *virtually none*, of the research activity submitted.

remainder, has received the grade which the panel felt was justified on balance."

(iii) "In order to attain a point on the scale a submission had to exceed the requirements of the next lower point. For example, in the description of 5, 'up to half' implies more than the maximum for 'some' required for a grade 4".

The overall performance of a department's research can be indicated by a point in UxI space, as in Fig. 1, where I denotes the fraction of submitted work at International level and U the fraction Unclassified. The vertical axis gives the International fraction, the horizontal axis gives the Unclassified fraction and the horizontal (or vertical) distance from the 45° line ($N = 0$) gives the fraction of National standard. For illustration, the point $(U, I) = (0.20, 0.35)$, for which $N = 0.45$, is marked in Fig. 1. Clearly, a department would always prefer to be positioned more towards the north-west, not the south-east, and from the more detailed guidance given, tradeoffs are possible towards the north-east. A higher fraction of Unclassified published work could be tolerated at the same rating level if there were more International standard work to compensate. In other words, rating indifference curves point towards the north-east.

The following points are marked in Fig. 2: (0.0, 0.5), (0.0, 0.1), (0.1, 0.1), (1/3, 0.0), (0.5, 0.0), (0.9, 0.0); each essentially specified as a boundary point from the information given in Table 1.

Boundary trade-off indifference lines can thus be postulated as sloping towards the north-east and going through one of these designated boundary points. In particular, the boundary between the rating regions $\{R_k = 1\}$ and $\{R_k = 2\}$ can be written as: $I = \alpha_1(U - 0.9)$ where $\alpha_1\,(0 \leq \alpha_1 < \infty)$ is a trade-off parameter. Likewise, the other trade-off boundaries are:

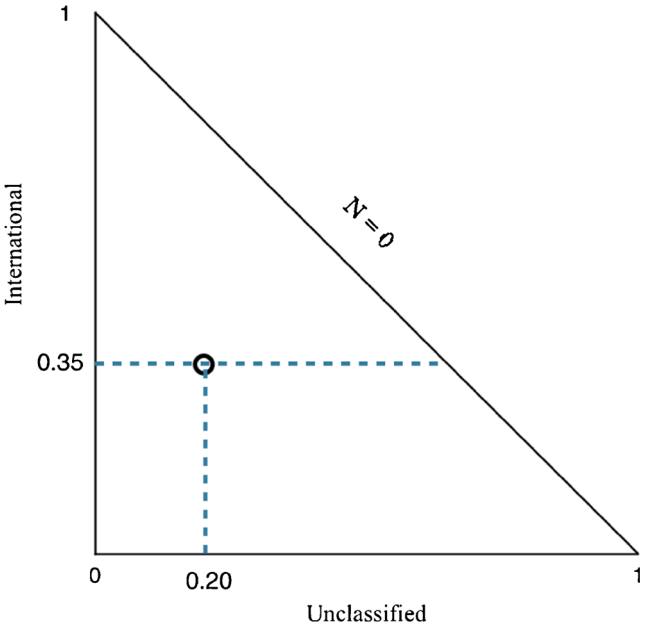

Figure 1: Interpretation of the criteria

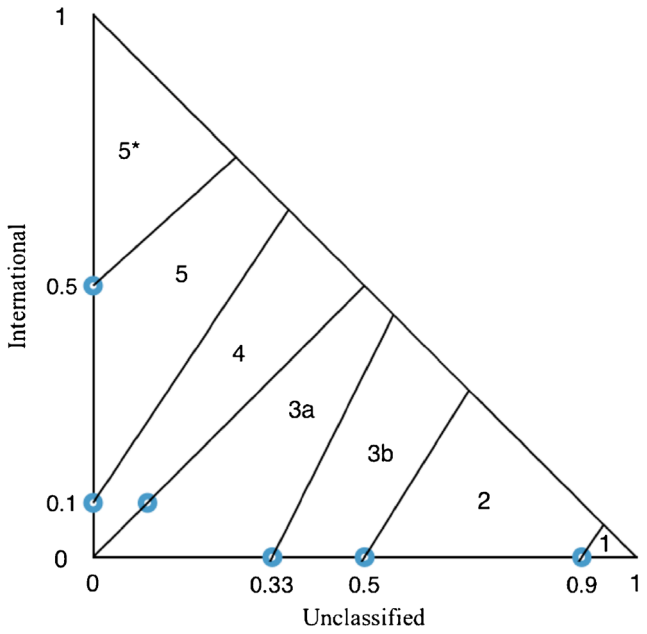

Figure 2: Rating category boundaries

$I = \alpha_2(U - 0.5)$, $3I = \alpha_3(3U - 1)$, $(I - 0.1) = \alpha_4(U - 0.1)$, $(I - 0.1) = \alpha_5 U$ and $(I - 0.5) = \alpha_6 U$, where $0 \leq \alpha_r < \infty$ $(r = 1, 2, 3, 4, 5, 6)$. Re-parameterising by writing $a_r = \alpha_r/(1 + \alpha_r)$, so that $0 \leq a_r < 1\,(r = 1, 2, 3, 4, 5, 6)$, the trade-off lines can be expressed instead in NxI space as $I = a_1(0.1 - N)$, $I = a_2(0.5 - N)$, $3I = a_3(2 - 3N)$, $(I - 0.1) = a_4(0.8 - N)$, $(I - 0.1) = a_5(0.9 - N)$ and $(I - 0.5) = a_6(0.5 - N)$; noting that $I + N + U = 1$.

Rating Outcome Events Department k will be rated 1 $(R_k = 1)$ if $\sum_{j=1}^{J} N_{1jk} \leq a_1 \left[\frac{1}{10} N_k - \sum_{j=1}^{J} N_{2jk} \right]$ where $N_k = \sum_{j=1}^{J} N_{jk}$, the total number of papers assessed for department k, and $a_1 = \alpha_1/(1 + \alpha_1)$ is the parameter defining the boundary rate of compensation by a higher proportion of category 1 papers for a higher proportion of category 3 papers; $0 \leq a_1 < 1$. Similarly, department k will be

rated at most 2 $(R_k \leq 2)$ if $\sum_{j=1}^{J} N_{1jk} \leq a_2 \left[\frac{1}{2} N_k - \sum_{j=1}^{J} N_{2jk} \right]$,

rated at most 3 $(R_k \leq 3)$ if $\sum_{j=1}^{J} N_{1jk} \leq a_3 \left[\frac{2}{3} N_k - \sum_{j=1}^{J} N_{2jk} \right]$,

rated at most 4 $(R_k \leq 4)$ if $\sum_{j=1}^{J} N_{1jk} \leq a_4 \left[\frac{8}{10} N_k - \sum_{j=1}^{J} N_{2jk} \right] + \frac{1}{10} N_k$,

rated at most 5 $(R_k \leq 5)$ if $\sum_{j=1}^{J} N_{1jk} \leq a_5 \left[\frac{9}{10} N_k - \sum_{j=1}^{J} N_{2jk} \right] + \frac{1}{10} N_k$,

and rated at most 6 $(R_k \leq 6)$ if $\sum_{j=1}^{J} N_{1jk} \leq a_6 \left[\frac{1}{2} N_k - \sum_{j=1}^{J} N_{2jk} \right] + \frac{1}{2} N_k$;

where the constants a_2, a_3, a_4, a_5, a_6 are corresponding compensation trade-off parameters, with $0 \leq a_r \equiv \alpha_r/(1 + \alpha_r) < 1$, $(r = 2, 3, .., 6)$. To ensure non-contradictory quality requirements, natural constraints on the parameters are:

$$\frac{1}{2} a_6 + \frac{1}{2} \geq \frac{9}{10} a_5 + \frac{1}{10} \geq \frac{8}{10} a_4 + \frac{1}{10} \geq \frac{2}{3} a_3 \geq \frac{1}{2} a_2 \geq \frac{1}{10} a_1.$$

Departmental Rating Probabilities Given that $\left(\sum_{j=1}^{J} N_{1jk}, \sum_{j=1}^{J} N_{2jk} \right)$ has a bi-variate normal distribution with mean, $\underline{\mu}_k = (\mu_{1k}, \mu_{2k})$ and

variance-covariance matrix, $\underline{\Sigma}_k = \begin{bmatrix} \sigma_{1k}^2 & \rho_k\sigma_{1k}\sigma_{2k} \\ \rho_k\sigma_{1k}\sigma_{2k} & \sigma_{2k}^2 \end{bmatrix}$, the probability that department k will be rated at level RAE 1 ($R_k = 1$) is thus

$$\begin{aligned} P_{k1} &= P\left(\sum_{j=1}^{J} N_{1jk} \le a_1 \left[\frac{1}{10}N_k - \sum_{j=1}^{J} N_{2jk}\right]\right) \\ &= \Phi\left(\frac{0.1a_1N_k - \mu_{1k} - a_1\mu_{2k}}{\sqrt{\sigma_{1k}^2 + 2a_1\rho_k\sigma_{1k}\sigma_{2k} + a_1^2\sigma_{2k}^2}}\right), \end{aligned}$$

where $\Phi(.)$ is the (cumulative) distribution function of a standard normal random variable and

$$\begin{aligned} \mu_{1k} &= \sum_{j=1}^{J} N_{jk}p_{1j},\ \mu_{2k} = \sum_{j=1}^{J} N_{jk}p_{2j},\ \sigma_{1k} \\ \sigma_{1k} &= \sqrt{\sum_{j=1}^{J} N_{jk}p_{1j}(1-p_{1j})},\ \sigma_{2k} = \sqrt{\sum_{j=1}^{J} N_{jk}p_{2j}(1-p_{2j})} \end{aligned}$$

and correlation coefficient,

$$\rho_k = -\sum_{j=1}^{J} N_{jk}p_{1j}p_{2j} \Bigg/ \sqrt{\left(\sum_{j=1}^{J} N_{jk}p_{1j}(1-p_{1j}\right)\left(\sum_{j=1}^{J} N_{jk}p_{2j}(1-p_{2j})\right)}.$$

Similarly, the probability that the department will be rated *at most* 2 ($R_k \le 2$) is

$$P_{k2} = \Phi\left(\frac{0.5a_2N_k - \mu_{1k} - a_2\mu_{2k}}{\sqrt{\sigma_{1k}^2 + 2a_2\rho_k\sigma_{1k}\sigma_{2k} + a_2^2\sigma_{2k}^2}}\right),$$

rated *at most* 3 ($R_k \le 3$): $P_{k3} = \Phi\left(\frac{(2/3)a_3N_k - \mu_{1k} - a_3\mu_{2k}}{\sqrt{\sigma_{1k}^2 + 2a_3\rho_k\sigma_{1k}\sigma_{2k} + a_3^2\sigma_{2k}^2}}\right)$,

rated *at most* 4 ($R_k \le 4$): $P_{k4} = \Phi\left(\frac{0.1(1+8a_4)N_k - \mu_{1k} - a_4\mu_{2k}}{\sqrt{\sigma_{1k}^2 + 2a_4\rho_k\sigma_{1k}\sigma_{2k} + a_4^2\sigma_{2k}^2}}\right)$,

rated *at most* 5 ($R_k \le 5$): $P_{k5} = \Phi\left(\frac{0.1(1+9a_5)N_k - \mu_{1k} - a_5\mu_{2k}}{\sqrt{\sigma_{1k}^2 + 2a_5\rho_k\sigma_{1k}\sigma_{2k} + a_5^2\sigma_{2k}^2}}\right)$,

and rated *at most* 6 ($R_k \le 6$):$P_{k6} = \Phi\left(\frac{0.5(1+a_6)N_k - \mu_{1k} - a_6\mu_{2k}}{\sqrt{\sigma_{1k}^2 + 2a_6\rho_k\sigma_{1k}\sigma_{2k} + a_6^2\sigma_{2k}^2}}\right)$.

Data The rating, R_k, of each department is available and so is N_{jk} ($j = 1, 2, \ldots, J$), the number of assessed papers for department k in journal j. Let there be K_1 departments (numbered $k = 1, 2, \ldots, K_1$) rated as 1 ($R_k = 1$), $K_2 - K_1$ departments (numbered $k = K_1 + 1, K_1 + 2, \ldots, K_2$) rated as 2 ($R_k = 2$) and, in general, $K_r - K_{r-1}$ departments (numbered $k = K_{r-1} + 1$, $K_{r-1} + 2, \ldots, K_r$) rated as r ($R_k = r$), ($r = 2, 3, 4, 5, 6, 7$); with $K_7 = K$.

Likelihood Function Given the above information, the log likelihood function is:

$$\begin{aligned} l(\underline{p}_1, \underline{p}_2, \underline{a}) \;=\; & \sum_{k=1}^{K_1} \ln P_{k1} + \sum_{k=K_1+1}^{K_2} \ln(P_{k2} - P_{k1}) + \sum_{k=K_2+1}^{K_3} \ln(P_{k3} - P_{k2}) \\ & + \sum_{k=K_3+1}^{K_4} \ln(P_{k4} - P_{k3}) + \sum_{k=K_4+1}^{K_5} \ln(P_{k5} - P_{k4}) \\ & + \sum_{k=K_5+1}^{K_6} \ln(P_{k6} - P_{k5}) + \sum_{k=K_6+1}^{K_7} \ln(1 - P_{k6}) \end{aligned}$$

where the (column) vectors $\underline{p}_1 \equiv (p_{11}, p_{12}, ..., p_{1J})'$, $\underline{p}_2 \equiv (p_{21}, p_{22}, ..., p_{2J})'$ and $\underline{a} \equiv (a_1, a_2, ..., a_6)'$ are parameters to be estimated, or whose (joint) posterior distribution is required. Maximum likelihood estimation of the quality of each journal in a particular subject area is carried out and the corresponding (fitted) individual departmental research ratings obtained.

Maximising the Likelihood The first and second derivatives of $l \equiv l(\underline{p}_1, \underline{p}_2, \underline{a})$ with respect to all of the parameters of the model are derived and it is required to find the (MLE) values $\hat{\underline{p}}_1$, $\hat{\underline{p}}_2$ and $\hat{\underline{a}}$ of the vectors $\underline{p}_1$, $\underline{p}_2$ and $\underline{a}$ such that $\frac{\partial l}{\partial \underline{p}_1} = \underline{0}$, $\frac{\partial l}{\partial \underline{p}_2} = \underline{0}$ and $\frac{\partial l}{\partial \underline{a}} = \underline{0}$, if possible, but subject to constraints on values; and this is accomplished by an exhaustive iterative computer search. The estimation requires $\frac{1}{2}\hat{a}_6 + \frac{1}{2} \geq \frac{9}{10}\hat{a}_5 + \frac{1}{10} \geq \frac{8}{10}\hat{a}_4 + \frac{1}{10} \geq \frac{2}{3}\hat{a}_3 \geq \frac{1}{2}\hat{a}_2 \geq \frac{1}{10}\hat{a}_1$ and, in each case, $0 \leq \hat{p}_{1j} \leq 1$, $0 \leq \hat{p}_{2j} \leq 1$, $0 \leq \hat{p}_{3j} \leq 1$, $\hat{p}_{1j} + \hat{p}_{2j} + \hat{p}_{3j} = 1$, and $0 \leq \hat{a}_r \leq 1$. The constrained problem is thus one of Kuhn-Tucker form. Note that if the likelihood function dominates the prior (for instance, with independent uniform Beta (1,1) priors), the posterior distribution of $\underline{q} \equiv (\underline{p}_1', \underline{p}_2', \underline{a}')'$ is approximately Normal with mean the MLE $\hat{\underline{q}} \equiv (\hat{\underline{p}}_1', \hat{\underline{p}}_2', \hat{\underline{a}}')'$ and variance-covariance matrix: $-\left\{\left[\frac{\partial^2 l}{\partial \underline{q} \partial \underline{q}'}\right]^{-1}\right\}_{\underline{q}=\hat{\underline{q}}}$. However, since the objective is to have a transparent audit of expert assessments, maximum likelihood seems quite appropriate. The iterative modifications

to $\hat{\underline{q}} \equiv (\hat{\underline{p}}_1', \hat{\underline{p}}_2', \hat{\underline{a}}')'$ can be accomplished by the Newton-Raphson procedure: $\hat{\underline{q}}_2 = \hat{\underline{q}}_1 - \left\{ \left[\frac{\partial^2 l}{\partial \underline{q} \partial \underline{q}'} \right]^{-1} \cdot \frac{\partial l}{\partial \underline{q}} \right\}_{\underline{q}=\hat{\underline{q}}_1}$.

Model Extension Let p_k be the probability of classifying the quality of the k^{th} department's research one grade higher than suggested by publications alone, let q_k be the probability of classifying the research quality one grade lower, each of the associated contingencies being independent of each other and of the department's initial rating; and use logit models to describe p_k and q_k: $p_k = \frac{e^{\underline{c}' \underline{x}_k}}{1+e^{\underline{c}' \underline{x}_k}}$, $q_k = \frac{e^{\underline{d}' \underline{y}_k}}{1+e^{\underline{d}' \underline{y}_k}}$ where $\underline{x}_k$, $\underline{y}_k$ are vectors of values of regressor variables concerning the k^{th} department and $\underline{c}$, $\underline{d}$ corresponding coefficient vectors for all departments. The probabilities of the various ratings given to the k^{th} department's research are now as follows:

$$
\begin{aligned}
P_k(1) &\equiv P(R_k = 1) = \{(1-p_k) + p_k q_k\} P_{k1} + q_k(1-p_k)[P_{k2} - P_{k1}] \\
P_k(2) &\equiv P(R_k = 2) = p_k(1-q_k) P_{k1} + \{(1-p_k)(1-q_k) + p_k q_k\}[P_{k2} - P_{k1}] \\
&\quad + q_k(1-p_k)[P_{k3} - P_{k2}] \\
P_k(3) &\equiv P(R_k = 3) = p_k(1-q_k)[P_{k2} - P_{k1}] + \{(1-p_k)(1-q_k) + p_k q_k\}[P_{k3} - P_{k2}] \\
&\quad + q_k(1-p_k)[P_{k4} - P_{k3}] \\
P_k(4) &\equiv P(R_k = 4) = p_k(1-q_k)[P_{k3} - P_{k2}] + \{(1-p_k)(1-q_k) + p_k q_k\}[P_{k4} - P_{k3}] \\
&\quad + q_k(1-p_k)[P_{k5} - P_{k4}] \\
P_k(5) &\equiv P(R_k = 5) = p_k(1-q_k)[P_{k4} - P_{k3}] + \{(1-p_k)(1-q_k) + p_k q_k\}[P_{k5} - P_{k4}] \\
&\quad + q_k(1-p_k)[P_{k6} - P_{k5}] \\
P_k(6) &\equiv P(R_k = 6) = p_k(1-q_k)[P_{k5} - P_{k4}] + \{(1-p_k)(1-q_k) + p_k q_k\}[P_{k6} - P_{k5}] \\
&\quad + q_k(1-p_k)[1 - P_{k6}]
\end{aligned}
$$

and $P_k(7) \equiv P(R_k = 7) = p_k(1-q_k)[P_{k6} - P_{k5}] + \{(1-q_k) + p_k q_k\}[1 - P_{k6}]$, where $P_{k1}, P_{k2}, P_{k3}, P_{k4}, P_{k5}, P_{k6}$ are as defined earlier. The log likelihood function is modified as:

$$
\begin{aligned}
l(\underline{p}_1, \underline{p}_2, \underline{a}, \underline{c}, \underline{d}) \;=\; & \sum_{k=1}^{K_1} \ln P_k(1) + \sum_{k=K_1+1}^{K_2} \ln P_k(2) + \sum_{k=K_2+1}^{K_3} \ln P_k(3) \\
& + \sum_{k=K_3+1}^{K_4} \ln P_k(4) + \sum_{k=K_4+1}^{K_5} \ln P_k(5) + \sum_{k=K_5+1}^{K_6} \ln P_k(6) \\
& + \sum_{k=K_6+1}^{K_7} \ln P_k(7)
\end{aligned}
$$

where the (column) vectors $\underline{p}_1 \equiv (p_{11}, p_{12}, ..., p_{1J})'$, $\underline{p}_2 \equiv (p_{21}, p_{22}, ..., p_{2J})'$, $\underline{a} \equiv (a_1, a_2, ..., a_6)'$ and $\underline{c} \equiv (c_0, c_1, c_2, c_3)'$, $\underline{d} \equiv (d_0, d_1, d_2, d_3)'$ are parameters to be estimated, or whose (joint) posterior distribution is required. The derivatives of the modified log-likelihood function with respect to all parameters can be updated, directly, using the previous results. To initiate the iterative computer search, starting values of the $\underline{p}_1$ and $\underline{p}_2$ vectors are obtained by considering each journal in relation to the number of times it was submitted by institutions of a particular grade, using a 1 to 7 scale; the vector $\underline{a}$ is set with starting values of 0.5 for each component; and for the covariate vectors $\underline{c}$ and $\underline{d}$, intercepts are set at small values in logarithms, -10, and the slopes at 0.

3 Results

Using the RAE2001 official published data (www.rae.ac.uk/2001) for each subject group in turn, the likelihood function is maximised, subject to the constraints on parameters, using the derivatives provided in Supporting Information File1; to yield the estimated quality proportions (probabilities) for all journals, and these are given in Supporting Information File2. The estimated probabilities of research quality are derived for Units of Assessment (UoA) relevant to the academic interests of Business Schools. Although many such schools made a single submission to Business & Management (UoA 43), some departments preferred to submit to areas such as Economics & Econometrics (UoA 38), Statistics & Operational Research (UoA 24) and Accounting & Finance (UoA 44). The procedure described above is implemented separately for each of these four units of assessment. The total number of research publications, $\sum_{j=1}^{J} \sum_{k=1}^{K} N_{jk}$, is

- 9942 in Business & Management, from 2413 researchers in $K = 97$ departments publishing in $J = 1538$ different journals;
- 3255 in Economics & Econometrics, from 798 researchers in $K = 41$ departments publishing in $J = 441$ different journals;
- 1571 in Statistics & Operational Research, from 368 researchers in $K = 46$ departments publishing in $J = 426$ different journals;
- 811 in Accounting & Finance, from 211 researchers in $K = 20$ departments publishing in $J = 236$ different journals.

Table 2 gives the numbers of departments and associated research staff assessed in each rating category, together with other information from the

Table 2: Research activity measures tabulated by subject and research rating

Research rating (R)	Number of departments (K)	Research staff FTE	Total academic staff FTE	Research council income £000	Other research income £000	PhDs awarded
Business & Management						
5*	3	268	292	7257.3	34,133.5	301
5	13	611	732	15,983.1	59,329.0	697
4	23	615	862	5509.7	33,204.1	594
3a	23	504	1189	4626.1	15,006.7	287
3b	17	260	948	1505.1	10,330.2	137
2	15	144	698	199.7	3490.4	93
1	3	12	34	0.0	679.0	2
	97	2413	4753	35,081.0	156,172.8	2111
Economics & Econometrics						
5*	4	138	147	16,463.7	11,244.8	194
5	9	275	302	8772.7	10,894.2	401
4	17	254	298	3080.6	6490.7	254
3a	10	126	160	784.0	2626.6	99
3b	1	6	16	0.0	399.2	0
	41	798	922	29,101.1	31,655.6	948
Statistics & Operational Research						
5*	6	66	83	3916.4	3245.8	110
5	15	129	145	4351.9	9638.7	185
4	14	116	137	2657.6	4256.2	129
3a	8	44	73	118.4	1138.2	38
3b	2	9	16	168.3	113.7	7
2	1	5	11	0.0	36.9	2
	46	368	465	11,212.6	18,429.4	471
Accounting & Finance						
5*	2	58	59	1646.7	3396.4	36
5	12	109	163	143.1	1488.6	84
4	3	30	58	119.1	244.2	32
3a	2	10	33	23.1	116.8	2
3b	1	4	14	0.0	9.0	1
	20	211	328	1932.0	5255.0	155

RAE data base: the total number of academic staff at the census date in departments that submitted research for assessment; the income received from research councils and other sources over the 5 years 1996–2000; and the number of PhD degrees awarded in that period.

The statistical returns enable the construction of the covariate vectors $\underline{x}$ and $\underline{y}$ that form the logit predictors of, respectively, an upward or downward adjustment to the rating if it were based on publications alone. Firstly, it is assumed that doctoral research studies and funded research projects will be positively related to the rating; accordingly, the number of PhD degrees awarded, research council income (RCI) and other research income (ORI) are restated per research staff FTE (full time equivalent), and these comprise

the $\underline{x}$ vector of explanatory variables. Secondly, it is assumed that small research groups, a low proportion of researchers in a department and a shortfall in the required number of research outputs (four) will be negatively related to the rating awarded; in this case, the number of research staff submitted by a department (RS), the ratio of research staff to total staff (RS/TS), and the proportion of the required (multiple of four) publications actually submitted (ALL4) form the $\underline{y}$ vector of explanatory variables. Table 3 gives the means of covariates, tabulated by subject and by rating, and Supporting Information File 3 includes individual departmental component values.

Estimated quality proportions were obtained for all journals under consideration and for illustration, Tables A, B, C, D, in Supporting Information File 2, report results for the 35 most frequently submitted publication outlets for each of the four subject groups. For instance, amongst the journals

Table 3: Summaries of logit covariate values

Research rating	Average size of research group	Submission rate (%)	Research council income per staff FTE	Other research income per staff FTE	PhDs awarded per staff FTE
Business & Management			£000	£000	
5*	89.5	92.0	27.0	127.2	1.12
5	47.0	83.5	26.2	97.2	1.14
4	26.8	71.4	9.0	54.0	0.97
3a	21.9	42.4	9.2	29.8	0.57
3b	15.3	27.4	5.8	39.8	0.53
2	9.6	20.6	1.4	24.3	0.65
1	3.8	34.2	0.0	59.0	0.17
Economics & Econometrics					
5*	34.4	93.7	119.7	81.8	1.41
5	30.6	91.1	31.9	39.6	1.46
4	14.9	85.3	12.1	25.5	1.00
3a	12.6	78.4	6.2	20.9	0.79
3b	6.0	38.7	0.0	66.5	0.00
Statistics & Operational Research					
5*	11.0	79.5	59.3	49.2	1.67
5	8.6	88.8	33.8	75.0	1.44
4	8.3	85.0	22.8	36.6	1.11
3a	5.5	59.8	2.7	26.0	0.87
3b	4.5	56.3	18.7	12.6	0.78
2	5.0	47.2	0.0	7.4	0.40
Accounting & Finance					
5*	28.9	98.3	28.5	58.8	0.62
5	9.1	67.0	1.3	13.6	0.77
4	9.9	50.9	4.0	8.2	1.08
3a	5.2	31.1	2.2	11.2	0.19
3b	3.5	25.0	0.0	2.6	0.29

in which Business & Management researchers publish most frequently, the highest ranking are *Organization* (estimated at 78.5 % International and 21.5 % National) and *Journal of Business Finance and Accounting* (77.7 % International and 22.3 % National). Some Business & Management journals are estimated at 100 % International quality, but these are not listed amongst the highest frequency journals in Table A. Those with more than 20 submissions are: *International Journal of Technology Management, Cambridge Journal of Economics, Accounting, Organizations and Society, Research Policy, Business History* and*International Journal of Forecasting.* In contrast, the following high frequency Economics & Econometrics journals are estimated as entirely International quality: *European Economic Review, Journal of Economic Theory, Journal of Political Economy, Quarterly Journal of Economics, International Economic Review, Econometric Theory* and *American Economic Review.* Similar inferences may be drawn about other types of publication outlet. For instance, with regard to authored books, 24.8 % are deemed to involve International quality research in Business & Management, 41.3 % in Economics & Econometrics, 47.4 % in Statistics & Operational Research and 38.9 % in Accounting & Finance.

The estimated trade-offs between International standard research and Unclassified, at the rating boundaries, are reported in Table 4; a few being fixed as 45° lines when there is no data. These are depicted in Fig. 3 where the maximum likelihood estimates of overall departmental research quality fractions, $\left(\hat{\mathrm{U}}, \hat{\mathrm{I}}\right) \equiv \frac{\sum_{j=1}^{J} N_{jk}(\hat{p}_{3j}, \hat{p}_{1j})}{N_k}$, are plotted also; and the latter provide departmental fitted ratings. The individual departmental co-ordinates $\left(\hat{I}, \hat{N}, \hat{U}\right)$ are given in the Appendix.

In Statistics & Operational Research and in Accounting & Finance, the ratings may be modelled on the basis of publications alone, with 100 %

Table 4: Trade-offs between international and unclassified research at the rating margins

Estimated coefficient	Rating margin	Business & Management	Economics & Econometrics	Statistics & Operational Research	Accounting & Finance
α_1	1/2	1.00	1.00	1.00	1.00
α_2	2/3b	2.41	1.00	0.70	1.00
α_3	3b/3a	1.81	1.46	1.51	0.82
α_4	3a/4	0.70	1.05	0.96	0.82
α_5	4/5	1.03	1.99	2.44	1.66
α_6	5/5*	0.13	0.66	0.96	2.28

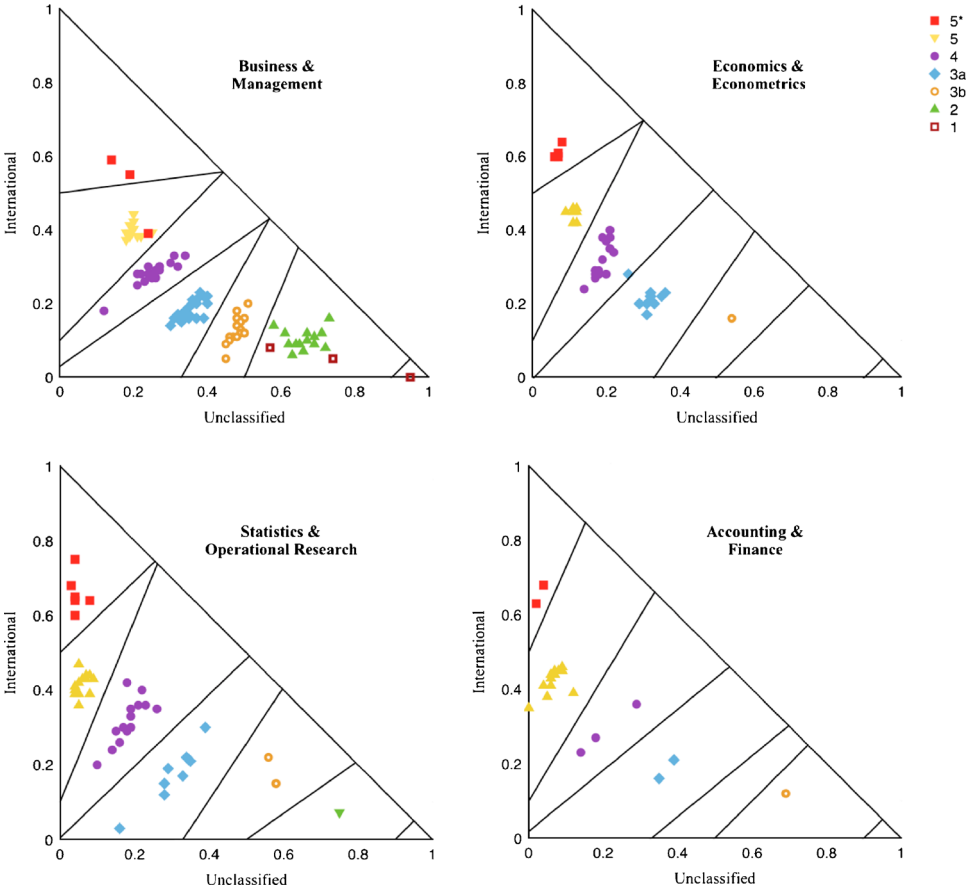

Figure 3: Departmental fitted ratings and boundary trade-off lines (cf. the individual departmental co-ordinates given in the Appendix)

Table 5: Logit estimation of the probability of classifying the quality of research one grade higher or one grade lower than suggested by publications alone

		Business & Management	Economics & Econometrics	Statistics & Operational Research	Accounting & Finance
c_0	Constant	−9.93	−16.40	−21.02	−16.43
c_1	PhDs awarded	0.09	−1.98	−9.38	−2.46
c_2	Research council income	0.23	0.04	−0.37	−0.91
c_3	Other research income	0.12	−0.27	−0.03	−0.49
d_0	Constant	−12.88	−11.87	−14.22	−12.63
d_1	Research staff	−0.01	−0.16	−0.66	−0.23
d_2	Submission rate: staff	−0.09	−1.20	−2.28	−0.63
d_3	Submission rate: publications	−2.39	−1.90	−4.16	−2.73

and 95 % fits, respectively, but in Business & Management and Economics & Econometrics there is some evidence that high levels of other research activity could have influenced the outcome a little; cf. the positive coefficients in Table 5. However, the latter might be driven by the basic desire to accommodate outliers.

The log-likelihood values given in Table 6 are not so large in absolute value and this indicates that the model fits very well. The corresponding probability of correct classification, the geometric mean $\sqrt[K]{e^{\ln L}}$, is between 0.82 and 0.88; remarkably high given that K is between 20 and 97. In relation to assessing hypotheses concerning the actual rating of a department, standard errors are proportional to the perpendicular distance of the fitted points from the estimated boundary trade-off lines. Hence, very few of the given ratings can be challenged. The procedure separates departments well into classes, but three departments do remain 'mis-classified' in Business & Management, one in Economics & Econometrics and maybe one in Accounting & Finance (cf. Table 6 and Fig. 3).

Further error analysis is provided by the estimated rating distribution for each department, given in the Appendix, where the likelihood component and its associated estimated probability of department k being correctly rated, $P(R_k)$, is also given. The few outliers are indicated in the Appendix by their larger contributions, $lnP(R_k)$**,** to the overall log likelihood, the mean departmental contributions being −0.20, −0.14, −0.16 and −0.13, for the four subject groups. The five outliers, or mis-classified departments, have individual log likelihood components a multiple of between 6 and 23 of their subject group's respective mean contribution; three being under-rated and two over-rated. With the very large outlier in Business & Management, there is some suggestion that the estimated slope of the 5/5* trade-off line is considerably reduced in mitigation; and this could have helped to justify

Table 6: Classification accuracy

	Business & Management	Economics & Econometrics	Statistics & Operational Research	Accounting & Finance
Log-likelihood, ln L	−19.77	−5.54	−7.57	−2.64
Number of departments, K	97	41	46	20
Prob (correct classification), $\sqrt[K]{e^{\ln L}}$	0.82	0.87	0.85	0.88
Departments with median $<R_k$	1	0	0	1
Departments with median $>R_k$	2	1	0	0

Table 7: Estimates of research quality proportions by subject

	Business & Management (%)	Economics & Econometrics (%)	Statistics & Operational Research (%)	Accounting & Finance (%)
International	28.8	39.3	39.0	45.2
National	40.4	44.2	46.5	44.7
Unclassified	30.8	16.5	14.5	10.1

another high rating (cf. Fig. 3). Overall, this audit suggests that 29 to 45 % of research was deemed to be of International quality, and a further 40 to 47 % of National quality, as summarised in Table 7. The proportion of research deemed of International quality appears to be lower in Business & Management, where a higher proportion of research is also deemed not to meet even National standards, than in the other three disciplines considered. In Accounting & Finance, the panel appears to deem 90 % of research to be of either International or National standard. Perhaps such differences reflect the basic chauvinistic attitudes of the various subject group panels. However, this paper concerns only a panel's consistency within its subject group. Note, though, that there are differences in implied ratings of certain journals considered by more than one panel; for instance, the Journal of the Operational Research Society is rated as 60 % International by the Business & Management panel but only 9 % International by Statistics & OR.

4 Conclusion

The expert assessments considered in this paper seem to be largely consistent within each unit; the model fits the data very well indeed with only very few outliers. Some additional positive attributes might explain a department being upgraded but there is no evidence of downgrading by negative attributes. This audit thus essentially supports in general the consistency of assessment of RAE2001, but there are one or two surprising 'mis-classifications' that still do require some explanation. The statistical auditing procedure developed here interestingly illustrates how expert assessments might be modelled and checked for consistency even when no information is made available about how the assessors arrived at their decisions. Statisticians have a big role to play and the methodology developed here might provide a better alternative to the use of basic metrics.

Appendix
Estimated rating probabilities and quality proportions

	R_k	$P(1)$	$P(2)$	$P(3)$	$P(4)$	$P(5)$	$P(6)$	$P(7)$	$P(R_k)$	$\ln P(R_k)$	I	N	U
Business & Management													
London Business School	7	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.59	0.27	0.14
Lancaster University	7	0.00	0.00	0.00	0.00	0.00	0.12	0.88	0.88	−0.13	0.55	0.27	0.19
University of Warwick	7	0.00	0.00	0.00	0.00	0.07	0.92	0.01	0.01	−4.60	0.39	0.38	0.24
University of Reading	6	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	−0.00	0.44	0.36	0.20
City University	6	0.00	0.00	0.00	0.00	0.01	0.99	0.00	0.99	−0.01	0.42	0.38	0.20
University of Oxford	6	0.00	0.00	0.00	0.00	0.01	0.99	0.00	0.99	−0.01	0.41	0.40	0.19
University of Cambridge	6	0.00	0.00	0.00	0.00	0.00	0.99	0.00	0.99	−0.01	0.41	0.40	0.19
University of Leeds	6	0.00	0.00	0.00	0.00	0.01	0.99	0.00	0.99	−0.01	0.40	0.39	0.20
University of Nottingham	6	0.00	0.00	0.00	0.00	0.00	0.99	0.00	0.99	−0.01	0.39	0.42	0.19
Imperial College	6	0.00	0.00	0.00	0.00	0.01	0.99	0.00	0.99	−0.01	0.39	0.44	0.18
UMIST	6	0.00	0.00	0.00	0.00	0.09	0.63	0.28	0.63	−0.46	0.39	0.37	0.25
Aston University	6	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	−0.01	0.39	0.42	0.19
University of Bath	6	0.00	0.00	0.00	0.00	0.06	0.94	0.00	0.94	−0.06	0.38	0.40	0.22
London School of Economics	6	0.00	0.00	0.00	0.00	0.06	0.94	0.00	0.94	−0.06	0.38	0.41	0.21
University of Manchester	6	0.00	0.00	0.00	0.00	0.02	0.97	0.01	0.97	−0.03	0.38	0.43	0.19
Cardiff University	6	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	−0.00	0.37	0.45	0.18
Brunel University	5	0.00	0.00	0.00	0.17	0.75	0.07	0.00	0.75	−0.29	0.33	0.33	0.34
University of Southampton	5	0.00	0.00	0.00	0.02	0.94	0.03	0.00	0.94	−0.06	0.33	0.36	0.31
University of Bradford	5	0.00	0.00	0.00	0.05	0.94	0.01	0.00	0.94	−0.07	0.31	0.39	0.30
University of Surrey	5	0.00	0.00	0.00	0.02	0.94	0.04	0.00	0.94	−0.06	0.30	0.42	0.27
Birkbeck College	5	0.00	0.00	0.00	0.06	0.84	0.10	0.00	0.84	−0.17	0.30	0.43	0.27
University of Strathclyde	5	0.00	0.00	0.00	0.03	0.97	0.00	0.00	0.97	−0.03	0.30	0.38	0.32
University of Portsmouth	5	0.00	0.00	0.00	0.00	0.94	0.06	0.00	0.94	−0.07	0.30	0.46	0.24
University of Birmingham	5	0.00	0.00	0.00	0.04	0.92	0.05	0.00	0.92	−0.09	0.30	0.44	0.27
University of Sheffield	5	0.00	0.00	0.00	0.05	0.92	0.03	0.00	0.92	−0.08	0.29	0.44	0.27
Queen's University Belfast	5	0.00	0.00	0.00	0.01	0.96	0.03	0.00	0.96	−0.04	0.29	0.46	0.26
University of Hull	5	0.00	0.00	0.00	0.08	0.85	0.07	0.00	0.85	−0.16	0.29	0.45	0.26
Loughborough University	5	0.00	0.00	0.00	0.02	0.91	0.07	0.00	0.91	−0.09	0.28	0.47	0.24
University of Exeter	5	0.00	0.00	0.00	0.14	0.64	0.22	0.00	0.64	−0.44	0.28	0.48	0.24
University of St Andrews	5	0.00	0.00	0.00	0.11	0.78	0.12	0.00	0.78	−0.25	0.28	0.46	0.25
University of Glasgow	5	0.00	0.00	0.00	0.06	0.72	0.23	0.00	0.72	−0.33	0.28	0.49	0.22

Cranfield University	5	0.00	0.00	0.00	0.00	0.83	0.17	0.00	0.83	−0.19	0.28	0.51	0.21
University of Stirling	5	0.00	0.00	0.00	0.04	0.93	0.03	0.00	0.93	−0.07	0.27	0.48	0.25
University of Edinburgh	5	0.00	0.00	0.00	0.05	0.92	0.03	0.00	0.92	−0.08	0.27	0.48	0.25
Keele University	5	0.00	0.00	0.00	0.06	0.93	0.01	0.00	0.93	−0.07	0.27	0.47	0.26
Royal Holloway, London	5	0.00	0.00	0.00	0.05	0.92	0.02	0.00	0.92	−0.08	0.27	0.49	0.25
King's College London	5	0.00	0.00	0.00	0.07	0.81	0.12	0.00	0.81	−0.21	0.26	0.51	0.23
Heriot-Watt University	5	0.00	0.00	0.00	0.03	0.88	0.08	0.00	0.88	−0.13	0.25	0.53	0.21
University of Luton	5	0.00	0.00	0.00	0.19	0.51	0.29	0.00	0.51	−0.67	0.18	0.69	0.12
University of Salford	4	0.00	0.00	0.05	0.86	0.09	0.00	0.00	0.86	−0.15	0.23	0.40	0.38
University of Wales, Swansea	4	0.00	0.00	0.06	0.92	0.02	0.00	0.00	0.92	−0.09	0.22	0.38	0.40
University of West of England	4	0.00	0.00	0.05	0.94	0.01	0.00	0.00	0.94	−0.06	0.22	0.39	0.39
University of Aberdeen	4	0.00	0.00	0.05	0.88	0.07	0.00	0.00	0.88	−0.13	0.21	0.42	0.37
University of Leicester	4	0.00	0.00	0.09	0.78	0.13	0.00	0.00	0.78	−0.25	0.21	0.43	0.36
University of Brighton	4	0.00	0.00	0.01	0.96	0.03	0.00	0.00	0.96	−0.04	0.20	0.44	0.36
Open University	4	0.00	0.00	0.07	0.93	0.00	0.00	0.00	0.93	−0.07	0.20	0.40	0.40
University of Hertfordshire	4	0.00	0.00	0.02	0.96	0.02	0.00	0.00	0.96	−0.04	0.20	0.44	0.36
Middlesex University	4	0.00	0.00	0.00	0.99	0.01	0.00	0.00	0.99	−0.01	0.20	0.44	0.36
Glasgow Caledonian University	4	0.00	0.00	0.01	0.99	0.00	0.00	0.00	0.99	−0.01	0.20	0.44	0.37
Manchester Metropolitan	4	0.00	0.00	0.02	0.95	0.03	0.00	0.00	0.95	−0.05	0.19	0.46	0.35
University of Ulster	4	0.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00	−0.00	0.18	0.48	0.34
South Bank University	4	0.00	0.00	0.02	0.93	0.05	0.00	0.00	0.93	−0.07	0.17	0.50	0.33
De Montfort University	4	0.00	0.00	0.01	0.99	0.01	0.00	0.00	0.99	−0.02	0.17	0.48	0.34
University of Luton	4	0.00	0.00	0.05	0.86	0.09	0.00	0.00	0.86	−0.15	0.17	0.51	0.32
University of Gloucestershire	4	0.00	0.00	0.05	0.93	0.02	0.00	0.00	0.93	−0.07	0.17	0.48	0.35
University of Newcastle	4	0.00	0.00	0.22	0.71	0.06	0.00	0.00	0.71	−0.34	0.16	0.47	0.37
University of Kent	4	0.00	0.00	0.07	0.92	0.02	0.00	0.00	0.92	−0.09	0.16	0.49	0.35
Kingston University	4	0.00	0.00	0.02	0.94	0.04	0.00	0.00	0.94	−0.06	0.16	0.53	0.31
University of North London	4	0.00	0.00	0.26	0.73	0.01	0.00	0.00	0.73	−0.31	0.16	0.46	0.39
Bournemouth University	4	0.00	0.00	0.03	0.91	0.06	0.00	0.00	0.91	−0.10	0.16	0.53	0.32
University of Durham	4	0.00	0.00	0.04	0.95	0.01	0.00	0.00	0.95	−0.05	0.15	0.52	0.33
University of East Anglia	4	0.00	0.00	0.03	0.91	0.06	0.00	0.00	0.91	−0.09	0.14	0.56	0.30
University of Wales, Aberystwyth	3	0.00	0.07	0.83	0.10	0.00	0.00	0.00	0.83	−0.19	0.20	0.29	0.51
Sheffield Hallam University	3	0.00	0.05	0.75	0.20	0.00	0.00	0.00	0.75	−0.29	0.18	0.34	0.48
University of North London	3	0.00	0.09	0.82	0.09	0.00	0.00	0.00	0.82	−0.19	0.16	0.34	0.50
Nottingham Trent University	3	0.00	0.01	0.99	0.00	0.00	0.00	0.00	0.99	−0.02	0.16	0.33	0.50
University of Plymouth	3	0.00	0.05	0.81	0.14	0.00	0.00	0.00	0.81	−0.21	0.16	0.37	0.48
University of Westminster	3	0.00	0.05	0.92	0.03	0.00	0.00	0.00	0.92	−0.08	0.15	0.36	0.49

University of Glamorgan	3	0.00	0.02	0.93	0.05	0.00	0.00	0.00	0.93	−0.07	0.14	0.38	0.48
University of Wolverhampton	3	0.00	0.14	0.77	0.09	0.00	0.00	0.00	0.77	−0.27	0.13	0.38	0.49
University of Huddersfield	3	0.00	0.16	0.81	0.03	0.00	0.00	0.00	0.81	−0.21	0.12	0.37	0.50
University of Northumbria	3	0.00	0.11	0.86	0.03	0.00	0.00	0.00	0.86	−0.15	0.12	0.39	0.49
University of Lincoln	3	0.00	0.14	0.85	0.01	0.00	0.00	0.00	0.85	−0.17	0.12	0.38	0.50
University of Greenwich	3	0.00	0.10	0.79	0.11	0.00	0.00	0.00	0.79	−0.24	0.11	0.42	0.47
Napier University	3	0.00	0.13	0.75	0.11	0.00	0.00	0.00	0.75	−0.28	0.11	0.42	0.48
University of Abertay Dundee	3	0.01	0.12	0.71	0.16	0.00	0.00	0.00	0.71	−0.34	0.11	0.43	0.46
Staffordshire University	3	0.00	0.04	0.88	0.08	0.00	0.00	0.00	0.88	−0.13	0.10	0.44	0.46
Liverpool John Moores	3	0.00	0.05	0.84	0.11	0.00	0.00	0.00	0.84	−0.18	0.09	0.45	0.45
London Guildhall University	3	0.09	0.12	0.66	0.14	0.00	0.00	0.00	0.66	−0.41	0.05	0.50	0.45
Robert Gordon University	2	0.01	0.99	0.00	0.00	0.00	0.00	0.00	0.99	−0.01	0.16	0.12	0.73
Buckinghamshire Chilterns	2	0.00	0.64	0.36	0.00	0.00	0.00	0.00	0.64	−0.45	0.14	0.28	0.58
Oxford Brookes University	2	0.00	0.81	0.18	0.00	0.00	0.00	0.00	0.81	−0.21	0.12	0.27	0.61
University of East London	2	0.00	0.98	0.02	0.00	0.00	0.00	0.00	0.98	−0.02	0.12	0.21	0.67
Southampton Institute	2	0.02	0.98	0.00	0.00	0.00	0.00	0.00	0.98	−0.03	0.12	0.16	0.71
University of Central England	2	0.01	0.98	0.02	0.00	0.00	0.00	0.00	0.98	−0.03	0.11	0.20	0.69
Oxford Brookes University	2	0.01	0.97	0.02	0.00	0.00	0.00	0.00	0.97	−0.03	0.10	0.22	0.67
Coventry University	2	0.02	0.94	0.04	0.00	0.00	0.00	0.00	0.94	−0.06	0.09	0.26	0.64
University College Northampton	2	0.00	0.98	0.02	0.00	0.00	0.00	0.00	0.98	−0.02	0.09	0.29	0.62
University of Sunderland	2	0.01	0.98	0.01	0.00	0.00	0.00	0.00	0.98	−0.02	0.09	0.26	0.65
University of Derby	2	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.09	0.22	0.69
Anglia Polytechnic University	2	0.01	0.99	0.00	0.00	0.00	0.00	0.00	0.99	−0.01	0.09	0.23	0.69
Leeds Metropolitan University	2	0.03	0.97	0.00	0.00	0.00	0.00	0.00	0.97	−0.03	0.08	0.20	0.72
Queen Margaret Edinburgh	2	0.01	0.98	0.01	0.00	0.00	0.00	0.00	0.98	−0.02	0.07	0.27	0.66
University of Paisley	2	0.03	0.95	0.02	0.00	0.00	0.00	0.00	0.95	−0.06	0.06	0.30	0.63
Trinity & All Saints	1	0.27	0.29	0.21	0.15	0.05	0.02	0.00	0.27	−1.31	0.08	0.35	0.57
Bolton Institute of HE	1	0.08	0.92	0.00	0.00	0.00	0.00	0.00	0.08	−2.55	0.05	0.21	0.74
Dartington College of Arts	1	0.85	0.15	0.00	0.00	0.00	0.00	0.00	0.85	−0.16	0.00	0.05	0.95
										−19.77	0.29	0.40	0.31
Economics & Econometrics													
University of Essex	7	0.00	0.00	0.00	0.00	0.00	0.09	0.91	0.91	−0.10	0.60	0.33	0.07
London School of Economics	7	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	−0.00	0.64	0.29	0.08
University College London	7	0.00	0.00	0.00	0.00	0.00	0.08	0.92	0.92	−0.09	0.60	0.33	0.06
University of Warwick	7	0.00	0.00	0.00	0.00	0.00	0.06	0.94	0.94	−0.06	0.61	0.32	0.07

University of Cambridge	6	0.00	0.00	0.00	0.00	0.01	0.99	0.00	0.99	−0.01	0.46	0.42	0.12
University of Exeter	6	0.00	0.00	0.00	0.00	0.19	0.80	0.02	0.80	−0.23	0.42	0.47	0.11
University of Leicester	6	0.00	0.00	0.00	0.00	0.10	0.88	0.02	0.88	−0.13	0.45	0.45	0.11
Birkbeck College	6	0.00	0.00	0.00	0.00	0.03	0.95	0.02	0.95	−0.05	0.45	0.46	0.09
Queen Mary, London	6	0.00	0.00	0.00	0.00	0.05	0.93	0.02	0.93	−0.07	0.46	0.43	0.11
University of Nottingham	6	0.00	0.00	0.00	0.00	0.07	0.93	0.00	0.93	−0.07	0.42	0.46	0.11
University of Oxford	6	0.00	0.00	0.00	0.00	0.03	0.97	0.00	0.97	−0.03	0.45	0.43	0.12
University of Southampton	6	0.00	0.00	0.00	0.00	0.02	0.98	0.01	0.98	−0.02	0.46	0.43	0.11
University of York	6	0.00	0.00	0.00	0.00	0.10	0.90	0.00	0.90	−0.11	0.42	0.46	0.12
University of Birmingham	5	0.00	0.00	0.00	0.05	0.93	0.02	0.00	0.93	−0.08	0.34	0.44	0.22
University of Bristol	5	0.00	0.00	0.00	0.00	0.91	0.09	0.00	0.91	−0.10	0.38	0.43	0.19
Brunel University	5	0.00	0.00	0.00	0.05	0.89	0.06	0.00	0.89	−0.12	0.35	0.44	0.21
University of Durham	5	0.00	0.00	0.00	0.07	0.85	0.08	0.00	0.85	−0.17	0.32	0.48	0.19
University of East Anglia	5	0.00	0.00	0.00	0.18	0.79	0.03	0.00	0.79	−0.24	0.28	0.52	0.20
University of Kent	5	0.00	0.00	0.00	0.07	0.83	0.09	0.00	0.83	−0.18	0.29	0.55	0.17
University of Liverpool	5	0.00	0.00	0.00	0.05	0.75	0.19	0.00	0.75	−0.28	0.38	0.41	0.21
Royal Holloway, London	5	0.00	0.00	0.00	0.01	0.87	0.12	0.00	0.87	−0.14	0.40	0.39	0.21
University of Manchester	5	0.00	0.00	0.00	0.03	0.96	0.01	0.00	0.96	−0.04	0.28	0.54	0.18
University of Newcastle	5	0.00	0.00	0.00	0.15	0.74	0.11	0.00	0.74	−0.30	0.28	0.54	0.18
University of Sussex	5	0.00	0.00	0.00	0.06	0.85	0.09	0.00	0.85	−0.16	0.29	0.54	0.17
University of Edinburgh	5	0.00	0.00	0.00	0.03	0.83	0.13	0.00	0.83	−0.18	0.37	0.43	0.20
University of Glasgow	5	0.00	0.00	0.00	0.09	0.85	0.06	0.00	0.85	−0.16	0.29	0.53	0.18
University of Strathclyde	5	0.00	0.00	0.00	0.08	0.84	0.08	0.00	0.84	−0.17	0.24	0.62	0.14
University of St Andrews	5	0.00	0.00	0.00	0.07	0.88	0.05	0.00	0.88	−0.13	0.28	0.55	0.17
University of Stirling	5	0.00	0.00	0.00	0.13	0.79	0.08	0.00	0.79	−0.23	0.27	0.56	0.17
University of Wales, Swansea	5	0.00	0.00	0.00	0.11	0.81	0.07	0.00	0.81	−0.21	0.28	0.54	0.18
London Guildhall University	4	0.00	0.00	0.01	0.89	0.10	0.00	0.00	0.89	−0.11	0.23	0.45	0.32
University of East London	4	0.00	0.00	0.03	0.83	0.13	0.00	0.00	0.83	−0.18	0.20	0.49	0.31
Manchester Metropolitan	4	0.00	0.00	0.02	0.94	0.04	0.00	0.00	0.94	−0.06	0.17	0.53	0.31
City University	4	0.00	0.00	0.03	0.87	0.11	0.00	0.00	0.87	−0.15	0.22	0.46	0.32
Keele University	4	0.00	0.00	0.00	0.43	0.57	0.00	0.00	0.43	−0.84	0.28	0.46	0.26
Loughborough University	4	0.00	0.00	0.01	0.99	0.01	0.00	0.00	0.99	−0.01	0.22	0.43	0.35
University of Sheffield	4	0.00	0.00	0.01	0.98	0.01	0.00	0.00	0.98	−0.03	0.23	0.41	0.36
University of Surrey	4	0.00	0.00	0.00	0.94	0.06	0.00	0.00	0.94	−0.06	0.22	0.46	0.32
University of Aberdeen	4	0.00	0.00	0.01	0.97	0.02	0.00	0.00	0.97	−0.03	0.20	0.47	0.33
University of Dundee	4	0.00	0.00	0.00	0.90	0.09	0.00	0.00	0.90	−0.10	0.20	0.51	0.29
University of Northumbria	3	0.00	0.01	0.88	0.11	0.00	0.00	0.00	0.88	−0.12	0.16	0.30	0.54
										−5.54	0.39	0.44	0.17

Statistics & Operational Research													
University of Warwick	7	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	−0.00	0.75	0.21	0.04
University of Bristol	7	0.00	0.00	0.00	0.00	0.00	0.02	0.98	0.98	−0.02	0.68	0.30	0.03
University of Cambridge	7	0.00	0.00	0.00	0.00	0.00	0.01	0.99	0.99	−0.01	0.65	0.31	0.04
Lancaster University	7	0.00	0.00	0.00	0.00	0.00	0.11	0.89	0.89	−0.12	0.64	0.28	0.08
University of Oxford	7	0.00	0.00	0.00	0.00	0.00	0.05	0.95	0.95	−0.06	0.64	0.32	0.04
University of Kent	7	0.00	0.00	0.00	0.00	0.01	0.30	0.69	0.69	−0.37	0.60	0.36	0.04
University of Nottingham	6	0.00	0.00	0.00	0.00	0.03	0.77	0.20	0.77	−0.27	0.47	0.48	0.05
University of Newcastle	6	0.00	0.00	0.00	0.00	0.02	0.84	0.14	0.84	−0.17	0.47	0.47	0.05
Queen Mary, London	6	0.00	0.00	0.00	0.00	0.13	0.81	0.06	0.81	−0.21	0.44	0.48	0.08
University of Southampton	6	0.00	0.00	0.00	0.00	0.04	0.93	0.03	0.93	−0.07	0.44	0.50	0.07
University of Surrey	6	0.00	0.00	0.00	0.00	0.15	0.76	0.10	0.76	−0.28	0.43	0.50	0.07
Heriot-Watt University	6	0.00	0.00	0.00	0.00	0.17	0.81	0.02	0.81	−0.21	0.43	0.48	0.09
University College London	6	0.00	0.00	0.00	0.00	0.07	0.88	0.05	0.88	−0.13	0.43	0.51	0.06
University of Sheffield	6	0.00	0.00	0.00	0.00	0.06	0.88	0.06	0.88	−0.12	0.42	0.53	0.05
University of Glasgow	6	0.00	0.00	0.00	0.00	0.03	0.95	0.02	0.95	−0.05	0.42	0.53	0.05
Imperial College	6	0.00	0.00	0.00	0.00	0.04	0.89	0.07	0.89	−0.12	0.41	0.55	0.04
University of Bath	6	0.00	0.00	0.00	0.00	0.03	0.95	0.02	0.95	−0.06	0.40	0.56	0.04
University of St Andrews	6	0.00	0.00	0.00	0.00	0.24	0.75	0.02	0.75	−0.29	0.39	0.53	0.08
University of Southampton	6	0.00	0.00	0.00	0.00	0.08	0.87	0.04	0.87	−0.14	0.39	0.57	0.05
University of Leeds	6	0.00	0.00	0.00	0.00	0.05	0.91	0.04	0.91	−0.10	0.39	0.58	0.04
University of Salford	6	0.00	0.00	0.00	0.00	0.05	0.95	0.00	0.95	−0.05	0.36	0.59	0.05
Open University	5	0.00	0.00	0.00	0.01	0.79	0.20	0.00	0.79	−0.24	0.42	0.40	0.18
University of Aberdeen	5	0.00	0.00	0.00	0.09	0.76	0.14	0.01	0.76	−0.27	0.40	0.38	0.22
University of Sussex	5	0.00	0.00	0.00	0.07	0.90	0.03	0.00	0.90	−0.10	0.36	0.41	0.23
London School of Economics	5	0.00	0.00	0.00	0.01	0.98	0.01	0.00	0.98	−0.02	0.36	0.43	0.21
UMIST	5	0.00	0.00	0.00	0.08	0.78	0.14	0.00	0.78	−0.24	0.35	0.46	0.19
University of Liverpool	5	0.00	0.00	0.00	0.11	0.88	0.00	0.00	0.88	−0.12	0.35	0.39	0.26
University of Manchester	5	0.00	0.00	0.00	0.11	0.77	0.12	0.00	0.77	−0.27	0.33	0.48	0.19
University of Durham	5	0.00	0.00	0.00	0.08	0.88	0.05	0.00	0.88	−0.13	0.30	0.51	0.19
University of Reading	5	0.00	0.00	0.00	0.03	0.93	0.04	0.00	0.93	−0.07	0.30	0.53	0.17
University of Strathclyde	5	0.00	0.00	0.00	0.07	0.88	0.05	0.00	0.88	−0.13	0.29	0.53	0.18
University of Exeter	5	0.00	0.00	0.00	0.09	0.72	0.19	0.00	0.72	−0.33	0.29	0.56	0.15
University of Edinburgh	5	0.00	0.00	0.00	0.07	0.87	0.06	0.00	0.87	−0.14	0.26	0.59	0.16
Brunel University	5	0.00	0.00	0.00	0.04	0.93	0.03	0.00	0.93	−0.07	0.24	0.61	0.14
University of Birmingham	5	0.00	0.00	0.00	0.13	0.73	0.14	0.00	0.73	−0.31	0.20	0.70	0.10
University of Plymouth	4	0.00	0.00	0.05	0.73	0.22	0.00	0.00	0.73	−0.31	0.30	0.31	0.39

Goldsmiths College	4	0.00	0.01	0.13	0.64	0.21	0.00	0.00	0.64	−0.44	0.22	0.44	0.34
Nottingham Trent University	4	0.00	0.00	0.05	0.86	0.08	0.00	0.00	0.86	−0.15	0.21	0.44	0.35
City University	4	0.00	0.00	0.00	0.89	0.11	0.00	0.00	0.89	−0.12	0.19	0.52	0.29
University of North London	4	0.00	0.00	0.08	0.85	0.07	0.00	0.00	0.85	−0.16	0.17	0.50	0.33
University of Greenwich	4	0.00	0.00	0.08	0.74	0.17	0.01	0.00	0.74	−0.30	0.15	0.57	0.28
Keele University	4	0.00	0.00	0.05	0.88	0.06	0.00	0.00	0.88	−0.12	0.12	0.60	0.28
Coventry University	4	0.00	0.00	0.03	0.85	0.08	0.03	0.00	0.85	−0.16	0.03	0.81	0.16
Napier University	3	0.00	0.01	0.85	0.14	0.00	0.00	0.00	0.85	−0.17	0.22	0.22	0.56
University of Westminster	3	0.00	0.18	0.76	0.06	0.00	0.00	0.00	0.76	−0.27	0.15	0.27	0.58
Staffordshire University	2	0.00	0.92	0.08	0.00	0.00	0.00	0.00	0.92	−0.09	0.07	0.18	0.75
										−7.57	0.39	0.47	0.14
Accounting & Finance													
London School of Economics	7	0.00	0.00	0.00	0.00	0.00	0.01	0.99	0.99	−0.01	0.68	0.29	0.04
University of Manchester	7	0.00	0.00	0.00	0.00	0.00	0.04	0.96	0.96	−0.04	0.63	0.35	0.02
University of Stirling	6	0.00	0.00	0.00	0.00	0.00	0.99	0.00	0.99	−0.01	0.45	0.48	0.08
University of Strathclyde	6	0.00	0.00	0.00	0.00	0.01	0.98	0.01	0.98	−0.02	0.45	0.46	0.09
University of Essex	6	0.00	0.00	0.00	0.00	0.00	0.97	0.02	0.97	−0.03	0.45	0.48	0.07
University of Glasgow	6	0.00	0.00	0.00	0.00	0.01	0.97	0.02	0.97	−0.03	0.44	0.50	0.06
University of Exeter	6	0.00	0.00	0.00	0.00	0.02	0.96	0.03	0.96	−0.05	0.41	0.53	0.06
University of Durham	6	0.00	0.00	0.00	0.00	0.02	0.95	0.04	0.95	−0.06	0.44	0.49	0.07
University of Bristol	6	0.00	0.00	0.00	0.00	0.02	0.94	0.05	0.94	−0.06	0.43	0.51	0.06
University of West of England	6	0.00	0.00	0.00	0.00	0.01	0.93	0.07	0.93	−0.08	0.41	0.55	0.04
University of Wales, Bangor	6	0.00	0.00	0.00	0.00	0.04	0.93	0.03	0.93	−0.08	0.46	0.45	0.09
University of Newcastle	6	0.00	0.00	0.00	0.00	0.07	0.86	0.06	0.86	−0.15	0.38	0.57	0.05
University of Edinburgh	6	0.00	0.00	0.00	0.00	0.17	0.83	0.00	0.83	−0.19	0.39	0.50	0.12
University of Paisley	6	0.00	0.00	0.00	0.01	0.03	0.81	0.14	0.81	−0.21	0.35	0.65	0.00
University of Aberdeen	5	0.00	0.00	0.00	0.07	0.84	0.10	0.00	0.84	−0.18	0.27	0.54	0.18
Glasgow Caledonian University	5	0.00	0.00	0.00	0.13	0.84	0.04	0.00	0.84	−0.18	0.36	0.35	0.29
University of Dundee	5	0.00	0.00	0.00	0.08	0.82	0.10	0.00	0.82	−0.20	0.23	0.63	0.14
Sheffield Hallam University	4	0.00	0.02	0.03	0.89	0.06	0.00	0.00	0.89	−0.12	0.16	0.49	0.35
University of Liverpool	4	0.00	0.00	0.05	0.85	0.10	0.00	0.00	0.85	−0.17	0.21	0.41	0.39
University of Central Lancashire	3	0.00	0.52	0.45	0.02	0.00	0.00	0.00	0.45	−0.79	0.12	0.20	0.69
										−2.64	0.45	0.45	0.10

References

burkitt, b. and baimbridge, m. (1995) "Publication performance in The Economic Journal and UFC research rankings", *Applied Economics,* 27 (4): 397–402.

doyle, j., arthurs, a., green, r., mcaulay, l., pitt, m., bottomley, p. and evens, w. (1996) 'The judge, the model of the judge, and the model of the judged as judge: analyses of the UK 1992 research assessment exercise data for business and management studies', *Omega: International Journal of Management Science*, 24 (1): 13–28.

easton, g. and easton, d.m. (2003) 'Marketing journals and the research assessment exercise', *Journal of Marketing Management*, 19 (1/2): 5–24.

geary, j., marriott, l. and rowlinson, m. (2004) 'Journal rankings in business and management and the 2001 research assessment exercise in the UK'. *British Journal of Management*, 15: 95–141.

johnes, j., taylor, j. and francis, b. (1993) 'The research performance of UK universities: a statistical analysis of the results of the 1989 research selectivity exercise', *Journal of the Royal Statistical Society Series A*, 156 (2): 271–286.

marston, c. and ayub, a. (2000) "Relationship between publications in selected journals and Research Assessment Exercise rankings in 1996 for UK accountancy departments", *Accounting Education*, 9 (1): 93–102.

mckay, s. (2003) 'Quantifying quality: can quantitative data ("metrics") explain the RAE ratings for social policy and administration?', *Social Policy and Administration,* 37 (5): 444–467.

taylor, j. (1995) 'A statistical analysis of the 1992 research assessment exercise', *Journal of the Royal Statistical Society Series A*, 158 (2): 241–261.

taylor, j. (2011) 'The Assessment of Research Quality in UK Universities: Peer Review or Metrics?', *British Journal of Management*, 22 (2): 202–217.

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Paper received: 23 September 2014.