Professorial Salaries and Research Performance in UK Universities[*]

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August 1, 2017

Abstract

We study the relationship between academic salaries and research performance. We use individual level data on the salary of all UK university professors, matched to the performance of departments from the 2014 government evaluation of research. Our empirical analysis shows that both pay level and pay inequality in a department are positively related to performance. It also shows that the pay-performance relationship is driven by a feature of the research evaluation that allows academics to transfer the affiliation of published research across universities. Our findings can be rationalized by a simple model of university pay determination, which shows how the observed pay-performance relationship can be explained by the incentives inherent in the research evaluation process.

Keywords: Higher education competition, Research funding, University sector, Salary inequality, Research Excellence Framework.

JEL Codes: D47, H42, I28, L30.

[*]We are grateful to Jacques Maraisse, Paula Stephan, Todd Zangler, and the audiences at the 2017 RES Conference in Bristol, at the 2017 BRICK Workshop on the Economics of Science (Turin), at the 2017 Barcelona GSE Forum, and at the 2017 AISUK conference for helpful comments.

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1 Introduction

The pay structure is a key driver of the performance of firms. A positive correlation between firm performance and average pay is firmly established in the literature (e.g. Nickell and Wadhwani 1990, Nickell et al. 1994, Hildreth and Oswald 1997, Abowd et al. 1999, and Lazear 2000). Some evidence suggests also that firms with higher within-firm pay *inequality* achieve better performance (Grund and Westergaard-Nielsen 2008, Edmans and Gabaix 2015, Mueller et al. 2016).

The pay-performance relationship holds true not just in commercial firms, but also in some organisations which lack a monetary measure of success, such as schools (Lavy 2009). Does it also hold for universities? Do universities which pay more, and vary salaries more across their academics, perform better? A subject of amused or heated discussions among academics, there is surprisingly little systematic evidence on this important question. Moreover, the limited existing literature has focused on broad national differences in university pay (Altbach et al. 2012) or the internal labor markets of universities (Oyer 2007, Haeck and Verboven 2012) rather than variation among institutions within a country.

In this paper we study in detail the relationship between pay and performance in academic departments using a rich dataset covering all UK universities. The UK setting offers two key features of interest for policy makers around the globe intent on reforming the higher education sector. First, unlike many other European countries, full professors' salaries are not subject to national regulation, other than a agreed minimum. Universities are free to compete over professorial pay, and anecdotal evidence suggests that they do so fiercely. Indeed our data exhibits large observed salary differences, with the highest paid professors in some of the elite institutions earning as much as seven times the national minimum. Second, the systematic and comprehensive assessment of research provided by the Research Excellence Framework (REF), determines the government "block" research funding, a vital source of research income for UK institutions. The importance of the REF performance is leveraged by its being a hefty determinant of the ranking published in several university league tables. It therefore also affects indirectly other sources of research income, student recruitment, and prestige. Hence UK universities have strong incentives to recruit and retain professors who may improve their REF performance. In this paper we strive to uncover whether they set pay structures to pursue this goal.

Our analysis draws upon a dataset comprising the pay of all full professors and the performance of their department in the REF carried out in 2014. We find a positive relationship between professorial pay and REF performance. This finding is very robust: it holds when we control for a range of departmental characteristics plus academic discipline and university type fixed effects. It also holds across the whole range of academic disciplines. Interestingly, we find that the pay-performance relationship is weaker, though still statistically significant, in the most well-known research intensive universities, and stronger among those established more recently. We also find a positive relationship between professorial pay inequality, measured by the Gini coefficient of salaries within a department, and REF performance at the department level. Unlike the mean salary, this finding is strongest in the most prestigious universities, and is statistically significant for disciplines in the sciences and engineering, but not in medicine and biology, the social sciences, the arts and humanities.

In further empirical analysis, we investigate whether specific features of the REF give rise to the observed pay-performance relationship. We show that this relationship appears to be driven by the research evaluation, which creates a veritable "transfer market" for academics. As explained in detail in Section 2.1, in the REF exercise three dimensions are measured to assess research performance: output, environment, and impact. The output score is determined by the quality of the publications of the members of the department *at the census date*, irrespectively of where the research was carried out. Environment and impact are instead evaluated through written submissions, and focus on activities carried out in the department over the entire time period assessed, irrespective of which institution is currently employing the researcher who contributed to them. That is, "output" component is transferable, while the "environment" and "impact" components are not.[1] We find that the positive association between salary and overall performance is in large part due to the relationship between salary and the evaluation of the "transferable" research output. We find a weaker link between average salary and the impact performance. This result is consistent with universities giving more weight, when hiring or promoting academics, to a high performance in output, the "transferable" dimension, in turn suggesting that they do deliberately try to attract professors whose track record affects the REF performance. While we cannot firmly establish causality in these results – our institutional setting does not offer natural experiments in the data – our findings are consistent with universities targeting their pay setting behavior towards maximising returns from the national research evaluation exercise.

Finally, we provide some evidence for ''insider" behaviour among the REF panel members: *ceteris paribus*, departments in which at least one member of staff sits on the REF peer-review evaluation panel perform better in the exercise. Interestingly, this effect is driven only by the environment and impact components of the aggregate quality measure, and is strongest in social sciences and in arts and humanities, arguably the subject areas and the quality measures which require more subjective judgement by the panel members.

The association between research performance and average pay and pay inequality

[1] To use a fictitious example, suppose Professor Lapping publishes important papers while he is employed by Poppleton University. He then moves to Porterhouse College *before* the REF census date. Then his publications will be included in the "output" submission of Porterhouse College and in the "impact" submission of Poppleton University.

which we find in the UK university sector can be rationalized in very simple models. We close the paper by sketching one where universities aim at maximising an aggregate measure of research success, which in turn determines the research funding they will receive from the government. Research is produced using elastically supplied capital and different kinds of labour, to capture different attributes of the academics employed. Our model predicts a positive correlation between the research performance of a department, the average salary of its staff, and inequality in departmental pay, consistently with the empirical evidence we have uncovered.

The paucity of information on individual pay has constrained the analysis of the previous incarnations of the REF. Early comprehensive studies (e.g. Johnes et al. 1993, Taylor 1995, Sharp and Coleman 2005) have emphasised the role played by systematic biases in the panels' quality assessment, based on characteristics of the institutions: new universities vs. more established ones, institutions based in England vs. those based in other parts of the country, units of assessment that had a panel member vs. those which did not, and so on. Controlling for the quality of the submission in the 1996 and 2001 assessments of the economics and econometrics departments, Clerides et al. (2011) do not find systematic evidence of biases in favour of specific institutions. The exception is membership in the panel, which has a positive and significant impact on the ranking of the department in the 1996 exercise. This is in line, as well as with this paper, with Butler and McAllister's (2009) study of the evaluation of the political science panel in the 2001 exercise.[2]

If the link between *institutions'* average pay and their research performance is relatively unexplored, a long established literature links an *individual's* compensation and their research productivity. Measuring the latter is challenging. The early work by Diamond (1986) uses citations as an indicator of a researcher's impact, and finds that the marginal effect of an additional citation on individual income is positive. Other contributions distinguish between the number of citations, used as a proxy for "quality", and the measure of "quantity" given by the number of papers published. Most analyses study a small sample of departments (e.g. Hamermesh et al. 1982, Moore et al. 1998 and Bratsberg et al. 2010). In a recent paper, Hamermesh and Pfann (2012) consider instead the members of a larger group of 43 economics department at public institutions in the United States, and find a positive association between output and salaries. This holds both when output is measured by quality, proxied by citations, or by quantity, the number of papers. As far as we know, Sgroi and Oswald (2013) is the only paper which provides a solid theoretical foundation to the balance between quality and quantity. A small recent strand of this literature studies the determinants of individuals' research output in continental Europe: among these, Bosquet and Combes (2017), Zinovyeva and Bagues (2010, 2015) and Checchi et al. (2014) in France,

[2]The important role played by the panel composition on the evaluation process of academics has been emphasised also by Zinovyeva and Bagues (2015) for the case of Spain.

Spain, and Italy, respectively. The first of these shows that the characteristics of colleagues matter for research, while the last two focus on the link between research performance and the chances of promotion. Kwiek's recent contribution (2017), on the other hand, shows how in continental Europe, salary increases are associated with increases in administrative and managerial duties.

The rest of the paper proceeds as follows. The main features of the REF and the data used in the analysis are described in Section 2. Our empirical results are presented in Section 3. The simple theoretical model of resource allocation within universities that we use to interpret our results is presented in Section 4, and Section 5 concludes. Additional results and more information on the UK university sector are available in the Appendices.

2 Data

Our dataset combines public information on the submissions and results from the REF, available on the REF 2014 website, with information on the characteristics of UK professors in post in October 2013, the month of the census date for the inclusion of academic staff in the REF. In this section we start by presenting the institutional environment of the REF, we discuss next the sample construction, and we report some summary statistics.

2.1 Research Excellence Framework (REF) Outcome Data

The REF 2014 was a government run evaluation to assess the quality of research in UK higher education institutions.[3] As well as ensuring accountability for public investment in research and producing evidence of its benefits, the assessment informs the selective allocation of the annual "block" budget for research to institutions. This funding is the so-called QR (quality related) allocation, and, unlike the funds distributed by the research councils, which pay for specific projects, universities are free to choose how to allocate them across projects, and indeed disciplines. The funding allocated on the basis of REF results is substantial. It corresponds to approximately one quarter of all taxpayer money awarded to higher education institutions.[4]

The REF involves peer-review assessment by 36 subject-specific expert panels of the "reach and significance" of the research carried out by the academics submitted for assessment. The 36 panels are grouped into four "Main Panels", corresponding to very broad disciplinary areas: medicine and biology, the other sciences and engineering, the social sciences, and the arts and humanities. Universities are not obliged to submit all their departments for evaluation, nor are they compelled to submit all the academic members of

[3]Similar exercises have been carried out a regular intervals since 1992, with early runs in 1986 and 1989, as explained on the REF website

[4]Detailed information of how public funds are allocated to UK universities can be found at www.hesa.ac.uk/stats-finance. The full set of REF rules, the identity of the reviewers, and the outcomes are available at www.ref.ac.uk.

each department taking part in the assessment exercise. By not doing so though they forgo part of their funding, which is based on a formula increasing in the number of academics submitted.

Panels assess academic departments in three areas: research output, environment, and impact. Output is assessed through the evaluation of scholarly work (such as books or journal articles), with each academic required to submit four different items.[5] Outputs are attributed to the academic at the institution in which they are employed on 31 October 2013, the REF census date, even when they were produced while the faculty member was employed by a different institution. The environment component is a written submission describing the achievements of the academic department, together with data on research grant income and PhD completions. Similarly, impact is assessed by considering written 'case studies', one for every eight academics submitted, accompanied by supporting evidence which shows how the research of the department has brought benefits *outside of academia* through, for example, influence on government policy or industry practice.

As a result of the evaluation, each academic department is assigned a numerical 'quality' profile which describes the percentage of the department's output, environment and impact rated on a 5-point "star" scale from 4* to 0*, where 4* is defined as "Quality that is world-leading in terms of originality, significance and rigour" and 0* is "Quality that falls below the standard of nationally recognised work."[6] The profiles of the three components (output, impact and environment) are aggregated into a single quality profile, given by a weighted average of the three components, with weights 65%, 20%, and 15% for the three components. Formally, let π_i^s be the proportion of department (i,k)'s submission respectively judged to be of quality $s^\star$, with $s = 0, 1, \ldots, 4$. π_i^s is then given by

$$\pi_i^s = 0.65 O_i^s + 0.2 I_i^s + 0.15 E_i^s \quad s = 0, 1, \ldots, 4, \tag{1}$$

where O_i^s, I_i^s, and E_i^s are the shares of department i's research output, impact and environment which has been attributed a grade $s^\star$ by the panel. Clearly $\sum_{s=0}^{4} O_i^s = 1$, and similarly for I_i^s and E_i^s and hence for π_i^s.

The quality profiles (1) of individual departments are typically used to construct two indicators. The first is the grade point average, GPA, which is used by the media in the public discourse to rank departments in national league tables. GPA is calculated as a weighted average of the scores, with the proportion in each category as weight: department i's GPA is

[5] Hamermesh and Pfann (2012) find a negative correlation between the number of citations and the number of papers published by the members of a sample of top US economics departments. Thus the small number of items individuals are required to submit for the REF, might indicate that the UK policy maker preferences are skewed towards the "quality" of research, measured by citations, rather than the sheer publication count.

[6] A tongue-in-cheek analysis of the accuracy of these definition is carried out in the intriguing paper by Règibeau and Rockett (2016).

calculated simply as:

$$GPA_i = \sum_{s=0}^{4} \pi_i^s s. \tag{2}$$

The second indicator is a funding score formula, FS, which is used by the government as the basis to determine research funding allocations. This formula is intended to provide incentives towards high quality research, and so it gives high weight to $4^\star$ output, and no weight to output judged less than $3^\star$.[7] With the above notation, and N_i denoting the number of full–time equivalent researchers submitted by institution i, its yearly funding until the following evaluation exercise is given by

$$FS_i = \Gamma_i \left(4\pi_i^4 + \pi_i^3\right) N_i, \tag{3}$$

where Γ_i is a coefficient of proportionality which is subject specific and determined every year depending on the overall public funding for universities.

Do UK universities place greater emphasis on their GPA or funding scores? Institutions are not required to submit all their academics; instead they may choose whom to submit for assessment. The presence of N_i in (3), but not in (2), thus creates for them an important trade-off. GPA, for its immediacy and simplicity is a good measure of prestige, used in many league tables. If institutions only cared about the GPA, then they should submit very few researchers, in the limit only their very best ones. This however would harm their funding, which is proportional to the number of staff submitted for assessment. To account for these potentially different objectives, in our analysis we consider both measures of performance: We report funding scores in the main text and GPA in the Appendix.

The three components of the quality indicator in generate different incentives in recruitment and retention of academics. These differences can be used to understand whether universities try to attract academics with the view to enhance their REF success. An individual department which hires a professor just before the REF census date is able to reap the rewards for that academic's research output over the previous years, even though the research was conducted at a different institution. This is not true, however, for impact, the research leading to which must have been carried out in the department (indeed, as in the example in footnote 1, the academic's previous employer can include her work as one of its case studies). Similarly, it would be hard for a department to argue that someone with a very short tenure could have had the opportunity to affect its research "environment". Therefore, the value to the institution of an academic's outputs travels with her, but the value of her contribution to the environment and especially her impact does not. This

[7] While institutions did not know the exact details of the formula, which were determined after the publication of the results, (Else 2015), they knew the principles which would underpin it.

suggests that, when hiring (or responding to outside offers) prior to the REF census date, institutions should value more a researcher with a stellar publication record, even though she has no demonstrable impact outside academia, than a researcher whose less prestigious recent publications can however be shown to have influenced a certain Act of Parliament, an EU directive, or industry practice.

2.2 Sample Construction

To construct our dataset, we match individual characteristics of UK professors with information on the REF performance of the department of which they are members. The characteristics of the pay and age structure of UK departments are derived from data provided by the UK Higher Education Statistical Agency (HESA). This agency collects administrative information about all individuals employed with the academic rank of full professor by a higher education institution in the UK as of October 2013.[8] HESA matches each individual to one of the 36 REF panels, and therefore we use the composition of departments determined by this match, even if there may be instances in which an individual in a given department is submitted to a different panel for assessment (for example, an economics member of staff might have been submitted to the management panel). Information about the average pay and its dispersion within a department is obtained from this data, which also reports details of the age structure of departments' professoriate: for each department, we know the fraction of professors whose age falls in each ten-year band.

The departmental characteristics are calculated excluding all professors paid a full-time equivalent of less than a threshold value of £$50,500$ in 2013.[9] To reduce the possibility of identifying individuals, the sample is limited to units with more than three full-time equivalent professors, and we exclude units which were not submitted to the REF. We also omit the only department of the London Business School, which has very low reliance on government funding, and is an extreme outlier, in regards of salaries, as it pays on average more than three times the national average. Together these restrictions reduce our sample from approximately $17,000$ full-time equivalent professors to $16,400$. The final piece of information we add is the total remuneration of the universities' heads, typically known as Vice Chancellors, which is published every year in the Times Higher Education newspaper.

We partition departments into the four "Main Panels" defined by the REF exercise. We also divide universities into five groups, according to their institutional characteristics.

[8]There are approximately $17,000$ full-time equivalent professorial positions in the UK which are filled by approximately $19,000$ individuals, some of whom work part-time.

[9]This is to account for the fact that in some institutions there are academics who are paid a very low full-time equivalent annual pay, and are employed for a very small fraction of the time (a typical figure is 10%). Our understanding is that some institutions classify as professorial staff collaborators (such as external examiners) who would be considered external payees in other institutions, and whose research cannot be submitted to the REF evaluation. All our results are robust if we include also professors paid less than the threshold.

Table 1: Department Summary Statistics

(a) Department-Level Pay Summary Statistics

	Mean	Median	SD	Min	25th	75th	Max
Professorial FTE	13.88	9.00	20.08	3.00	5.00	15.00	311.00
Average Salary	73.55	72.71	9.83	50.87	66.78	78.65	128.46
Gini Coefficient Salary	0.08	0.08	0.04	0.00	0.05	0.10	0.36
% Age under 40	5.10	0.00	8.77	0.00	0.00	8.33	66.67
% Age 41-50	30.98	30.77	18.37	0.00	20.00	42.11	100.00
% Age 51-60	38.31	36.36	19.41	0.00	25.00	50.00	100.00
% Age over 60	25.61	23.81	18.45	0.00	12.90	33.53	100.00
Vice Chancellor Pay (£000s)	299.49	282.00	63.41	143.00	259.00	326.00	623.00
Department has a REF Panel Member	0.38	0.00	0.49	0.00	0.00	1.00	1.00
Academic FTE Submitted to REF	33.40	24.50	32.41	2.00	15.71	38.50	449.74

(b) Department-Level REF Summary Statistics

	Mean	Median	SD	Min	25th	75th	Max
Funding Score	58.82	37.50	74.16	0.36	20.60	69.56	939.96
Overall Grade Point Average	2.96	3.01	0.33	1.51	2.78	3.20	3.78
Outputs Grade Point Average	2.86	2.90	0.29	1.39	2.70	3.06	3.68
Environment Grade Point Average	3.13	3.15	0.60	0.75	2.75	3.60	4.00
Impact Grade Point Average	3.15	3.27	0.55	0.70	2.87	3.52	4.00

Notes: Sample size = 1139 academic departments submitted to REF 2014. Professorial FTE is the total FTE of professors in the department. FTE submitted to REF 2014 measures the total number of FTE (including non-professorial researchers) submitted to the REF evaluation. Vice Chancellor pay is total remuneration (including salary and discretionary payments). Department has a REF Panel Member is a dummy variable indicating whether the REF 2014 main panel or sub-panel included a member of the department. Total salary bill is sum of departmental professorial pay. Definitions of Funding Score and other REF Grade Point Average variables are provided in the main text.

These are the most established universities, which include the original Russell group, labeled "Russell" – Oxbridge, LSE, and the authors' institution among them; the founding members of the recently disbanded "1994 group", which comprised younger and smaller research-intensive universities, – York, Essex, Queen Mary among them; "New Universities" mostly created from locally controlled vocational institutions; "specialist" institutions, such as the Royal College of Arts, whose focus is exclusively on a single discipline; and the rest, mostly universities with historically less emphasis on research (such as Hull, Bradford), labeled "Others". A full listing of the groups is provided in Appendix A.

2.3 Summary Statistics

Summary data on the characteristics of the 1139 academic departments that comprise our final dataset are reported in Table 1. The average department has approximately 14 professors (Full-Time Equivalent, FTE), with an average pay at around £74,000. The number of professorial FTE in a department ranges from 3 to over 300, for one very large medical school. Average salary ranges from just above £50,000 to just below £130,000. The Gini coefficient for departmental pay is on average low at 0.08 but varies between zero (completely equal pay) to 0.36.[10] Notice that, given the minimum pay constraint, the maximum theoretical value for the department with the country's average membership and pay is around 0.3. Over two thirds of professors fall in the 41-60 age range. The table also includes summary data for the total number of full-time equivalent staff, including non-professors, submitted to the REF, the pay of the university Vice Chancellor, and a dummy indicating whether a member of academic staff from the department sat on the REF peer-review panel. We use these variables as controls in our analysis.

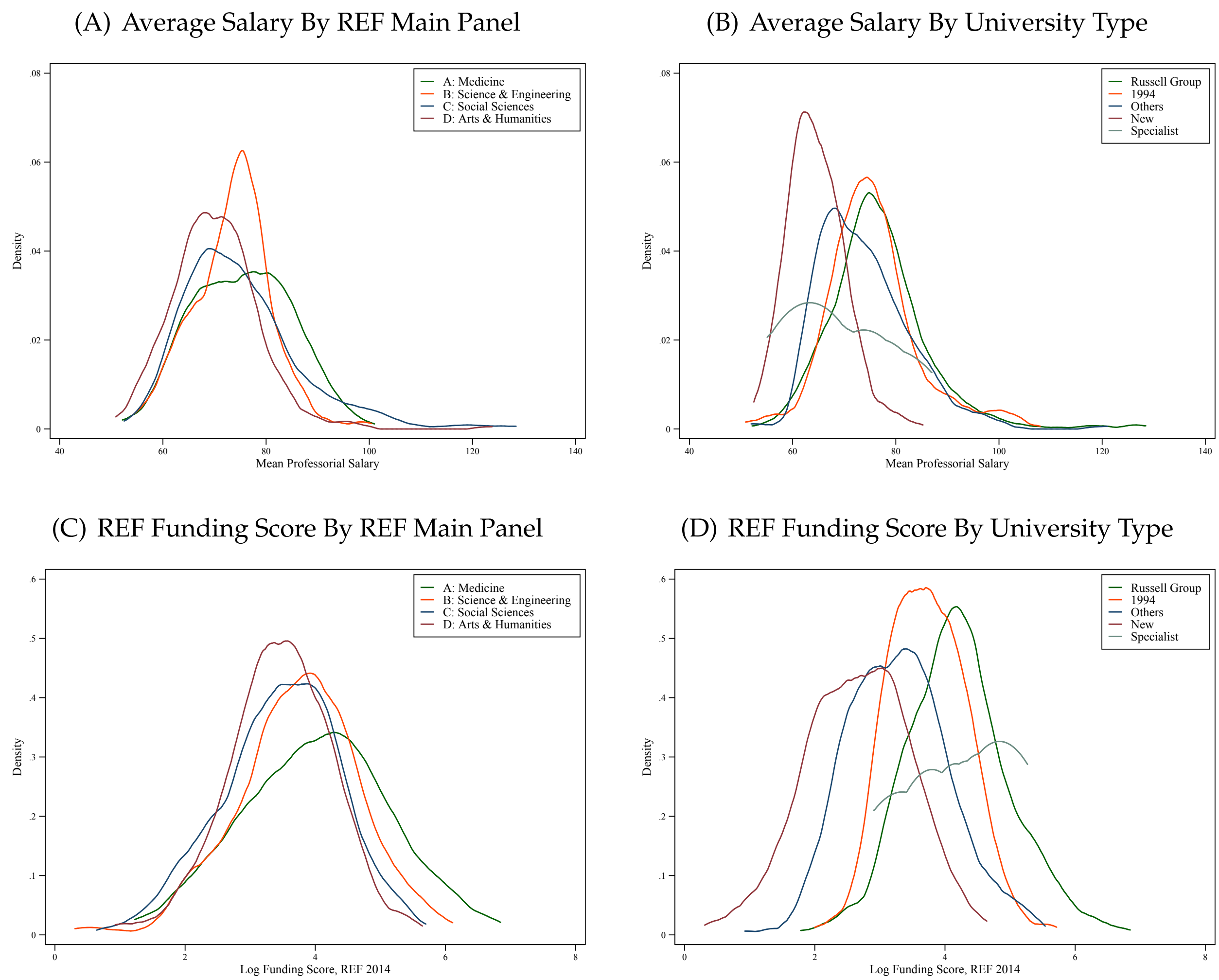
The lower part of the table summarises the performance of departments in the REF exercise. The mean overall grade point average is 2.96 out of a theoretical maximum of 4, ranging from 1.51 to 3.78. These GPA scores translate to funding score values, given in equation (3), from just above 0 to over 900. Summary data is also provided for each component of the GPA quality score, showing that some departments managed to obtain top score for their research environment and research impact. A breakdown of average scores across the full quality profile is reported in Table A1 in the Appendix.

The distribution of average departmental salary and of REF funding scores is shown in Figure 1. Departments are grouped according to the REF main panel which evaluated them (on the LHS plots), and by the type of their university (on the RHS plots). The top plots in Figure 1 illustrate a right-tail of high paying departments across panels and university types, with more pronounced skewness in the social sciences and specialist universities. The distributions of funding scores, shown in the bottom plots, are similar across panels, with a higher average among the medicine panel due to the typically large size of medical schools. For this and other reasons, we repeat in the online appendix the analysis excluding all the department in the "Clinical Medicine" unit of assessment. Plot D shows variation in performance across university types, suggesting a hierarchical ranking with the Russell group of universities on average the strongest performers, followed by the "1994" group, the "Others" and the "New Universities".

Table 2 shows the correlation matrix across the different measures of research performance we consider in our study. Note that the correlations between the GPA score and its components are well below 1, indicating that the panels judges each component

[10] Academic pay dispersion has grabbed little attention; exception are studies of inequalities due to sex and race. See for example Porter et al. (2008).

Figure 1: Distribution of Average Salary and REF Performance (Funding Score) Among Academic Departments by REF Main Panel and University Type, 2013



Note: The upper part of the Figure illustrates distribution of average departmental salary among academic departments classified by REF Main Panel and university type. The lower part shows the distribution of REF Funding Score in academic departments, again classified by REF Main Panel and university type. Kernel density functions, epanechnikov kernel.

Table 2: Correlation Between REF Performance Measures

	Funding Score	GPA Score	GPA Outputs	GPA Environment	GPA Impact
Funding Score	1				
GPA Score	0.473***	1			
GPA Outputs	0.369***	0.901***	1		
GPA Environment	0.506***	0.845***	0.635***	1	
GPA Impact	0.379***	0.777***	0.477***	0.644***	1

Note: Sample size = 1139 departments submitted to REF 2014. For explanation of REF performance measures see main text. Denotes significance at 10% level, ** 5% level, *** at 1% level.

separately. Given that the GPA score is valued by the institutions as a signal of their relative standing, they probably care about their rank in the research field more than about the absolute value of the score. With this in mind we note that the rank correlation between GPA and funding score is 0.77.

Figure 2 illustrates a strong positive relationship between average salary and pay inequality measured by the departmental Gini coefficient across all main panels and university types.

Figure 3 illustrates the unconditional correlation between our main variables of interest: average departmental pay and funding score. It shows a positive average pay-performance gradient across subject areas and university types. The slopes of the fitted regression lines are similar across main panels, but less so across university types: the fitted line has a lower gradient in the Russell group universities and is steeper in the "New Universities". These differences in the pay-research performance relationship are confirmed in our econometric analysis.

3 Results

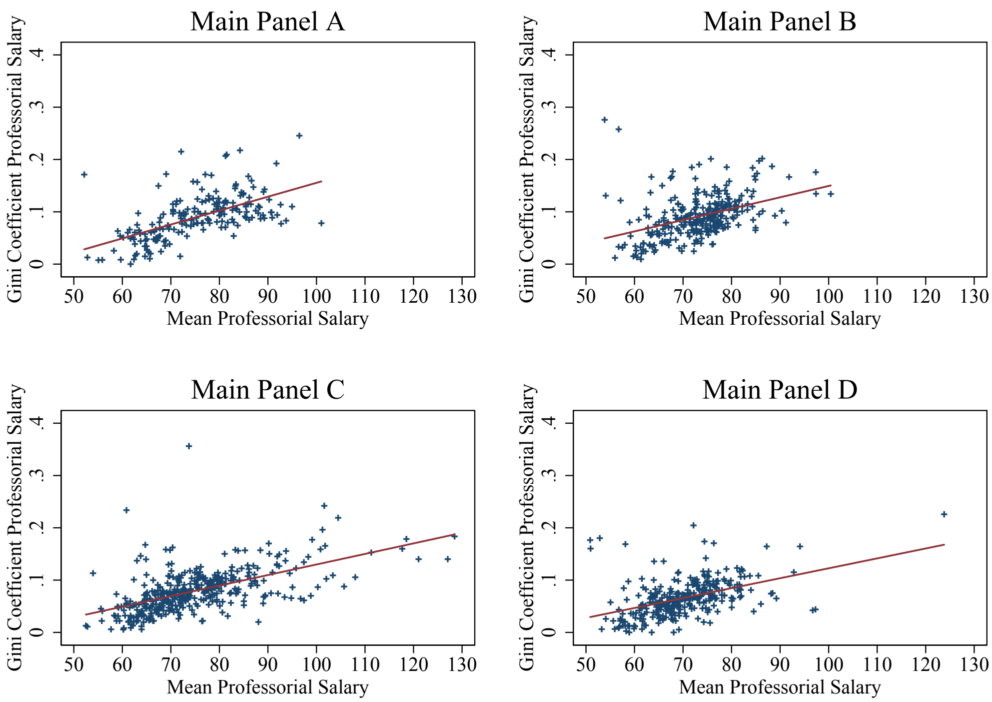
In this section we present our main results. We aim to uncover the association between pay and performance in UK academic departments. To this end, we estimate a series of econometric models taking the following general form:

$$REFOutcome_{ik} = \beta_0 + \beta_1 AvSalary_{ik} + \beta_2 Gini_{ik} + \beta_3 \mathbf{X}_{ik} + \phi_i + \psi_t + \epsilon_{ik}, \quad (4)$$

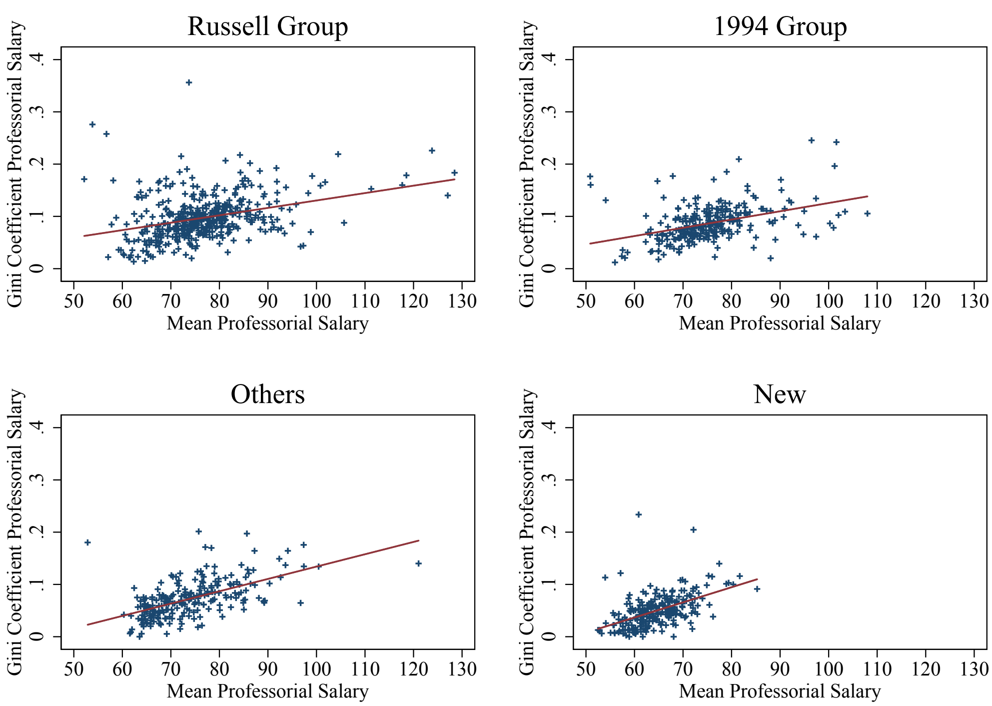
where $REFOutcome_{ik}$ is a measure of REF success for the submission made by university k, which is of university type t (i.e. "Russell", "1994 group" etc.), to the panel assessing disciplinary field i. In the main analysis the REF outcome is the natural log of the funding score, but in the appendix we report also results for the determinants of the overall GPA.

Figure 2: Correlation Between Mean Pay and Gini Coefficient of Pay

(A) By REF Main Panel



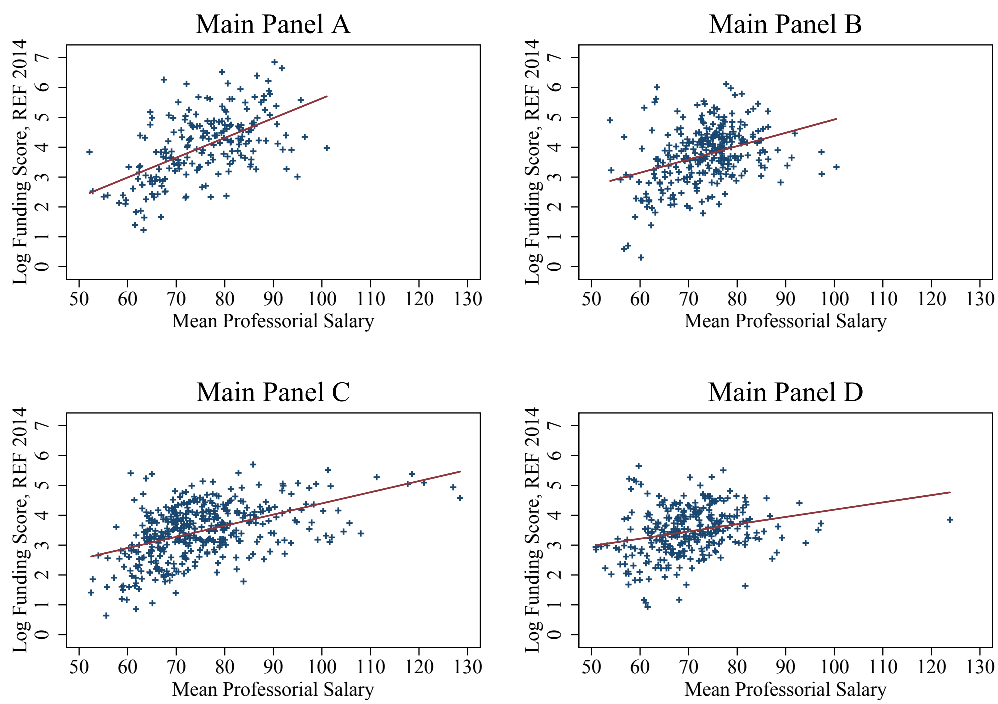
(B) By University Type



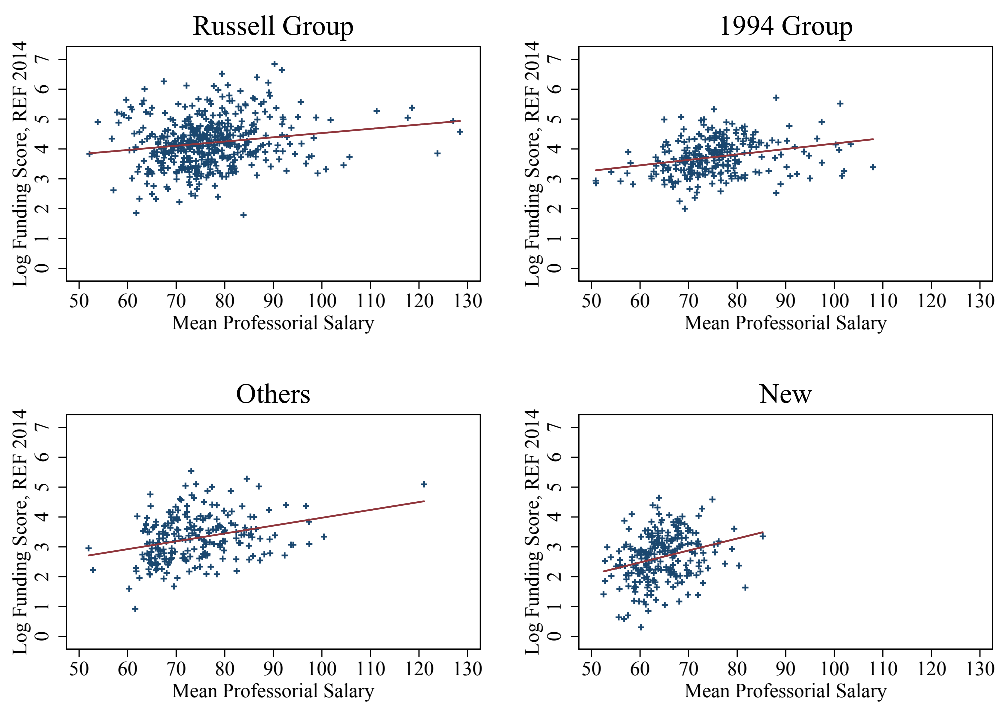
Note: Each observation is an individual academic department. Figure show scatter plots and fitted regression lines. Observations grouped by REF Main Panel (Plot group A) and University Type (Plot group B).

Figure 3: Correlation Between Mean Pay and REF Funding Score

(A) By REF Main Panel



(B) By University Type



Note: Each observation is an individual academic department. Figure show scatter plots and fitted regression lines. Observations grouped by REF Main Panel (Plot group A) and University Type (Plot group B)

The results obtained using the two dependent variables are qualitatively very similar (see Figures A4 and A5, Tables 3, and A3 in the Appendix).

$AvSalary_{ik}$ and $Gini_{ik}$ are the average salary of the professoriate in department (i, k), in logs, and inequality in department (i, k), measured by the Gini coefficient of the professors' salaries.[11] The matrix $\mathbf{X}_{ik}$ contains additional controls including the total number of professorial full time equivalents (FTE), the total number of FTE members of staff submitted to the REF (both in logs), an indicator for whether the department had a member of staff serving on the corresponding REF panel, the total remuneration of the university's head (in logs), and the share of individuals in the professoriate who are respectively below 40 years of age, between 41 and 50 years of age, and between 51-60 years of age, with the professors older than 60 as the reference group. In some specifications we also include discipline (ϕ_i, $i = 1, \ldots, 36$) and institution type (ψ_t, $t = 1, \ldots, 5$) fixed effects to account respectively for unobserved characteristics common to all departments in the same subject and to departments in similar institutions. The large number of institutions, and the fact that many of them submitted very few departments, or even only one, prevents us from including institution fixed effects.

Table 3 presents our main results. Column (1) shows estimates from a parsimonious specification in which the only regressors are average salary and inequality measured by the Gini coefficient. The coefficients on both variables are positive and strongly statistically significant at the 1% level. In Column (2) we add a series of covariates to the model, which improve more than three-fold the fit of our specification. Results indicate that the size of the submission, measured by the *total* number of academic staff, thus including non-professors, improves REF performance. At the same time, the additional effect of submitting professors rather than less senior staff is not significantly different from zero. Moreover, we find that having a member of staff on the corresponding REF panel has a positive and significant effect on the REF funding score. There is also a positive association between REF performance and the university head's total compensation (see Figure A6 in the Appendix for more details). With the inclusion of controls in Column (2) the magnitude of the impact of the average salary and of the Gini coeffcient decrease, while remaining statistically significant at the 1% level.

In Columns (3) and (4) we additionally include unit of assessment and institution type fixed effects. This improves further the fit of the models, from an already very high value of 0.87, to over 90%. In both specifications the average wage and the measure of inequality keep a robust link with REF performance, though their coefficient is lowered in value and inequality is less precisely estimated when we include the institution type fixed effect.

[11] An alternative measure of pay inequality within a department is given by the variance of log salary, which has a correlation coefficient with the Gini measure of 0.93. Results using this alternative measure are very similar and available upon request.

Table 3: OLS Regression Estimates: Department Pay Characteristics and REF 2014 Performance. Dependent Variable: REF Funding Score

	(1) No controls	(2) + Controls	(3) + Unit FE	(4) + Uni. Type FE
Log Average Salary	1.903***	0.550***	0.917***	0.566***
	(0.221)	(0.096)	(0.092)	(0.091)
Gini Coefficient Salary	7.306***	0.816***	0.876***	0.482*
	(0.693)	(0.314)	(0.287)	(0.268)
Log Professorial FTE		0.033	0.149***	0.109***
		(0.021)	(0.021)	(0.020)
Log REF FTE		1.128***	1.106***	1.065***
		(0.023)	(0.021)	(0.020)
Panel Member = 1		0.148***	0.093***	0.062***
		(0.022)	(0.021)	(0.019)
Log Vice Chancellor Pay		0.261***	0.158***	0.087*
		(0.054)	(0.049)	(0.047)
% Age under 40		0.121	0.397***	0.276***
		(0.121)	(0.113)	(0.105)
% Age 41-50		-0.068	0.140*	0.087
		(0.066)	(0.062)	(0.058)
% Age 51-60		-0.102	0.011	-0.069
		(0.064)	(0.060)	(0.056)
1994 Group Uni. = 1				-0.030
				(0.024)
Other Type Uni. = 1				-0.207***
				(0.027)
New Uni = 1				-0.416***
				(0.033)
Specialist Uni = 1				-0.065
				(0.112)
R-squared	0.252	0.870	0.901	0.916
Observations	1139	1139	1139	1139

Notes: Sample size = 1139 academic departments submitted to REF 2014. Dependent variable is the natural log of research funding score. Column (1) includes log average salary and gini coefficient only. Additional columns add control variables as described in table header. Standard errors in parenthesis. * Denotes significance at 10% level, ** 5% level, *** at 1% level.

The magnitude of the effects we have uncovered is substantial. The results in our preferred specification, Column (4), indicate that a 10% increase in average salary is associated with a 5.7% increase in the REF funding. There is also a non negligible size effect: a 10% increase in the size of the total REF submission is associated to a 10.6% increase in REF funding: if two identical departments (with all co-variates equal to the sample size) were to merge, their aggregate REF funding would increase by 6.5%. The additional effect of a 10% increase in the number of professorial FTE employed, keeping the overall size constant, is a modest 1.1% increase in the REF funding. Having a member of the department on the evaluation panel increases instead the funding score by over 6%: arguably a non-negligible effect. Finally, age seems to matter little: while the coefficient for under 40 is significant[12] only few professors are under 40. We find very similar results when GPA score is used as the dependent variable; see Table A2 in the Appendix.

The analysis of the fixed effect coefficients offers us an insight on systematic differences across fields that are not captured by our observables. Figure 4 displays plots of the unit of assessment fixed effects with 95% confidence intervals, taking as baseline the Economics and Econometrics panel. To gain insights on the magnitude of these effects, a department in the discipline with the highest fixed effect (sports science or communications and media studies) would receive approximately *twice*[13] the annual funding than an otherwise identical department in the discipline with the lowest estimated fixed effect (economics and econometrics).[14]

This lower REF success on average of the Economics and Econometrics UK departments could be due either to a lower "quality" of the average submission in the field, or to a more "demanding" assessment of research by this panel's members, and our data are unable to shed any light on which of these alternative explanation is more likely. Using a methodology which measures quality as the number of citations attracted by papers published in high quality journals, Oswald (2015) argues however that the quality of UK economics is high.

3.1 Results by Subject Groups

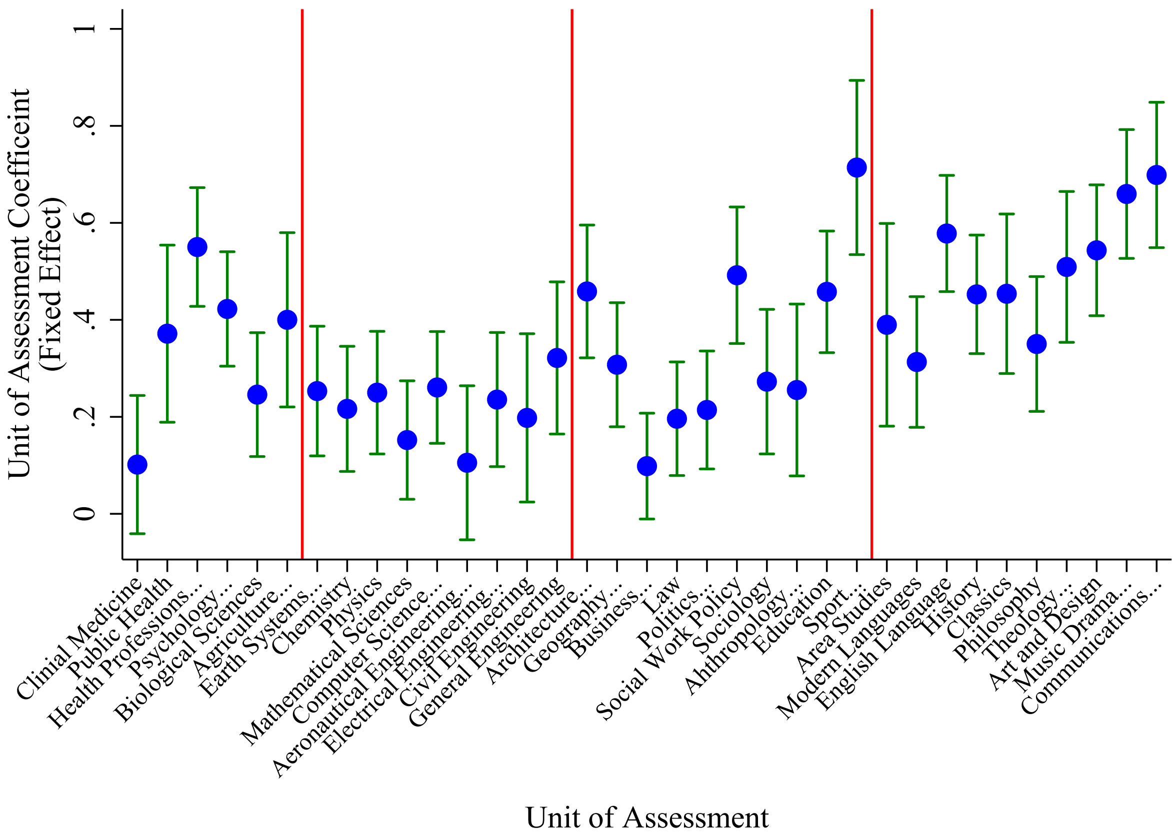
So far our analysis has highlighted the existence of a strong positive relationship between average professorial wage and REF performance. One important question is whether the shape of this relationship varies across fields. We tackle this question in two ways. First, we

[12]The average department has 14.4 members, so replacing an over 40 professor with a younger one increases the number of under 40 professors by 6.94%. Given a coefficient of 0.276, *ceteris paribus* this swap increases the funding score by 1.9%.

[13]In a regression of $\ln Y$ on covariates, if a dummy variable switches from 0 to 1, the percentage impact on Y is $100\,(e^c - 1)$, where c is the estimated coefficient of the dummy variable. See Halvorsen and Palmquist (1980) and Giles (1982) for details.

[14]Recall that the total funding accruing to an institutions following its departments' research quality is calculated according to (3). Since the value of Γ_i in economics and econometrics, sports science and communication and media studies is the same, their relative actual annual funding is equal to their relative funding score.

Figure 4: Plot of Estimated Unit of Assessment Fixed Effects from Regression Model (Omitted Unit: Economics and Econometrics)



Note: Figure shows a plot of the estimated unit of assessment fixed effects from Table 3, Column 4. Omitted group is Unit of Assessment 18, Economics and Econometrics. 95% confidence intervals shown in whiskers.

estimate the main model specification of Column (2) in Table 3, separately for sub-samples corresponding to the four main REF panels, including university type fixed effects. Then we repeat the exercise by running a series of subject specific models for each of the 36 units of assessment.

The results by main panel are reported in Table 4. The effect of average salary is positive and statistically significant for all panels. It is considerably larger in the main panel A (medicine and biology), than in the other subject areas: all the coefficients are pairwise statistically significantly different, except the difference between main panels B and D, whose equality is only weakly rejected, with a p-value of 0.0906. Moreover, the independent role of the inequality in wages in the overall sample appears to be driven by the disciplines in main panel B, science and engineering. The coefficients for the other main panels are both smaller and not estimated precisely. Furthermore, the effect of having a panel member uncovered in Column (2) of Table 3 is less statistically significant and smaller in value for medicine and biology than for the social sciences and the arts and humanities. Using the GPA score as the measure of research performance yields qualitatively very similar results, as we show in Table A3 in the Appendix.

The difference across main panels conceals some heterogeneity among the disciplines that make up the four groups. Figure 5 plots the coefficient estimates for the average professorial wage, with 95% confidence intervals shown in bars, from the same model specification as in Column (2) of Table 4, run separately by subject. Interestingly, our findings indicate that the positive and significant relationship between average professorial wage and REF performance holds for *all* disciplines. At the same time, some important differences in the magnitude of the effects emerge, even *within* each main panel. In particular, the link between professorial pay and research performance appears to be particularly strong in Clinical Medicine, Philosophy, Theology, Psychology and Earth Systems. It is instead much weaker in Sports Related Studies, Area Studies, English Language and Literature, and History.

A possible source of concern with the results in Figure 5 is that the determinants of the salary structure in Clinical Medicine might differ from those in other academic subjects. This is because a large proportion of the academics employed in these departments work also for, and are separately paid by, the National Health Service, and their salary structure might well be driven by different considerations. For this reason, in Table A6 we reproduce the same results as in Column (4) of Table 3 in the sample that excludes all the departments submitted to the Clinical Medicine unit of assessment. The results are unaffected.

3.2 Results by University Types

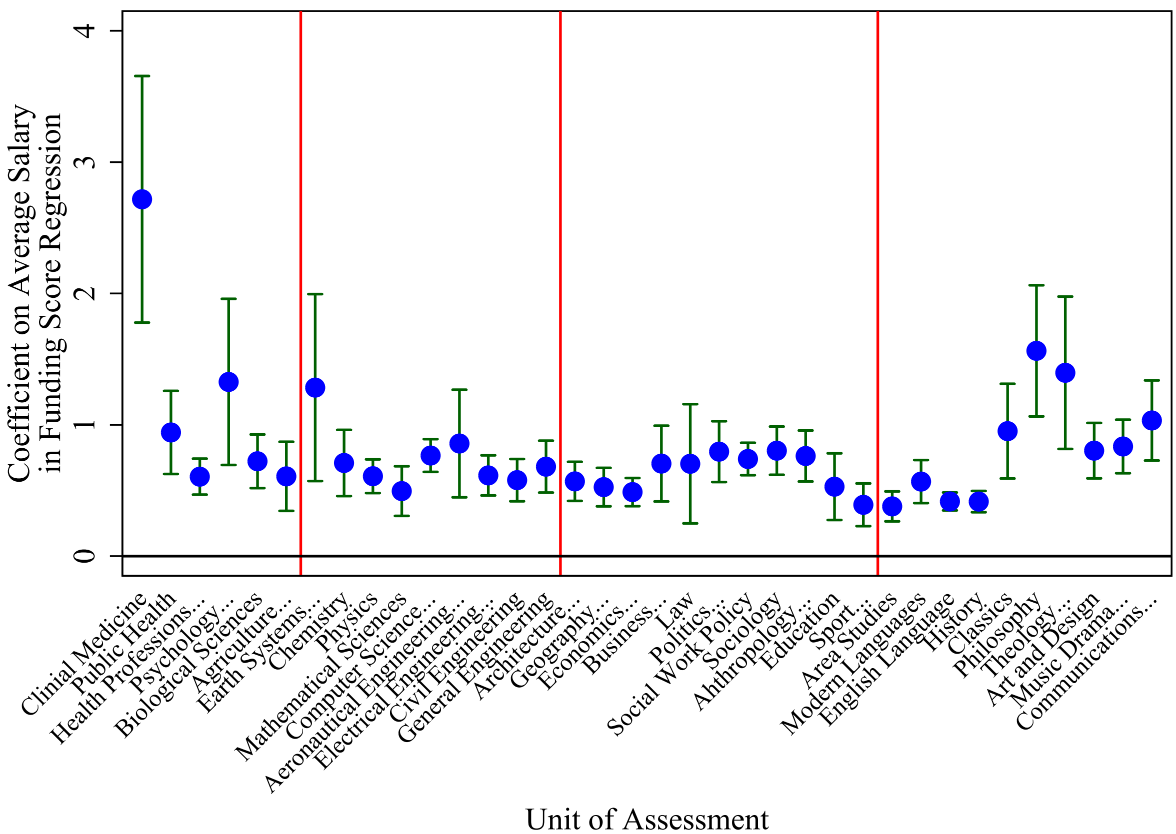
As suggested by Panel (D) of Figure 1, the average REF performance differs across university types, with Russell group universities ahead of the other groups. To what extent is this result

Table 4: OLS Regression Estimates By REF Main Panel

	(1) Panel A	(2) Panel B	(3) Panel C	(4) Panel D
Log Average Salary	1.215***	0.709***	0.419**	0.851***
	(0.251)	(0.202)	(0.164)	(0.162)
Gini Coefficient Salary	1.079	1.695***	0.661	0.314
	(0.707)	(0.569)	(0.571)	(0.564)
Log Professorial FTE	-0.032	0.158***	0.019	0.156***
	(0.035)	(0.047)	(0.041)	(0.041)
Log REF FTE	1.135***	1.083***	1.225***	1.028***
	(0.045)	(0.049)	(0.042)	(0.038)
Panel Member = 1	0.086*	0.093*	0.168***	0.128***
	(0.050)	(0.044)	(0.040)	(0.038)
Log Vice Chancellor Pay	0.226*	0.149	0.213*	0.193*
	(0.128)	(0.107)	(0.097)	(0.086)
% Age under 40	0.468	0.595*	0.161	0.150
	(0.360)	(0.277)	(0.199)	(0.185)
% Age 41-50	-0.042	0.064	0.012	0.151
	(0.172)	(0.143)	(0.118)	(0.100)
% Age 51-60	-0.047	-0.099	-0.039	-0.000
	(0.149)	(0.147)	(0.116)	(0.097)
R-squared	0.926	0.896	0.848	0.876
Observations	194	276	380	289

Note: Dependent variable is natural log of research funding score. OLS regression estimated on four mutually exclusive samples of academic departments categorised by REF Main Panel. * Denotes significance at 10% level, ** 5% level, *** at 1% level.

Figure 5: Coefficient Plots From Unit of Assessment Sample OLS Regressions



Note: Figure shows regression coefficient values and 95% confidence intervals (shown by vertical whisker bars) for coeffiecient estimates on average pay variable in OLS regression of funding score against average pay and controls (control variables as in Table 3, Column 3). Separate regressions estimated for each unit of assessment sample.

affected by the shape of the pay–performance relationship? To answer this question, in Table 5 we run the same specification as in Column (3) of Table 3 on four different subgroups of institutions: the "Russell group", the "1994 group", the "New Universities" and the "Others" (we omit specialist universities as they represent a total of only eight departments).

We find that the relationship between average professorial wage and REF performance becomes progressively stronger as we move from the "Russell group" institutions to the "New universities", roughly following the quality of research, as depicted in Figure 3, Panel (B).[15] This result holds true also when we exclude from our analysis Cambridge and Oxford, two institutions that offer substantial non-monetary compensation to many senior academics, for example in the form of subsidised accommodation. The same patterns continue to hold also when we replace funding score with the GPA score as the dependent variable. These results are available in Table A6 and Table A3 in the appendix.

3.3 Results by Score Components

As we have described in Section 2.1, the overall research profile of a unit is obtained as a weighted average of the profiles in each of the three components of the assessment: outputs, environment, and impact. Importantly, while output can easily be transferred across departments by hiring the faculty member who has produced it, this is not the case for environment and impact. Thus we expect that if universities use higher salaries to improve their REF performance, the effect of salaries should be stronger on the measure of output than on the other components of overall funding score. To assess this implication, in Table 6 we run the specification from Column (4) of Table 3, which includes unit and institution type fixed effects, and is reported for convenience in Column (1) of Table 6, three more times, each with only one of the separate components of the overall REF funding score as dependent variables.

The new results are presented in Columns (2) – (4). As we can see, the overall positive association between average salary and REF performance is driven primarily by the relationships between salary and output and between salary and environment funding score. There is weaker evidence for a positive relationship between average salary and impact funding score, which is consistent with the rules of the REF which are such that institutions cannot "buy-in" impact success. Cross-model tests of the equality of the coefficients on average salary in the model for output (2) against the model for impact (4), and also the model for environment (3) against the model for impact (4), in both cases reject the equality of coefficients at the 5% level. Note also that larger departments, those with more professors, especially those aged under 40, and those where pay inequality is higher do better in the environment component. The latter is perhaps evidence that the panel

[15] T-tests for the equivalence of means strongly reject equality between any two pairs of the average salary coefficients of Table 5.

Table 5: OLS Regression Estimates By University Type

	(1) Russell	(2) 1994	(3) Others	(4) New
Log Average Salary	0.183*	0.358*	1.225***	1.683***
	(0.103)	(0.173)	(0.262)	(0.389)
Gini Coefficient Salary	0.800***	1.102*	-0.984	-1.143
	(0.297)	(0.513)	(0.754)	(1.074)
Log Professorial FTE	0.089***	0.143***	0.262***	0.147*
	(0.024)	(0.040)	(0.055)	(0.070)
Log REF FTE	1.076***	0.995***	1.017***	1.070***
	(0.026)	(0.045)	(0.052)	(0.059)
Panel Member = 1	0.039*	0.080**	0.049	0.158*
	(0.022)	(0.034)	(0.052)	(0.085)
Log Vice Chancellor Pay	0.179***	-0.077	-0.070	-0.014
	(0.055)	(0.092)	(0.138)	(0.136)
% Age under 40	-0.103	0.604***	0.171	0.231
	(0.143)	(0.197)	(0.299)	(0.291)
% Age 41-50	0.007	0.320**	0.124	0.023
	(0.088)	(0.123)	(0.139)	(0.155)
% Age 51-60	-0.050	0.160	0.032	-0.217
	(0.086)	(0.116)	(0.128)	(0.147)
R-squared	0.940	0.883	0.886	0.813
Observations	428	260	225	219

Note: Dependent variable is natural log of research funding score. OLS regression estimated on four mutually exclusive samples of academic departments categorised by University Type. Sample of 'specialist' universities not included as it contains only 8 observations. See Appendix A for details of classifications of universities. * Denotes significance at 10% level, ** 5% level, *** at 1% level.

assess the environment on the basis of the situation at the submission date, which would make attracting superstars a possible way to improve the department's research environment score.

The results also indicate some interesting differences in the role played by our controls. We find that having a member of staff sitting on the panel has a positive and statistically significant effect on the funding score obtained for research environment and impact. There is no significant effect instead on the output funding score. These results are consistent with the idea that panel membership might be more important for the elements of the REF evaluation that are arguably more subjective, rather than for those which are based on more objective criteria such as the reputation of the outlet where a scholarly work has been published, its impact factor or the number of citations received.

Finally, results in these regressions also indicate a strong relationship between the age profile of the academic department and performance in outputs funding score, but not for environment and impact funding score, though the coefficient on the proportion of under-40 professors is positive and weakly significant in the model for outputs funding score.

4 A Simple Model of University Pay and Competition

In this section we present a simple theoretical model of university pay and competition which shows one way to rationalize our empirical results. The model illustrates how the pay-performance relationship arises due to the nature of the production of research and the incentives created by the research evaluation exercise.

We model the higher education sector as an industry comprising K universities, indexed by $k = 1, \dots, K$. They aim to maximise an aggregate measure of their research output in the n academic disciplines, indexed by $i = 1, \dots, n$. To do so, they acquire the necessary inputs: capital and academic labour with their budget, which itself is endogenously determined by the research performance produced by the capital and academic labour inputs.

We can think of the budget allocation as a two stage process. In the first stage, the central university administration allocates resources to the various disciplines; subsequently, the departments where each discipline is studied spend their devolved budget in order to maximise their objective function.

While a large body of literature emphasises the role played by conflicts of interest within large institutions (Milgrom and Roberts, 1992), in the case of universities it is plausible to assume that individual academics and the heads of both universities and departments all share the same goal with regards to research, namely the maximisation of its quality. For this reason we posit a complete information setting.

Table 6: OLS Regression Estimates: Department Pay Characteristics and REF Component Funding Scores

	(1) Overall Funding	(2) Outputs	(3) Environment	(4) Impact
Log Average Salary	0.566***	0.622***	0.771***	0.371*
	(0.091)	(0.093)	(0.184)	(0.197)
Gini Coefficient Salary	0.482*	0.421	1.757***	-0.071
	(0.268)	(0.274)	(0.557)	(0.593)
Log Professorial FTE	0.109***	0.082***	0.180***	0.159***
	(0.020)	(0.020)	(0.041)	(0.043)
Log REF FTE	1.065***	0.014	0.413***	0.172***
	(0.020)	(0.020)	(0.041)	(0.043)
Panel Member = 1	0.062***	0.028	0.150***	0.125***
	(0.019)	(0.020)	(0.039)	(0.041)
Log Vice Chancellor Pay	0.087*	0.176***	0.076	-0.036
	(0.047)	(0.048)	(0.095)	(0.101)
% Age under 40	0.276***	0.319***	0.494*	0.119
	(0.105)	(0.107)	(0.216)	(0.229)
% Age 41-50	0.087	0.133*	0.079	-0.018
	(0.058)	(0.060)	(0.119)	(0.126)
% Age 51-60	-0.069	-0.061	-0.005	-0.135
	(0.056)	(0.057)	(0.114)	(0.122)
1994 Group Uni. = 1	-0.030	-0.013	-0.003	-0.047
	(0.024)	(0.024)	(0.047)	(0.051)
Other Type Uni. = 1	-0.207***	-0.227***	-0.291***	-0.182***
	(0.027)	(0.028)	(0.055)	(0.059)
New Uni = 1	-0.416***	-0.394***	-0.628***	-0.443***
	(0.033)	(0.034)	(0.068)	(0.072)
Specialist Uni = 1	-0.065	-0.039	-0.496*	0.094
	(0.112)	(0.115)	(0.224)	(0.240)
R-squared	0.916	0.503	0.560	0.294
Observations	1139	1139	1139	1139

Note: Sample size = 1139 departments submitted to REF 2014. The dependent variable is obtained from formula (3). Column (1) is the same as Column (4) in Table 3. Column (2) the funding score for the department output component, Column (3) environment component and Column (4) impact component. Models include REF main panel and unit of assesment fixed effects. * Denotes significance at 10% level, ** 5% level, *** at 1% level.

4.1 The department optimisation problem

Academic departments are usually thought of as producing two goods: teaching and research. The focus of our analysis is on understanding the effects of the competition induced by the REF, and so we abstract from explicitly describing the teaching production process, and focus instead on research. Any teaching constraints, such as the requirement to recruit a given number of students, are implicitly captured in the production function or in the budget constraint.

Research is produced using three inputs: capital and two types of labour, for example, good professors and superstar academics. Let w_ℓ the salary of an academic of type ℓ and assume that its supply is given by [16]

$$L_\ell = \mu_\ell w_\ell, \qquad \ell = 1, 2. \tag{5}$$

L_ℓ is the amount of labour of type ℓ, $\ell = 1, 2$. The different elasticities in the supply function of the two types of labour capture different job market opportunities, which depend on an academic's research potential. The research output of university k in discipline i, $k = 1, \ldots, K$, $i = 1, \ldots, n$, is denoted by $\rho_{k,i}$, and obeys a Cobb-Douglas technology, a simplified special case of the functions typically used in empirical analyses of universities production function (for example, for the UK, see Thanassoulis et al. (2011)):

$$\rho_{k,i} = \theta_k L_1^{\alpha_1} L_2^{\alpha_2} K^{\beta_i}, \tag{6}$$

where K is the amount of capital, given by labs, equipment, technical personnel, and so on: this can be purchased in a competitive market at a price r. The parameters θ_k and β_i capture the fixed effects of our empirical specitfication. They characterise respectively the overall research productivity of an institution, due for example to different research environments and international connections,[17] and the importance of capital in a given discipline, which depends on factors such as laboratory costs and the like.

If a given department i receives a fixed budget B_i from the university central

[16] We therefore ignore any oligopsonistic interaction among institutions: taking them into account would change the absolute levels of academic employment and salaries, but would not alter their *relative* values across institutions and disciplines, which is the focus of our paper.

[17] We take θ_k to be exogenously fixed: it may depend on reputation or history, and in particular, it is not affected by changes in the quality of other departments. Thus our analysis is based on the idea that the correlation between the quality of the various departments in a given university is not a necessary consequence of technological spillovers, but may be caused by an unobserved factor, common to all departments. A similar set-up emerges if θ_k is interpreted as a measure of the cost of doing research, and if the plausible assumption is made that academics are willing to trade-off a university's prestige and overall research environment for a lower salary (see De Fraja and Valbonesi (2012), or De Fraja (2016)). If this is the case a prestigious university would find it easier to hire and retain high quality academics and for this reason enjoy a higher productivity.

administration, its budget constraint is given by:

$$rK + w_1 L_1 + w_2 L_2 = B_i. \tag{7}$$

Thus department i in institution k chooses K, L_1 and L_2 to maximise (6) subject to (5) and (7). To simplify notation, let

$$A_i = \alpha_1^{\frac{\alpha_1}{2}} \mu_1^{\frac{\alpha_1}{2}} \alpha_2^{\frac{\alpha_2}{2}} \mu_2^{\frac{\alpha_2}{2}} \left(\frac{2\beta_i}{r}\right)^{\beta_i}, \tag{8}$$

$$c_i = \alpha_1 + \alpha_2 + 2\beta_i. \tag{9}$$

Proposition 1. *The solution of the maximisation problem of department i in institution k satisfies:*

$$L_\ell = \sqrt{\frac{\alpha_\ell \mu_\ell}{c_i} B_i}, \qquad \ell = 1, 2, \tag{10}$$

$$K = \frac{2\beta_i}{c_i} \frac{B_i}{r}, \tag{11}$$

and the research output is given by

$$\rho^*_{k,i}(B_i) = \theta_k A_i \left(\frac{B_i}{c_i}\right)^{\frac{c_i}{2}}. \tag{12}$$

Proof. The problem of department i is:

$$\max_{L_1, L_2} \quad \ln \theta_k + \alpha_1 \ln L_1 + \alpha_2 \ln L_2 + \beta_i \ln K,$$
$$\text{s.t.: } rK = B_i - w_1 L_1 - w_2 L_2,$$
$$L_\ell = \mu_\ell w_\ell, \qquad \ell = 1, 2.$$

Substituting the constraints into the maximand, we can write this problem as:

$$\max_{L_1, L_2} \left\{ \ln \theta_k + \alpha_1 \ln L_1 + \alpha_2 \ln L_2 + \beta_i \ln \left(B_i - \frac{L_1^2}{\mu_1} - \frac{L_2^2}{\mu_2} \right) - \beta_i \ln r \right\}.$$

Solving the first order conditions of the above gives (10). It is easily checked that the second order conditions are satisfied. This, substituted into (7) and using definitions (8) and (9), gives the expression for the level of capital (11). The total research output (12) is also obtained by direct substitution. □

Proposition 1 indicates that the amount of both capital and labour employed by a department increase with the budget allocated to it, B_i, whereas the amount of labour (capital) employed declines (increases) with the importance of capital in the production process, measured by β_i. As for research output, it increases with the budget allocated to the unit, though it does not do so in proportion to the returns to scale, because labour costs increase with demand. The sign of the derivative of output with respect to the parameter β_i is the same as the sign of $\ln \frac{2\beta_i B_i}{c_i r}$: therefore it is negative when the budget is low, but it becomes positive for a large enough budget. In other words, small departments become smaller still as capital intensity increases, whereas large ones instead increase further in size. This tallies with the anecdotal observation that capital intensive departments tends to be large. An immediate consequence of Proposition 1 is the following.

Corollary 1. *Academic salaries in department i in institution k are given by:*

$$w_\ell = \sqrt{\frac{\alpha_\ell B_i}{c_i \mu_\ell}}, \qquad \ell = 1, 2. \tag{13}$$

The mean salary is given by

$$\bar{w} = \frac{\alpha_1 + \alpha_2}{\sqrt{\alpha_1 \mu_1} + \sqrt{\alpha_2 \mu_2}} \sqrt{\frac{B_i}{c_i}}, \tag{14}$$

the standard deviation by

$$\sigma_w = \frac{\left| \sqrt{\frac{\alpha_1}{\mu_1}} - \sqrt{\frac{\alpha 2}{\mu_2}} \right|}{\sqrt{\alpha_1 \mu_1} + \sqrt{\alpha_2 \mu_2}} \sqrt[4]{\alpha_1 \mu_1 \alpha_2 \mu_2} \sqrt{\frac{B_i}{c_i}}, \tag{15}$$

and the Gini coefficient by

$$G_i = \frac{\sqrt[4]{\alpha_1 \mu_1 \alpha_2 \mu_2}}{\alpha_1 + \alpha_2} \frac{\sigma_w}{\sqrt{\frac{B_i}{c_i}}}. \tag{16}$$

Proof. Simply substitute (10) into (5) to obtain (13). (14)-(16) are simple calculations. □

The derivative of both the mean salary (14) and of the standard deviation (15) is proportional to the derivative of the last term in each expression, which is $-c_i^{-\frac{3}{2}} B_i^{\frac{1}{2}} < 0$, when differentiating with respect to β_i, and $\frac{1}{2} c_i^{-\frac{1}{2}} B_i^{-\frac{1}{2}} > 0$ when differentiating with respect to B_i. As a result, the mean salary and the dispersion of salaries within a department are collinear, and both increase with the budget allocated to the department. Given that, *ceteris paribus*, a department's research output increases with its budget, the model predicts a positive association between average salary and research output and between inequality in salary and research output, which is consistent with the main findings of our empirical analysis.

4.2 The university maximisation problem

We now consider the university's allocation problem. We make the following assumptions regarding the objective function and the resources a university has at its disposal.

Assumption 1. *The objective function of university k is*

$$U_k = \sum_{i=1}^{n} u_i \rho^*_{k,i}(B_i), \qquad k = 1, \ldots, K. \tag{17}$$

That is, university k aims at maximising the total weighted research output of its departments, with exogenously given weights, u_i. The idea of (17) is that the university's management aims at maximising overall prestige, given by a weighted average of the prestige of its activities, and that funding raised in any way, including the government research allocation, is devoted to enhance research prowess. This simple formulation, in (17), conveyes the main idea of the model. It could be extended, with no conceptually important changes, for example, by making the payoff depending on an institution's rank in each discipline, rather than the level of its output, or including an exponent for the output. The latter would capture an institution's preference for equality or inequality, according to wheter the exponent is smaller or greater than 1.

The next assumption establishes a link between research success and the overall budget made available by the funding agency to university k, which is denoted by $\bar{B}_k$. While these budgets are in practice allocated each year on the basis of past success, we can think of the simultaneous set-up presented here as the steady state.

Assumption 2. *The overall budget allocated by the government to university k is*

$$\bar{B}_k = \sum_{i=1}^{n} \gamma_i \rho^*_{k,i}(B_i). \tag{18}$$

The weights γ_i are exogenously given, fixed by the government agency in charge of university funding. A linear formulation is a very natural starting point for the analysis. While the funding agency could adopt a different funding formula, for example by giving higher or lower weight to larger departments, as we explain in Section 2.1, the formula used in practice in the 2014 REF is linear in the performance of an institution's departments. With this formula, the government rewarded excellence by skewing the measure of performance strongly towards high quality outputs, but the sum of the funding of two departments would not be altered by their merging. This seems a desirable property. Incorporating external sources of revenues, such as sponsorships, grant funding, income from patents or donations from alumni, would not alter the analytical set-up, as all these are positively related to prestige. Note furthermore that the funding weights γ_i need not be proportional to the utility weights in (17), u_i.

Recall definitions (8) and (9) to write university k's problem as:

$$\max_{\{B_i\}_{i=1}^n} \quad \sum_{i=1}^{n} u_i \theta_k A_i c_i^{-\frac{c_i}{2}} B_i^{\frac{c_i}{2}} \tag{19}$$

$$\text{s.t.:} \sum_{i=1}^{n} B_i = \sum_{i=1}^{n} \gamma_i \theta_k A_i c_i^{-\frac{c_i}{2}} B_i^{\frac{c_i}{2}}. \tag{20}$$

Corollary 2. *Let $\beta_i < 1 - \frac{\alpha_1+\alpha_2}{2}$. Then there exists a $\lambda_k > 0$, such that the solution of university k's problem is given by:*

$$B_i = c_i \left(\frac{(u_i + \lambda_k \gamma_i) A_i \theta_k}{2\lambda_k} \right)^{1-\frac{c_i}{2}}, \qquad i = 1, \ldots, n. \tag{21}$$

Proof. The first order conditions for the Lagrangian of problem (19)-(20) are

$$\frac{1}{2} u_i \theta_k A_i c_i^{1-\frac{1}{2}c_i} B_i^{\frac{1}{2}c_i - 1} - \lambda_k \left(1 - \frac{1}{2} \gamma_i \theta_k A_i c_i^{1-\frac{1}{2}c_i} B_i^{\frac{1}{2}c_i - 1} \right) = 0, \qquad i = 1, \ldots, n.$$

Rearranging, we derive (21). For this condition to identify a maximum, $\frac{1}{4} B_i^{\frac{1}{2}c_i - 2} (c_i - 2) c_i^{1-\frac{1}{2}c_i}$ must be negative, which is the case if $c_i < 2$, that is if $\beta_i < 1 - \frac{\alpha_1+\alpha_2}{2}$, as assumed. □

Corollary 2 implies that, in the steady state, universities with a higher θ_k will be able to devote more resources to all their departments, which will also produce higher output. This holds in every discipline i, implying that there is a ranking of institutions, with some performing better in all disciplines and paying their professors more. As a result, the model can explain the empirical pattern that some groups of universities dominate in the research evaluation across (nearly) all disciplines, and in particular the Russell Group in the UK context.[18]

Finally, note that to close the model, (21) is substituted into (20) to obtain λ_k as a function of the β_i's and θ_k, and the other parameters, which are constant across disciplines and institutions. Writing this as $\lambda(\theta_k; \boldsymbol{\beta})$, where $\boldsymbol{\beta} = (\beta_1, \ldots, \beta_n)$, we can determine the research

[18]Note also that in the special case where the ratio between u_i and γ_i is constant in i, that is when the relative "prestige" of any two disciplines equals their relative funding, the Lagrange multiplier disappears from the budget allocation (21). That is, in this case, and only in this case, all departments in a given university grow and shrink proportionally according to its funding.

output of each discipline as a function of the exogenous parameters:[19]

$$\rho^*_{k,i} = \theta_k A_i c_i^{\frac{c_i}{2}} \left(\frac{\left(\frac{u_i}{\lambda(\theta_k;\boldsymbol{\beta})} + \gamma_i \right) A_i \theta_k}{2} \right)^{c_i\left(1-\frac{c_i}{2}\right)} . \tag{22}$$

5 Conclusion

This paper studies the relationship between pay and research performance in UK universities. The UK setting is especially interesting because universities research quality is periodically assessed in a national exercise, the REF, and they can freely compete on the salaries they offer to senior academics, to maximize their standings.

Our empirical results show a positive pay-performance relationship in all disciplines. This is true both in subjects areas which anecdotal evidence suggests to be more competitive, such as business and management, economics, engineering, but also in subjects where there appears to be far less cross-institution movement of staff and possibly less competition, (among them, arts and humanities). Inequality of pay is also associated with higher research performance, especially in the more research intensive institutions.

That universities respond to the REF rules by pursuing academics who will contribute to the measured research performance is suggested also by our analysis of the three components that make up the aggregate research score. The positive salary-performance gradient is due mainly to the relationship between salary and scholarly publications: when an academic moves, this is the component of her recent record that can be transferred from one institution to another, whereas any "impact" that her research may have had contributes to the score of her previous institution.

Our main results can be rationalized using a simple theoretical model in which academics differ in their ability and are inputs into the production of research, and universities seek to maximise the weighted average of the research quality evaluations.

Those whose task is to design the details of the evaluation process should also consider our consistent finding that, after controlling for other potential covariates, panel membership is associated with stronger performance, and this result in turn is driven by the effect of panel membership on the arguably more subjective "environment" and "impact" components of the evaluation.

As a final caveat, we should stress that our results should be interpreted with care. The data is a rich source of information on the characteristics of academic departments and their performance in the REF exercise, but our econometric analysis allows us to model only

[19]Note that it is not practical to obtain explicit expressions for $\rho^*_{k,i}$, as it is highly non-linear in the parameters. For example, an increase in the capital-intensiveness of a discipline, measured by β_i, first increases the research performance then decreases it, due to the increase in cost and the beneficial effect of diverting resources to other "less expensive" disciplines.

associations between characteristics and performance. We do not have natural experiments in our data, or other sources of identification which could be used to establish an indisputable causal link.

While individual UK academics and administrators will no doubt find these results of much interest, they warrant wider attention, as they contain important lessons on the effects of liberalising pay and introducing competition for resources in a largely publicly funded system. These lessons may be useful for other European countries, which are in the process of developing and strengthening lively quasi-market systems in the university sector.

References

Abowd, J. M., F. Kramarz, and D. N. Margolis (1999). High wage workers and high wage firms. *Econometrica 67*, 251–333.

Altbach, P. G., L. Reisberg, M. Yudkevich, G. Androushchak, and I. F. Pacheco (2012). *Paying the Professoriate: A Global Comparison of Compensation and Contracts*. New York: Routledge.

Bosquet, C. and P.-P. Combes (2017). Sorting and agglomeration economies in french economics departments. *Journal of Urban Economics 101*, 27–44.

Bratsberg, B., J. Ragan, and J. Warren (2010). Does raiding explain the negative returns to faculty seniority? *Economic Inquiry 48*, 704–721.

Butler, L. and I. McAllister (2009). Metrics or peer review? Evaluating the 2001 UK research assessment exercise in political science. *Political Studies Review 7*, 3–17.

Checchi, D., G. De Fraja, and S. Verzillo (2014). Publish or perish? An analysis of the academic job market in Italy, 1991-2012. CEPR Discussion Paper 10084, London, UK.

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*, 565–583.

De Fraja, G. (2016). A theoretical analysis of public funding for research. *Rand Journal of Economics*. forthcoming.

De Fraja, G. and P. Valbonesi (2012). The design of the university system. *Journal of Public Economics 96*, 317–330.

Diamond, A. M. (1986). What is a citation worth? *Journal of Human Resources 21*, 200–215.

Edmans, A. and X. Gabaix (2015). Executive compensation: A modern primer. Technical Report 21131, NBER Working Paper Series.

Else, H. (2015). Research funding formula tweaked after REF 2014 results. *Times Higher Education 20 February*.

Giles, D. E. (1982). The interpretation of dummy variables in semilogarithmic equations: Unbiased estimation. *Economics Letters 10*, 77–79.

Grund, C. and N. Westergaard-Nielsen (2008). The dispersion of employees' wage increases and firm performance. *ILR Review 61*, 485–501.

Haeck, C. and F. Verboven (2012). The internal economics of a university: Evidence from personnel data. *Journal of Labor Economics 30*, 591–626.

Halvorsen, R. and R. Palmquist (1980). The interpretation of dummy variables in semilogarithmic equations. *American Economic Review 70*, 474–475.

Hamermesh, D. and G. A. Pfann (2012). Reputation and earnings: The roles of quality and quantity in academe. *Economic Inquiry 50*, 1–16.

Hamermesh, D. S., G. E. Johnson, and B. A. Weisbrod (1982). Scholarship, citations and salaries: Economic rewards in economics. *Southern Economic Journal 49*, 472–481.

Hildreth, A. K. G. and A. J. Oswald (1997). Rent-sharing and wages: Evidence from company and establishment panels. *Journal of Labor Economics 15*, 318–337.

Johnes, J., J. Taylor, and B. Francis (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*, 271–286.

Lavy, V. (2009). Performance pay and teachers' effort, productivity, and grading ethics. *American Economic Review 99*, 1979–2011.

Lazear, E. (2000). Performance pay and productivity. *American Economic Review 90*, 1346–1361.

Milgrom, P. R. and J. Roberts (1992). *Economics, Organization and Management*. New York: Prentice Hall.

Moore, W. J., R. J. Newman, and G. K. Turnbull (1998). Do academic salaries decline with seniority? *Journal of Labor Economics 16*, 352–366.

Mueller, H. M., P. P. Ouimet, and E. Simintzi (2015). Wage inequality and firm growth. Technical Report 20876, NBER Working Paper Series.

Nickell, S., J. Vainiomaki, and S. Wadhwani (1994). Wages and product market power. *Economica 61*, 457–473.

Nickell, S. and S. Wadhwani (1990). Insider forces and wage determination. *The Economic Journal 100*, 496–509.

Oswald, Andrew J. (2015). The Objective Measurement of World-Leading Research. IZA Discussion Paper 8829, Bonn, Germany.

Oyer, P. (2007). Is there an insider advtange in getting tenure? *American Economic Review 97*, 501–205.

Porter, S. R., R. K. Toutkoushian, and J. V. Moore III (2008). Pay inequities for recently hired faculty, 1988-2004. *The Review of Higher Education 31*, 465–487.

Règibeau, P. and K. E. Rockett (2016). Research assessment and recognized excellence: Simple bibliometrics for more efficient academic research evaluations. *Economic Policy*, forthcoming.

Sgroi, D. and A. J. Oswald (2013). How should peer-review panels behave. *Economic Journal 123*, F255–F278.

Sharp, S. and S. Coleman (2005). Ratings in the research assessment exercise 2001 – the patterns of university status and panel membership. *Higher Education Quarterly 59*, 153–171.

Taylor, J. (1995). A statistical analysis of the 1992 research assessment exercise. *Journal of the Royal Statistical Society, Series A 158*, 241–261.

Thanassoulis, E., M. Kortelainen, G. Johnes, and J. Johnes (2011). Costs and efficiency of higher education institutions in England: A DEA analysis. *Journal of the Operational Research Society 62*, 1282.

Zinovyeva, N. and M. Bagues (2010). Does gender matter for academic promotion? Evidence from a randomized natural experiment. FEDEA Documento de Trabajo 2010-15, Madrid.

Zinovyeva, N. and M. Bagues (2015). The role of connections in academic promotions. *American Economic Journal: Applied Economics 7*, 264–292.

Appendix

In this appendix we report some further results that are of immediate interest to the analysis of the main paper. Further results are available online at https://www.dropbox.com/s/y4etcd5142zyk7z/de_fraja_et_al_app_05072017.pdf?dl=0.

Table A1: Summary Statistics Departmental Level REF Performance by Component

	mean	sd	min	max
Overall % 4*	26.59	14.70	0.00	79.00
Overall % 3*	47.28	11.81	3.00	83.00
Overall % 2*	22.21	12.12	0.00	75.00
Overall % 1*	3.41	5.50	0.00	55.00
Overall % 0*	0.51	1.35	0.00	11.00
Outputs % 4*	21.53	11.23	0.00	69.70
Outputs % 3*	48.34	12.21	0.00	100.00
Outputs % 2*	25.67	11.96	0.00	72.90
Outputs % 1*	3.93	5.77	0.00	60.60
Outputs % 0*	0.52	1.18	0.00	10.30
Environment % 4*	33.58	33.46	0.00	100.00
Environment % 3*	47.51	27.61	0.00	100.00
Environment % 2*	16.80	23.67	0.00	100.00
Environment % 1*	2.07	9.32	0.00	90.00
Environment % 0*	0.04	0.84	0.00	25.00
Impact % 4*	37.74	28.08	0.00	100.00
Impact % 3*	43.67	22.96	0.00	100.00
Impact % 2*	15.14	19.55	0.00	100.00
Impact % 1*	2.57	8.84	0.00	90.00
Impact % 0*	0.87	5.22	0.00	40.00

Note: Sample size = 1139 departments submitted to REF 2014. For explanation of REF performance measures see main text.

Table A2: OLS Regression Estimates: Department Pay Characteristics and REF 2014 Performance. Dependent Variable: Grade Point Average Score

	(1) No controls	(2) + Controls	(3) + Unit FE	(4) + Uni. Type FE
Log Average Salary	0.760***	0.473***	0.772***	0.476***
	(0.081)	(0.075)	(0.073)	(0.071)
Gini Coefficient Salary	1.815***	0.636***	0.483*	0.151
	(0.253)	(0.245)	(0.229)	(0.211)
Log Professorial FTE		0.027*	0.111***	0.078***
		(0.016)	(0.017)	(0.016)
Log REF FTE		0.132***	0.108***	0.074***
		(0.018)	(0.017)	(0.016)
Panel Member = 1		0.113***	0.075***	0.049***
		(0.018)	(0.016)	(0.015)
Log Vice Chancellor Pay		0.203***	0.132***	0.073*
		(0.042)	(0.039)	(0.037)
% Age under 40		0.171*	0.339***	0.235***
		(0.094)	(0.090)	(0.083)
% Age 41-50		0.017	0.120**	0.073
		(0.051)	(0.050)	(0.046)
% Age 51-60		-0.038	0.020	-0.050
		(0.050)	(0.047)	(0.044)
1994 Group Uni. = 1				-0.018
				(0.019)
Other Type Uni. = 1				-0.174***
				(0.021)
New Uni = 1				-0.348***
				(0.026)
Specialist Uni = 1				-0.077
				(0.088)
R-squared	0.203	0.367	0.497	0.580
Observations	1139	1139	1139	1139

Notes: Sample size = 1139 departments submitted to REF 2014. Dependent variable is GPA score. Column 1 includes log average salary and log sd salary only. Additional columns add control variables as described in table header. Vice Chancellor pay variable omitted from Column 5 as it is collinear with fixed effects. Standard errors in parenthesis. * Denotes significance at 10% level, ** 5% level, *** at 1% level.

Table A3: OLS Regression Estimates by Main Panel (Grade Point Average Score)

	(1) Panel A	(2) Panel B	(3) Panel C	(4) Panel D
Log Average Salary	0.827***	0.591***	0.436***	0.778***
	(0.196)	(0.153)	(0.126)	(0.144)
Gini Coefficient Salary	1.023*	1.170***	0.191	0.049
	(0.554)	(0.431)	(0.439)	(0.503)
Log Professorial FTE	-0.028	0.127***	0.014	0.135***
	(0.027)	(0.035)	(0.031)	(0.037)
Log REF FTE	0.115***	0.086*	0.209***	0.045
	(0.035)	(0.037)	(0.032)	(0.034)
Panel Member = 1	0.075*	0.080**	0.125***	0.108***
	(0.039)	(0.033)	(0.031)	(0.033)
Log Vice Chancellor Pay	0.200*	0.087	0.185**	0.173*
	(0.100)	(0.081)	(0.074)	(0.077)
% Age under 40	0.313	0.583***	0.190	0.147
	(0.282)	(0.210)	(0.152)	(0.165)
% Age 41-50	0.021	0.037	0.078	0.113
	(0.135)	(0.108)	(0.090)	(0.089)
% Age 51-60	-0.008	-0.084	0.023	-0.008
	(0.117)	(0.111)	(0.089)	(0.086)
R-squared	0.449	0.515	0.399	0.341
Observations	194	276	380	289

Note: Sample size = 1139 departments submitted to REF 2014. Dependent variable is GPA score. OLS regression estimated on four mutually exclusive samples of academic departments categorised by REF Main Panel. * Denotes significance at 10% level, ** 5% level, *** at 1% level.

Table A4: OLS Regression Estimates by University Type (Grade Point Average Score)

	(1) Russell	(2) 1994	(3) Others	(4) New
Log Average Salary	0.179*	0.360***	0.792***	1.535***
	(0.088)	(0.138)	(0.197)	(0.287)
Gini Coefficient Salary	0.528*	0.648	-0.715	-1.667*
	(0.255)	(0.410)	(0.568)	(0.793)
Log Professorial FTE	0.067***	0.110***	0.192***	0.125**
	(0.021)	(0.032)	(0.041)	(0.052)
Log REF FTE	0.059***	0.008	0.056	0.114***
	(0.022)	(0.036)	(0.039)	(0.044)
Panel Member = 1	0.023	0.064**	0.069*	0.139*
	(0.019)	(0.027)	(0.039)	(0.062)
Log Vice Chancellor Pay	0.169***	-0.083	-0.056	-0.020
	(0.047)	(0.074)	(0.104)	(0.101)
% Age under 40	-0.094	0.541***	0.103	0.238
	(0.122)	(0.157)	(0.225)	(0.215)
% Age 41-50	-0.009	0.270***	0.043	0.030
	(0.075)	(0.099)	(0.105)	(0.115)
% Age 51-60	-0.063	0.167*	-0.011	-0.134
	(0.073)	(0.093)	(0.096)	(0.109)
R-squared	0.384	0.442	0.494	0.474
Observations	428	260	225	219

Note: Sample size = 1139 departments submitted to REF 2014. OLS regression estimated on four mutually exclusive samples of academic departments categorised by University Type. Sample of 'specialist' universities not shown as it contains only 8 observations. * Denotes significance at 10% level, ** 5% level, *** at 1% level.

Table A5: OLS Regression Estimates: Department Pay Characteristics and REF Component GPA Scores

	(1) Overall GPA	(2) Outputs GPA	(3) Environment GPA	(4) Impact GPA
Log Average Salary	0.476***	0.436***	0.615***	0.494***
	(0.071)	(0.067)	(0.121)	(0.148)
Gini Coefficient Salary	0.151	0.221	0.807*	-0.538
	(0.211)	(0.199)	(0.360)	(0.439)
Log Professorial FTE	0.078***	0.055***	0.101***	0.130***
	(0.016)	(0.015)	(0.027)	(0.033)
Log REF FTE	0.074***	-0.003	0.330***	0.136***
	(0.016)	(0.015)	(0.027)	(0.033)
Panel Member = 1	0.049***	0.025*	0.093***	0.095***
	(0.015)	(0.014)	(0.026)	(0.032)
Log Vice Chancellor Pay	0.073*	0.129***	0.073	-0.108
	(0.037)	(0.035)	(0.063)	(0.076)
% Age under 40	0.235***	0.269***	0.240*	0.129
	(0.083)	(0.078)	(0.141)	(0.172)
% Age 41-50	0.073	0.109**	0.026	-0.012
	(0.046)	(0.043)	(0.078)	(0.095)
% Age 51-60	-0.050	-0.032	-0.049	-0.104
	(0.044)	(0.042)	(0.075)	(0.091)
1994 Group Uni. = 1	-0.018	-0.014	-0.009	-0.041
	(0.019)	(0.018)	(0.032)	(0.039)
Other Type Uni. = 1	-0.174***	-0.170***	-0.203***	-0.164***
	(0.021)	(0.020)	(0.037)	(0.045)
New Uni = 1	-0.348***	-0.305***	-0.483***	-0.383***
	(0.026)	(0.025)	(0.044)	(0.054)
Specialist Uni = 1	-0.077	-0.049	-0.365**	0.057
	(0.088)	(0.083)	(0.150)	(0.183)
R-squared	0.580	0.521	0.619	0.333
Observations	1139	1139	1139	1139

Note: Sample size = 1139 departments submitted to REF 2014. Dependent variable is Column 2 the grade-point-average score for the department output component, Column 3 environment component and Column 4 impact component. Models include REF main panel and unit of assesment fixed effects. * Denotes significance at 10% level, ** 5% level, *** at 1% level.

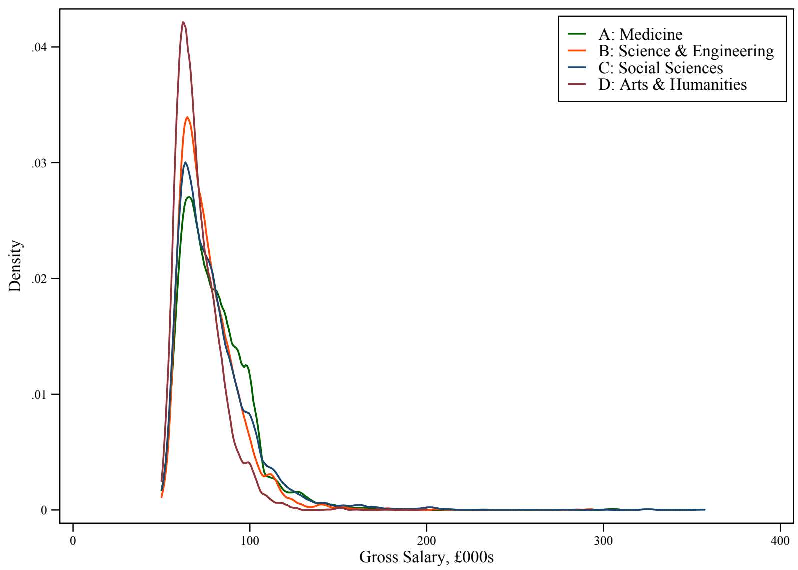
Table A6: OLS Regression Estimates: Department Pay Characteristics and REF 2014 Performance Omitting Medicine / Oxford & Cambridge. Dependent Variable: REF Funding Score

	(1) Omit Medicine	(2) Omit Oxbridge
Log Average Salary	0.554***	0.702***
	(0.092)	(0.099)
Gini Coefficient Salary	0.440	0.378
	(0.273)	(0.288)
Log Professorial FTE	0.111***	0.114***
	(0.020)	(0.021)
Log REF FTE	1.072***	1.057***
	(0.020)	(0.021)
Panel Member = 1	0.064***	0.053***
	(0.020)	(0.020)
Log Vice Chancellor Pay	0.079*	0.022
	(0.048)	(0.049)
% Age under 40	0.274***	0.293***
	(0.106)	(0.107)
% Age 41-50	0.078	0.106*
	(0.059)	(0.060)
% Age 51-60	-0.077	-0.069
	(0.056)	(0.057)
1994 Group Uni. = 1	-0.034	-0.013
	(0.024)	(0.024)
Other Type Uni. = 1	-0.209***	-0.192***
	(0.028)	(0.027)
New Uni = 1	-0.422***	-0.391***
	(0.033)	(0.033)
Specialist Uni = 1	-0.116	-0.053
	(0.133)	(0.112)
R-squared	0.909	0.909
Observations	1111	1085

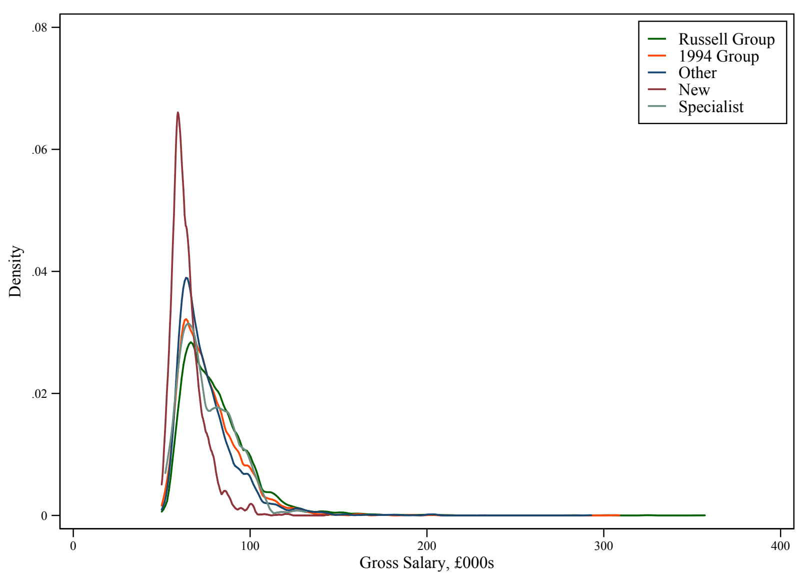
Notes: Dependent variable is natural log of research funding score. Column 1 excludes medicine unit of assessment. Column 2 excludes all submissions from Cambridge and Oxford. * Denotes significance at 10% level, ** 5% level, *** at 1% level.

Figure A1: Distribution of Pay of UK Professors by REF Main Panel and University Type, 2013

(A) By REF Main Panel



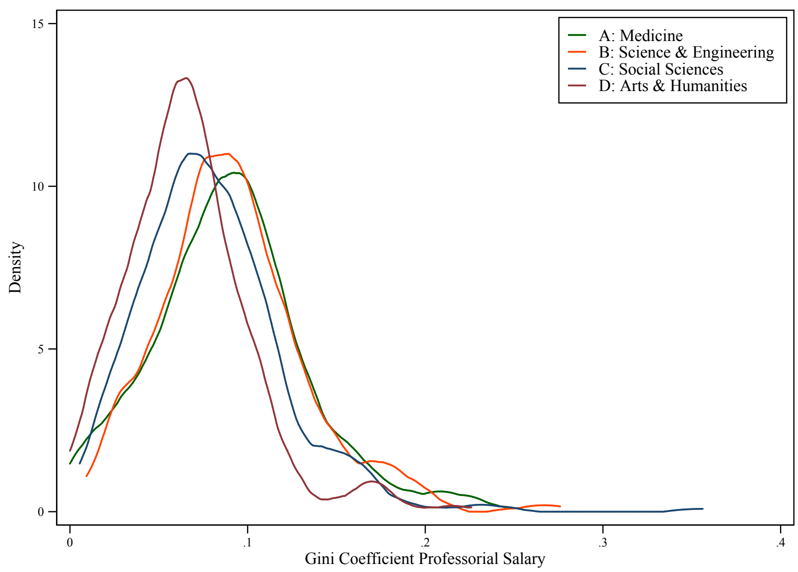
(B) By University Type



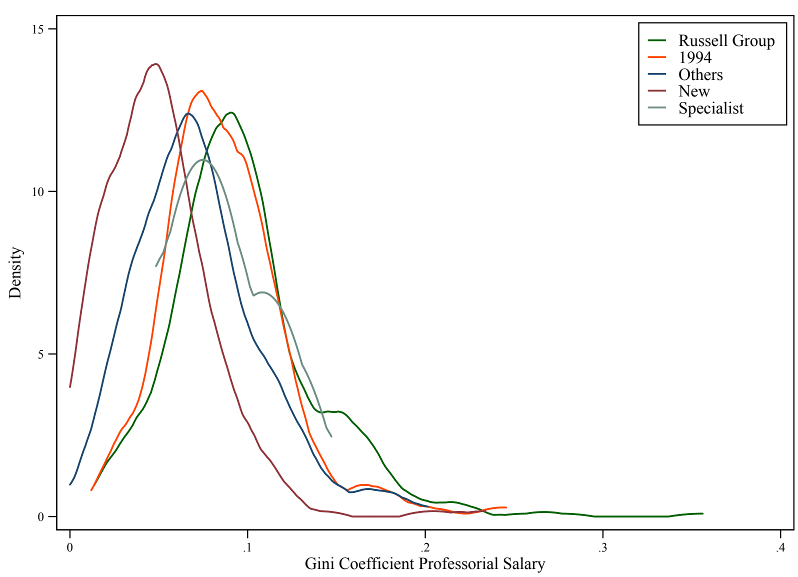
Note: Kernel density plots illustrates pay distribution for all UK Professors. Professors assigned to REF Main Panel by their affiliation to submitting unit within their University. Kernel density functions, epanechnikov kernel.

Figure A2: Distribution of Gini Coefficient in Salary Among Academic Departments by REF Main Panel and University Type

(A) Gini Salary By REF Main Panel



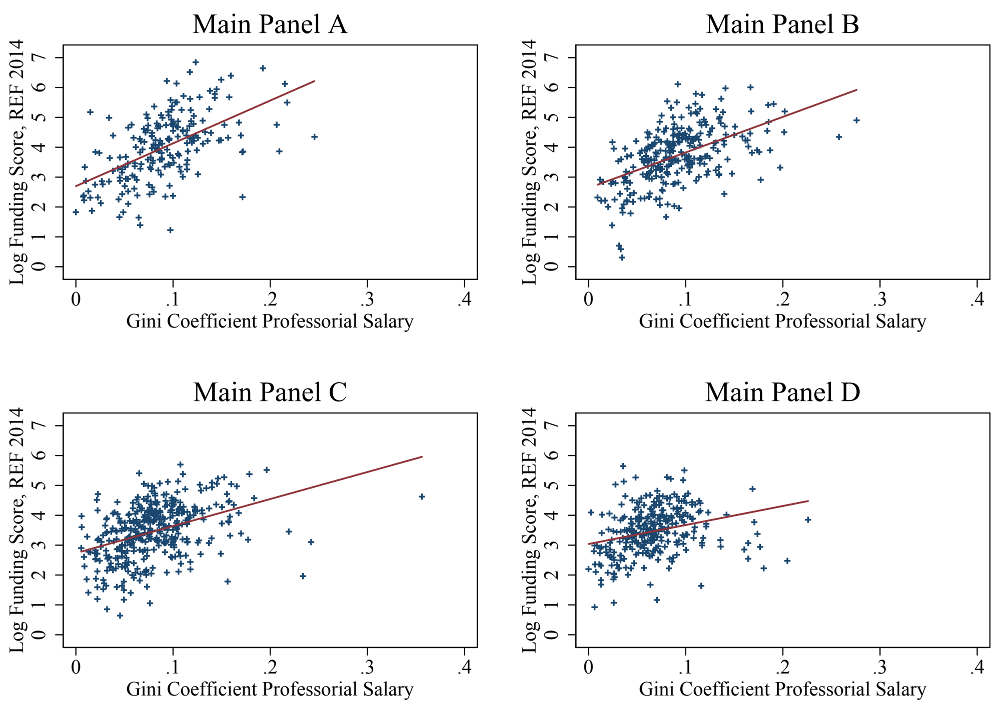
(B) Gini Salary By University Type



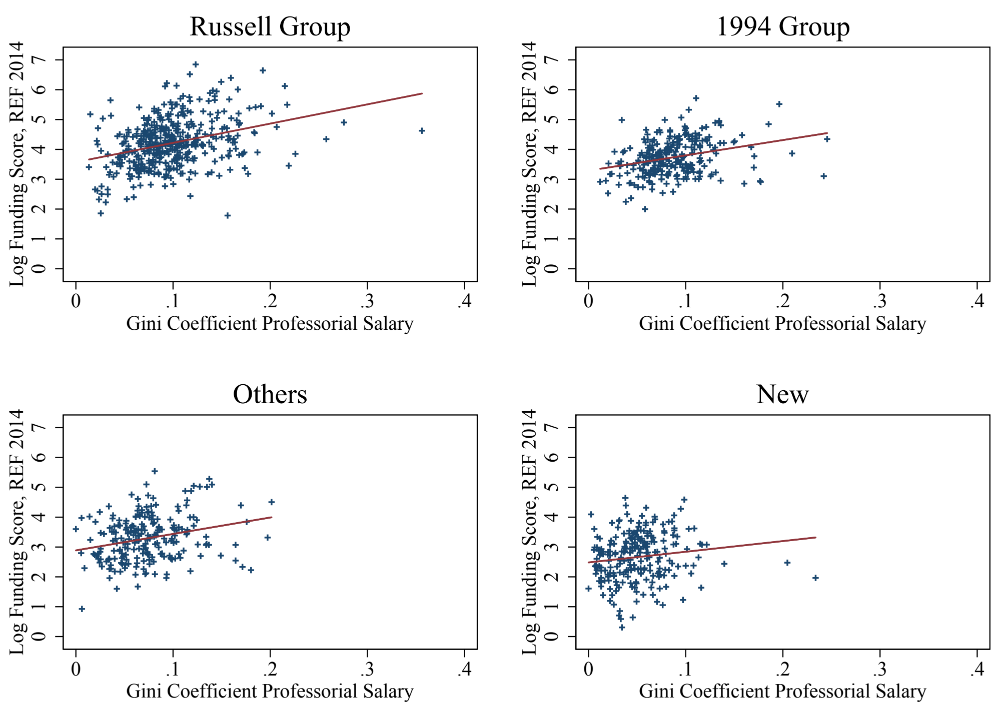
Note: Kernel density plots illustrate the distribution of the standard deviation of salary at the academic department level, sample size 1139 academic departments. Plot A groups departments by REF Main Panel, Plot B groups departments by University Type. Kernel density functions, epanechnikov kernel.

Figure A3: Correlation Between Gini Coefficient of Departmental Pay and Funding Score

(A) By REF Main Panel



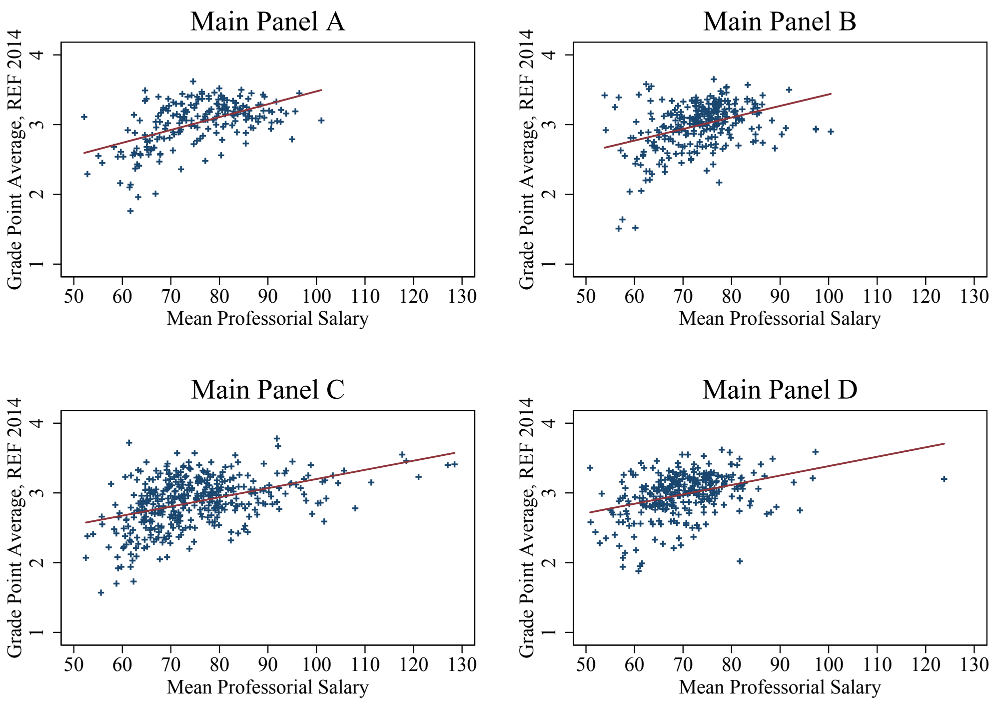
(B) By University Type



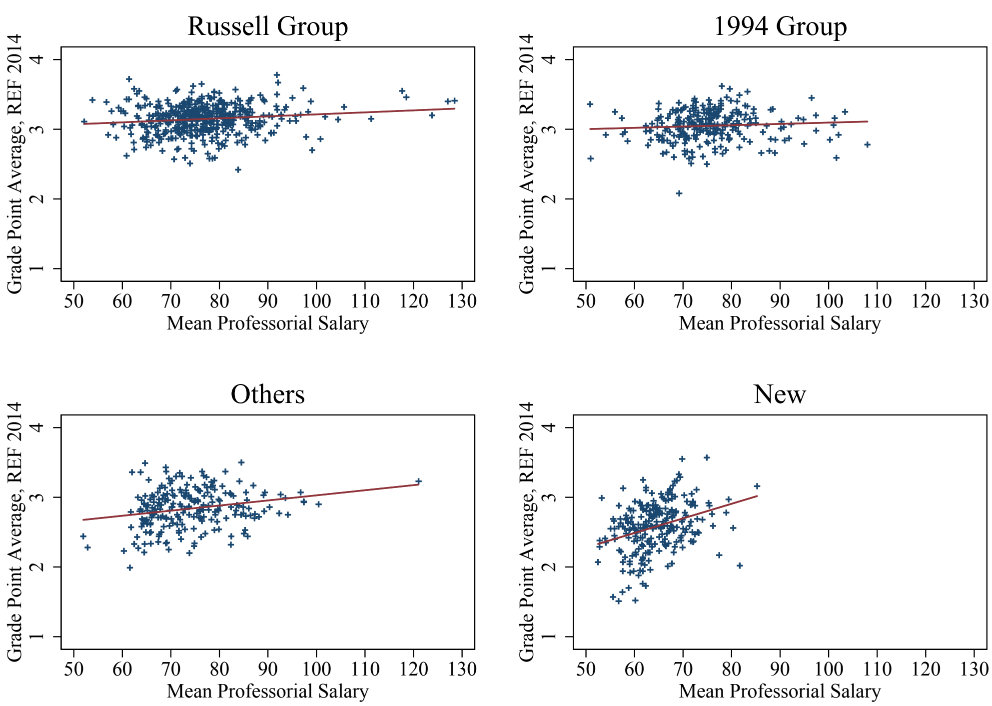
Note: Each observation represents an individual academic department. Figure show scatter plots and fitted regression lines. Observations grouped by REF Main Panel (Plot group A) and University Type (Plot group B)

Figure A4: Correlation Between Mean Pay and GPA Score

(A) By REF Main Panel



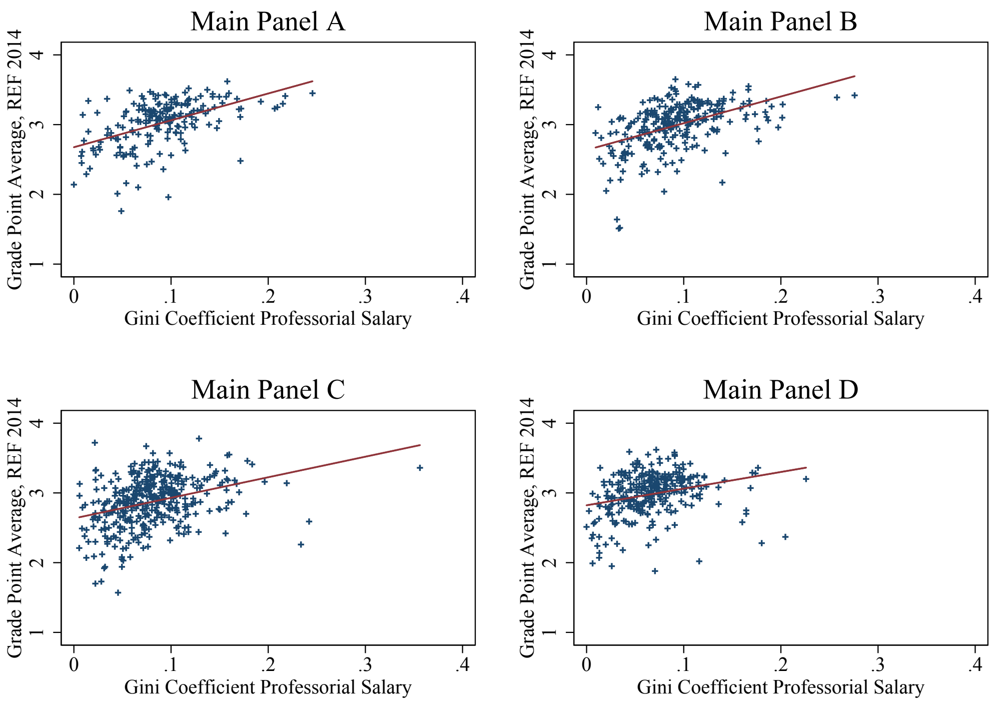
(B) By University Type



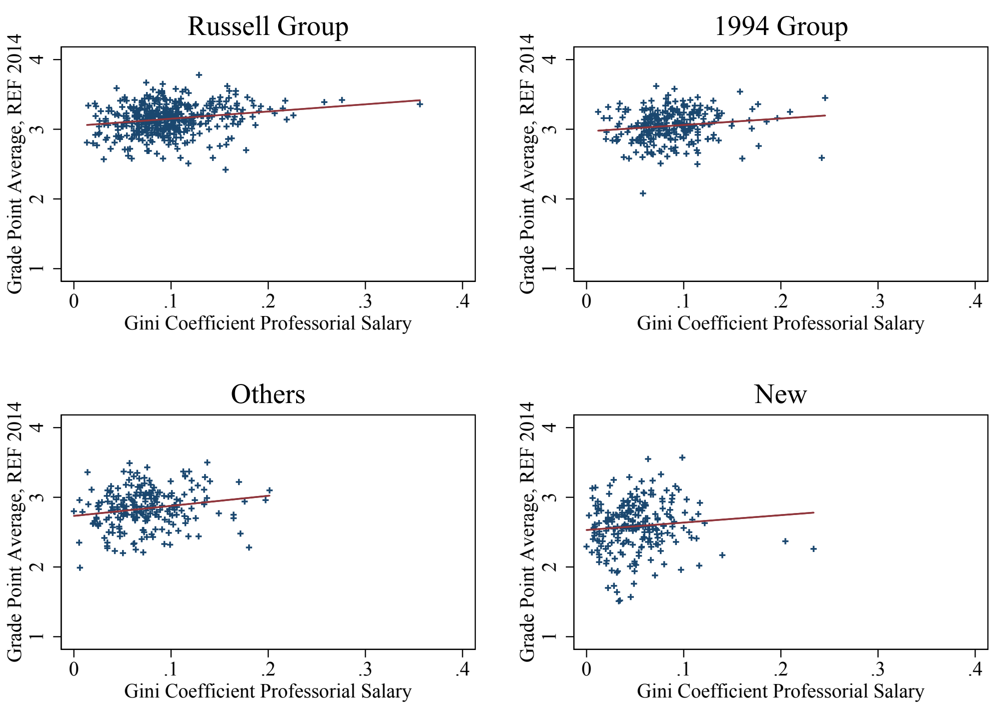
Note: Each observation represents an individual academic department. Figure show scatter plots and fitted regression lines. Observations grouped by REF Main Panel (Plot group A) and University Type (Plot group B).

Figure A5: Correlation Between Gini Pay and GPA Score

(A) By REF Main Panel

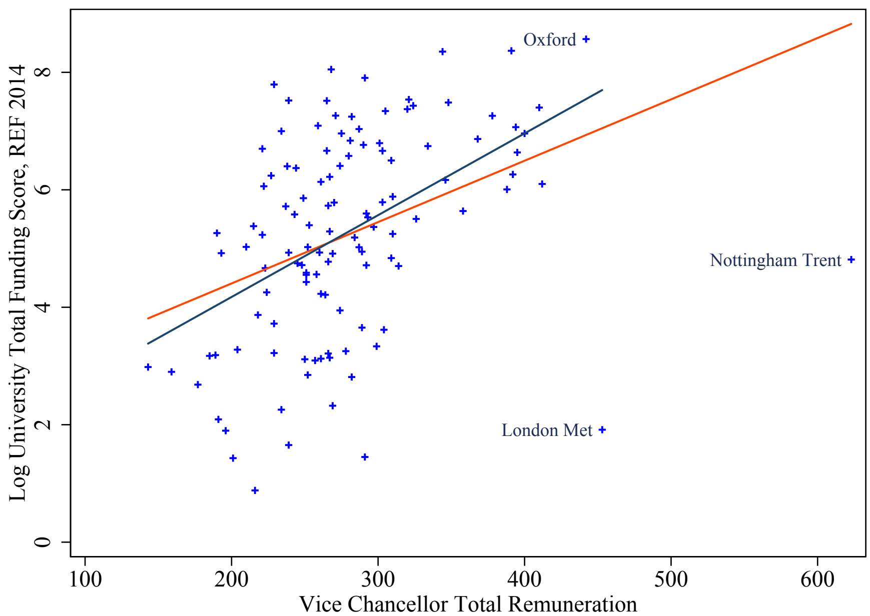


(B) By University Type



Note: Each observation represents an individual academic department. Figure show scatter plots and fitted regression lines. Observations grouped by REF Main Panel (Plot group A) and University Type (Plot group B).

Figure A6: Vice Chancellor Pay and Funding Score Performance



Note: Each observation corresponds to an individual university. Figure shows a scatter plot of total remuneration of university vice chancellors (x-axis, including pension contributions and discretionary payments) and log funding score (y-axis). The red fitted regression line is estimated on all observations; the blue fitted regression line is fitted on observations exlcuding the far-right outlier value.

A Classification of UK Universities by Types

This appendix lists the members of the University 'Type' Groups used in the analysis (excluding therefore institutions with fewer than three professors, or which did not make a submission to the REF, and the London Business School). These groupings are based the membership of University associations during the relevant period. For each institution, we give in brackets the number of panels to which a submission was made, the fulltime equivalent number of staff submitted, and the fulltime equivalent number of full professors in post in October 2013.

Russell Group: In 1994 a group of 17 'research intensive' UK universities formed an association known as the 'Russell Group', which grew to 20 Universities by 2006. In 2012 four additional universities joined from the newly-defunct '1994' group. Our classification of 'Russell Group' uses the 20 members from 2006 onwards on the basis that this group represents long-running core members.

University of Birmingham (29, 990, 411)
University of Bristol (26, 981, 487)
University of Cambridge (28, 1874, 711)
University of Leeds (26, 1015, 428)
University of Liverpool (16, 584, 253)
Imperial College, London (10, 1071, 612)
King's College London (19, 861, 496)
London School of Economics (12, 490, 249)
University College London (29, 2059, 902)
University of Newcastle-upon-Tyne (24, 809, 374)
University of Nottingham (23, 1053, 430)
University of Oxford (28, 2264, 905)
University of Sheffield (24, 770, 394)
University of Southampton (23, 878, 392)
University of Warwick (21, 907, 474)
University of Edinburgh (28, 1603, 558)
University of Glasgow (25, 887, 400)
Cardiff University (24, 679, 590)
The Queen's University of Belfast (21, 729, 193)
University of Manchester (30, 1426, 780)

The 1994 Group: The '1994' Group was also formed in 1994, its membership comprising smaller research-intensive universities that had not been invited to join the Russell Group. This group disbanded in 2012.

University of Bath (11, 414, 137)
University of Durham (20, 629, 250)
University of East Anglia (16, 353, 150)
University of Essex (10, 304, 131)
University of Exeter (19, 621, 230)
University of Lancaster (14, 503, 173)
University of Leicester (19, 576, 237)
Birkbeck College (11, 254, 92)
Queen Mary University of London (16, 556, 326)
Royal Holloway and Bedford (16, 360, 182)
School of Oriental and African Studies (8, 134, 78)
Loughborough University (13, 544, 154)
University of Reading (20, 537, 223)
University of Surrey (11, 362, 103)
University of Sussex (18, 443, 175)
University of York (23, 628, 264)
University of St Andrews (18, 498, 205)

"New" Universities: This group comprises institutions which were given status as universities from 1992 onwards. Prior to that time most of the members of this group were known as 'polytechnics' and delivered mainly post-high school technical education.

Buckinghamshire New University (1, 7, 6)
University of Chester (4, 45, 19)
Canterbury Christ Church University (2, 36, 8)
Edge Hill University (4, 55, 13)
Falmouth University (2, 50, 7)
Harper Adams University (1, 17, 3)
University of Winchester (1, 12, 4)
Liverpool Hope University (3, 38, 18)
University of Bedfordshire (7, 111, 47)
University of Northampton (1, 13, 3)
Roehampton University (6, 74, 34)
University of Worcester (1, 10, 3)
Anglia Ruskin University (5, 55, 35)
Bath Spa University (2, 26, 19)
Bournemouth University (4, 80, 35)
University of Brighton (6, 145, 29)
Birmingham City University (8, 98, 42)
University of Gloucestershire (4, 37, 15)
Coventry University (3, 44, 16)
University of East London (6, 78, 27)
University of Greenwich (3, 41, 12)
University of Hertfordshire (8, 138, 39)
University of Lincoln (9, 92, 34)
Kingston University (7, 115, 46)
Leeds Beckett University (5, 116, 31)
Liverpool John Moores University (9, 138, 47)
Manchester Metropolitan University (7, 220, 35)
Middlesex University (9, 257, 80)
De Montfort University (7, 136, 49)
Nottingham Trent University (7, 118, 58)
Oxford Brookes University (12, 204, 66)
University of Plymouth (13, 295, 101)
University of Portsmouth (5, 109, 25)
Sheffield Hallam University (7, 139, 37)
London South Bank University (1, 34, 4)
Teesside University (1, 16, 6)
University of West London (3, 29, 13)
University of the West of England (8, 192, 72)
University of Chichester (1, 8, 3)
University of Wolverhampton (7, 119, 37)
Cardiff Metropolitan University (2, 23, 9)
University of South Wales (4, 37, 16)
University of Abertay Dundee (1, 14, 3)
Queen Margaret University, Edinburgh (1, 8, 5)
Robert Gordon University (2, 20, 10)
Glasgow Caledonian University (5, 108, 41)
Edinburgh Napier University (5, 65, 28)
University of Ulster (14, 311, 123)
London Metropolitan University (2, 17, 9)

Specialists: This group comprises a set of high specialised universities offering a limited range of subjects including, in some cases, universities offering only a single subject.

Royal College of Art (1, 60, 7)
University of the Arts, London (1, 110, 27)
Royal Academy of Music (1, 14, 4)
Royal Northern College of Music (1, 11, 5)
Royal Veterinary College (1, 103, 33)
St George's Hospital Medical School (1, 44, 41)
London School of Hygiene and Tropical Medicine (1, 57, 66)
University for the Creative Arts (1, 21, 7)

Others: Universities not included in any of the above groups are assigned to this 'other' group.

The Open University (12, 325, 96)
Cranfield University (3, 224, 50)
University of Central Lancashire (11, 201, 52)
University of Huddersfield (10, 144, 61)
University of Westminster (8, 138, 53)
Aston University (5, 164, 45)
University of Bradford (4, 93, 44)
Brunel University London (15, 452, 97)
City University (10, 316, 141)
University of Hull (10, 244, 54)
University of Keele (13, 239, 71)
University of Kent (18, 500, 135)
Goldsmiths College (10, 210, 82)
University of Salford (8, 185, 71)
University of Strathclyde (14, 508, 174)
University of Aberdeen (19, 475, 236)
Heriot-Watt University (8, 212, 75)
University of Dundee (11, 287, 110)
University of Stirling (12, 239, 83)
Aberystwyth University (11, 202, 71)
Bangor University (2, 70, 17)
Swansea University (14, 330, 149)
Guildhall School of Music and Drama (1, 16, 105)