Working Papers in Economics & Finance
No. 2023-08

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Abstract

It is important to understand whether and in what ways performance-based public funds enhance universities' research output. Using a synthetic difference-in-differences analysis and propensity score methods to compare research productivity differences between UK universities' Economics and Business fields and their synthetic counterparts in the US during the REF period in contrast to the pre-REF period, we find a significant and consistent increase in peer-reviewed journal publications of UK universities since the introduction of REF in 2009. We further show that publication output per author declined as a result of increased collaboration while overall citations increased. Our findings further suggest that REF may have played a pivotal role in elevating research excellence in elite institutions.

JEL codes: O38; I23; H52

Keywords: Public funding; Research Productivity; Research Excellence Frameworks (REFs)

1. Introduction

Many countries adopt some performance-based research funding system (PRFS) in one form or another to distribute large scale public funds among their higher education institutions to support and sustain their research and innovation activities. It is crucial to understand whether and how such competitive funding policies for HEIs affect research and innovation in order to shape successful long-term science and innovation policies. The United Kingdom's (UK) implementation of the Research Excellence Framework (REF) provides a valuable laboratory to test the effects of such policies.

Despite the global adoption of PRFSs, they face significant criticism. Jacob and Lefgren (2011) do not find significant differences in scientific impact between funded and unfunded research. Gneezy et al. (2011) and Andersen and Pallesen (2008) demonstrate that incentives can sometimes be counterproductive, potentially eroding researchers' intrinsic motivation. Causal analysis of the effects of PRFSs on universities' research productivity remains a significant gap in the literature. This gap arises due to the challenge of establishing causality and limited counterfactuals among the universities subject to PRFS assessments (Banal-Estañol et al., 2023).

Our aim is to establish causal links between PRFSs and universities' research productivity. We examine the efficacy of REF in enhancing research performance within UK universities, focusing on Economics and Business fields using synthetic difference-in-differences (SDiD) and propensity score methods (PSM) and comparing UK departments with analogous US departments as synthetic control units over 2001-2021. Our results show that REFs promoted research performance in terms of quantity and quality. Compared to a synthetically created control group of US universities, the UK universities have demonstrated a sustained and consistent improvement in both the quantity and quality of research performance following the introduction of REF. Our results affirm the significant positive effect of the REFs on the number of publications, esp. top publications. We further show disparities between Russell Group and non-Russell Group universities in terms of the influence of REFs on research outcomes. Russell Group institutions have seen a substantial increase in publications, especially in prestigious journals, while non-Russell Group universities have experienced a relatively more modest growth.

This study offers noteworthy contributions on several fronts. First, it conducts a rigorous causal examination to evaluate the impact of REF on diverse research outcomes using a robust methodological fusion of synthetic difference-in-differences (SDiD) (Clarke et al., 2023; Huang et al., 2023) and propensity score methods (PSM) (Rosenbaum & Rubin, 1983; Dehejia & Wahba, 2002; Abadie & Imbens, 2016). Second, following Payne and Roberts (2010) that showed how flagship US universities outperformed non-flagship institutions in research due to higher funding, our research investigates potential disparities between Russell Group and non-Russell Group universities, shedding light on how REF affects research activities and inequalities within the academic landscape.

2. Background and Motivation

Performance-based research funding systems (PRFSs) are used by various countries to encourage research institutions to improve and accelerate their research work (Checchi et al., 2019). They are highly competitive funds where institutions get rewarded based on the ex-post assessment of institutions' research outcomes and funds are allocated to best-performing institutions (Checchi et al., 2019; Hicks, 2012; Zacharewicz et al., 2019). As demonstrated in Appendix 1, Table 1A, over the past few decades, many countries have transitioned from block funding to PRFSs (Checchi et al., 2019).

The contemporary PRFS of the UK is known as the REF which was introduced as a significant revision to its predecessor RAE. Significantly higher amount of funding was tied to the outcome of the REF starting from 2014. Moreover, there was an increased emphasis on world leading research embodied by top-tier peer-reviewed journal publications (Mingers & White, 2015; Geuna & Piolatto, 2016; Marques et al., 2017). A group of experts assigned to each "Unit of Assessment," encompassing various academic disciplines (hereinafter referred to as "panels"), evaluates the quality of research within that specific domain across all institutions in the UK. This assessment is conducted across three distinct categories: outputs, impact, and environment. Results are pivotal in determining financial allocations from funding bodies to research institutions and disciplines earmarked for future research endeavours.

A plethora of studies have undertaken assessments of PRFS effects using descriptive analyses. Butler (2003) illustrated the Australian funding allocation scheme, revealing a noteworthy increase in journal publication production over a decade. Nonetheless, concerns arose about

potential decreases in citation impact. Andersen and Pallesen (2008) establish a positive correlation between financial incentives and publications across 162 Danish research institutions. This supportive relationship encourages employees to engage in increased research publication activities intrinsically. In contrast, Auranen and Nieminen (2010) examined PRFSs across eight countries, revealing that financial incentives do not always straightforwardly elevate publication production.

Employing a linear regression model, Taylor (2011) uncovers significant insights from the RAE 2008. His analysis demonstrates a strong correlation between the three components of research activity—research output, impact, and research environment—and diverse quantitative indicators. These indicators encompass metrics such as the journal quality index, the count of research staff, past RAE outcomes, affiliation with the Russell Group, and the autonomy status of the department in economics or finance. Banal-Estañol et al. (2023) emphasized the favourable impact of REF 2014 on both the quantity and quality of scientific research from UK universities. However, they found no significant influence of REF 2014 on research productivity. The existing literature falls short in establishing a causal link between the effect of the REF on research outcomes within UK universities due to the absence of a suitable counterfactual synthetic control group with a PRFS. While some studies have explored the relationship between PRFSs and research outcomes (Banal-Estañol et al., 2023), there is a dearth of causal analysis of the effects of REF 2014 and REF 2021. Our unique approach bridges these gaps by utilising SDiD and PSM to establish causality, enabling us to discern the nuanced and sustained effects of PRFSs on research outcomes in the UK higher education landscape.

3. Data

We use the period from 2009 to 2021 as "treatment years", while the period between 2001 and 2008 is "pre-treatment years", as 2009 is the year of transition from RAE to REF. The transition from RAE to REF marked a significant shift in the UK's performance-based research funding system, with the REF carrying more weight for research from 2009 to 2014. Our study aims to determine the incremental impact of REF over RAE. Consequently, our dataset covers an extensive timeframe from 2001 to 2021, allowing us to thoroughly assess the shifts in research performance across these years.

Our study's initial sample encompasses 98 UK universities, specifically those that submitted their research portfolio to both REF 2014 and REF 2021 within Panels 18 (Economics and Econometrics) and/or 19 (Business and Management). In order to create a control group consisting of universities not subjected to REF or any PRFS, we carefully selected 116 US universities that possess either a Department of Economics or a Business School ranked in the top 25%, based on the December 2018 RePEc rating. We meticulously collected all research articles from the Scopus database that meet the following criteria: (i) affiliation with either the 98 UK institutions or the 116 US institutions, (ii) categorisation within the subject areas of 'Economics, Econometrics, and Finance' or 'Business, Management, and Accounting,' and (iii) publication dates falling between 2001 and 2021, with the exclusion of books and conference papers.

Our dataset exclusively comprises published articles identified through the ISSN code, while publications in books and conferences were excluded. This comprehensive dataset contains a total of 461,861 unique publications authored by 237,216 individuals and published across 2,519 journals during the period spanning from 2001 to 2021. To facilitate our analysis, we aggregated the publication data at both the institutional and yearly levels.

3.1 Outcome measures and descriptive statistics

In our evaluation of the university's research performance, we consider publications, citations, research productivity (publications per author), and citation productivity (citations per publication). To gauge research quality, we rely on the 2021 Chartered Association of Business Schools (CABS) classification of scientific journals from the Academic Journal Guide, categorizing journals on a scale from 1* (least influential) to 4** (most influential).

When quantifying "research output," we calculate the number of unique publications and citations attributed to each university (affiliation) for each year, covering all journals regardless of their CABS classification. These metrics are referred to as "All" publications, "All" citations, "All" research productivity, and "All" citation productivity.

To serve as a proxy for "research excellence," we specifically count the number of publications and citations falling within the 3*, 4*, and 4** categories according to the CABS classification for each university in each year. These are labelled as "Top" publications, "Top" citations,

"Top" research productivity, and "Top" citation productivity, respectively, for a comprehensive assessment of research quality and impact.

Table 1 provides a comprehensive overview of the descriptive statistics for the yearly averages of our research performance variables, encompassing both UK and US universities. For "All" publications per university per year, the range spans from 1 to 1176, with an average of 104.97. However, when we narrow our focus to top journals (CABS 3* & 4*), these numbers, specifically "Top" publications, exhibit a distinct pattern, with minimum, maximum, and average values of 1, 652, and 54.87, respectively. The standard deviations for "All" research productivity and "Top" research productivity show minimal differences, measuring 0.08 and 0.12, respectively.

Shifting to the number of "All" citations per university per year, we observe a range from 0 to 67,252, with an average of 4657.69. Similar to publications, when concentrating on top journals (CABS 3* & 4*), we find notably lower values for "Top" citations, with minimum, maximum, and average values of 2, 51116, and 3602.27, respectively. The measures of "All" citation productivity and "Top" citation productivity stand at 45.85 and 68.02, respectively.

Table 1 Descriptive statistics of research performance measures

Key Construct	Category	Mean	Std. Dev.	Min	Max
All publications	Count of all publications in journals, by university and year.	104.97	126.91	1	1176
All research productivity	Number of publications per author	0.39	0.08	0.1	1
Top publications	Count of publications in top journals only, by university and year	54.87	59.21	1	652
Top research productivity	Number of top publications per author, by university and year	0.39	0.12	0.05	2.42
All citations	Count of all citations in journals, by university and year	4657.69	6849.19	0	67252
All citation productivity	Citations per publication	45.85	36.02	0	569.75
Top citations	Count of citations in top journals only, by university and year	3602.27	4913.03	2	51116
Top citation productivity	Number of citations per publication in top journals, by university and year	68.02	50.38	1.4	650.33

3.2 Control variables

In this study, we incorporate income and expenditure as control variables based on their recognized potential to influence research capabilities and outcomes, as indicated in prior research (Banal-Estañol et al., 2023). The income variables encompass tuition fees, education contracts, funding body grants, research grants, other income, investment income, and donations and endowments, all of which represent the financial resources available to

universities. These financial resources have been established in previous studies as factors that can significantly impact research productivity and outcomes. Similarly, the expenditure variables, including staff costs, restructuring costs, other operating expenses, depreciation and amortization, and interest and other finance costs, represent the allocation of funds and institutional priorities.

By incorporating these financial factors as control variables in our estimation methods, we aim to mitigate potential confounding effects and enhance the accuracy and validity of our analysis. This approach allows us to assess the causal impact of the REFs on research outcomes in UK universities compared to a synthetic group of US universities with greater precision and rigour.

4.Estimation Methodology

We adopt the SDiD methodology, introduced by Arkhangelsky et al. (2021), combining the strengths of both Difference-in-Differences (DiD) and Synthetic Control (SC) methods. SDiD accommodates differing trends between treated and control units before a reform, similar to DiD models, while optimally generating matched control units, reducing the reliance on parallel trend assumptions like SC methods. Consequently, SDiD overcomes common pitfalls seen in standard DiD and SC methods, such as the inability to estimate causal relationships when parallel trends are not met in aggregate data with DiD and the requirement for the treated unit to be within a "convex hull" of control units with SC. Additionally, Arkhangelsky et al. (2021) provide formal evidence of the estimator's consistency and asymptotic normality, enhancing its credibility.

We establish a synthetic control group (Abadie and Gardeazabal, 2003) consisting of universities from the United States that did not undergo the REFs or any PRFS but exhibited comparable pre-treatment research outcome trends to their UK counterparts, forming the foundation for our comparative analysis.

Subsequently, we employ a sophisticated matching algorithm to create synthetic control units for each treated UK university. These synthetic controls are meticulously designed to closely mirror the pre-REF research outcomes of their respective UK counterparts. This careful matching process effectively eliminates any pre-existing trends in research outcomes, allowing us to attribute observed changes solely to the introduction of the REF.

Recognising the challenges posed by the large control set and the complexity introduced by multiple dimensions, we introduce an iterative procedure. This iterative approach involves applying the SDiD to all 98 treated UK universities and each outcome variable, initially considering all 116 US universities as potential control units. Subsequently, we refine our control set by eliminating US universities that do not significantly contribute to shaping optimal counterfactual synthetic units for any of the outcomes. This iterative process leads to the identification of a stable set of 23 US universities.

This "robust set of controls" is defined by its significance in shaping the synthetic units for at least one UK university and at least one outcome variable, with the flexibility to adapt the composition of optimal weights as needed for specific UK universities and outcomes. While we execute the matching process separately for each outcome variable, the collective consideration of all outcomes informs the selection of this robust control group.

Next, we employ a systematic PSM estimation strategy to investigate the causal impact of the REFs on research outcomes within UK universities while rigorously accounting for potential covariate effects. Our approach unfolds through distinct stages. Initially, we calculate propensity scores for each treated UK university, predicting their likelihood of being subject to the REFs by considering factors like income and expenditure variables (Rosenbaum & Rubin, 1983). These propensity scores form the foundation for ensuring comparability between the treated and control groups. Subsequently, we execute a meticulous matching process, pairing treated universities with suitable control counterparts from the United States, with a focus on closely aligning propensity scores. This matching procedure is pivotal in fostering covariate balance, thus ensuring that treated and control groups exhibit similarity in the distribution of covariates. Following successful matching, we assess covariate balance through established tests, further validating the comparability of our groups. We then proceed to estimate treatment effects by comparing post-REF research outcomes between treated and synthetic control groups. Aggregating these treatment effects provides an overarching assessment of the REF's impact on all treated UK universities, with statistical hypothesis tests determining the significance of these effects. To enhance comparability, we implement various PSM techniques, such as Probit, Logit, Probit with Neighbour Matching, Probit with Radial Matching, Probit with Kernel Matching, and Bootstrapping, within the common support group. This selection strengthens the robustness of our analysis and bolsters the credibility of our findings. Our central analysis revolves around comparing changes in research outcomes during

the pre-REF (2001-2008) and REF (2009-2021) periods in UK universities relative to the synthetic control group. This comprehensive approach enables us to isolate the incremental impact of the REFs on research performance (Abadie et al., 2010). While the complete control of all potential time-varying unobserved heterogeneity remains challenging, we mitigate potential biases by incorporating relevant control variables like income and expenditure (Heckman et al., 1997). In sum, our research aims to provide robust insights into the causal relationship between the REFs and research outcomes in UK universities, utilizing a meticulous and comprehensive PSM estimation strategy to address covariate effects and ensure the validity of our findings (Smith & Todd, 2005).

5. Results

We present the results in Tables 2 and 3 using the SDiD estimation method for 'All' publications and 'Top' publications, respectively. We show the yearly effects as well as the estimated ATT (for the overall period 2009–2021) on the outcomes of interest.

In terms of research output, the overall ATT reports a positive and significant change in the number of publications, showing an overall increase of 16.85 and 11.96 for 'All' and 'Top' publications per university department, respectively, mostly driven by the rise during all years of the treatment period (2009–2021). The result suggests that UK universities experienced a faster growth in the total number of publications compared to their counterpart US universities after the introduction of REF in 2009.

When comparing the 'All' publications to the 'Top' publications, it becomes evident that the impact of REFs is more pronounced on the former than the latter, indicated by the consistently high increasing trend in the number of publications over the years. One possible rationale for this difference might be that publishing in top journals often involves longer lead times for publication (Hadavand et al., 2022). Furthermore, the significant increase in the number of publications can be observed in Figure 2/2A, where panels A and A1 represent 'All' and 'Top' publications, respectively. The solid line, depicting UK universities after the initiation of REF, consistently shows an increasing trend in the number of publications compared to the dashed line, representing the counterfactual synthetic control group (US universities). These findings indicate a strong responsiveness of the university to the REF, encouraging researchers to focus

more on publications. Our results are in line with the findings of Checchi et al. (2019) and Banal-Estañol et al. (2023).

In both cases (Tables 2 and 3), research productivity shows an overall ATTs are negative and insignificant, with yearly negative and significant results. This decline in publications per author indicates that the REFs have led to increased collaboration among researchers, resulting in a higher number of authors per publication. Consequently, individual research productivity has decreased as recognition and awards are distributed among multiple authors. Figure 2/2A, panels B and B1, visually highlight the downward slope of research productivity in UK universities compared to the synthetic control group (represented by the dashed line representing US universities). Our findings support Carli et al. (2019) regarding the negative impact of the Italian PRFS on exceptional academics' productivity but contradict Bloch and Schneider (2016), who highlight the positive influence of the Norwegian PRFS, leading to increased publications per author.

The impact of REF on citations, as observed through SDiD, aligns with the DiD results, displaying a positive and significant overall ATT. On average, there is an increase of 998.84 and 723.77 citations for publications in 'All' and 'Top' journals, respectively, as shown in Tables 2 and 3. However, a noteworthy negative and significant trend in yearly citations emerges from 2012 and 2013 onwards in Tables 2 and 3, respectively. Several factors influence citations beyond just publishing in top journals. These factors include researchers' reputation, known as the Matthew effect, where researchers' scientific contributions may have an advantage over others and may influence citation positively (Jin et al., 2019).

Figure 2, panel C, reveals a relatively consistent upward trend in the citation pattern from 2009 to 2017 for "All" publications, substantially exceeding the citation rate of US universities. Conversely, panel C1 in Fig 2A, which represents "Top" publications, demonstrates a significantly higher citation pattern compared to US universities, but this trend started declining from 2014 onwards. Overall, the citation impact of REFs remains positive and significant, yet the yearly trends and differing patterns between "All" publications and "Top" publications suggest complex dynamics at play in the citation landscape.

Furthermore, the citations per publication in Tables 2 and 3 show an overall negative and insignificant Average Treatment Effect (ATT), with yearly negative and significant results.

This declining trend could likely be attributed to the REFs influence, which has encouraged increased collaboration among academic researchers, leading to a higher number of publications. However, citations typically take more time to accumulate.

In Figure 2/2A, panels D and D1 demonstrate that the citations per publication consistently surpass those of the counterfactual US universities. Despite the decreasing trend due to the rise in publications and the time it takes for citations to materialise, the impact of the REF initiative is apparent, as the citations in the UK remain consistently better than the counterfactual US universities. This suggests that the REFs have fostered a culture of improved citation performance, even though the yearly trends show negative results.

Table 2 REF: yearly effects and ATTs of All publication

	1	**2**	**3**	**4**
$ATT_{09\text{-}21}$	16.85***	-0.01	998.84***	-3.004
2009	22.36**	-0.064***	-258.9	-18.74***
2010	23.98**	-0.065***	-278.65	-23.77***
2011	22.09*	-0.074***	-987.41	-26.60***
2012	25.43**	-0.082***	-1173.45*	-31.21***
2013	29.89***	-0.096***	-1536.49**	-34.35***
2014	29.77***	-0.106***	-2137.62***	-38.80***
2015	27.46**	-0.113***	-2651.01***	-41.16***
2016	31.82***	-0.116***	-2886.41***	-44.16***
2017	31.27***	-0.120***	-3335.28***	-46.89***
2018	41.38***	-0.133***	-3868.08***	-52.03***
2019	38.03***	-0.145***	-4852.25***	-57.54***
2020	46.83***	-0.171***	-5301.78***	-60.99***
2021	44.47***	-0.181***	-6609.10***	-68.57***

P-value sig: 1% (***), 5% (**), and 10% (*),
1=Publications, 2=Research Productivity,
3=Citations, 4=Citation per publication

Table 3 REF: yearly effects and ATTs of Top publication

	1	2	3	4
$ATT_{09\text{-}21}$	11.96***	-0.006	723.77***	3.03
2009	13.89**	-0.07***	-2.15	-29.45***
2010	12.34***	-0.07***	-141.16	-34.64***
2011	12.86**	-0.09***	-654.07	-39.99***
2012	16.29***	-0.09***	-737.34	-47.61***
2013	18.81***	-0.11***	-1107.93**	-53.64***
2014	18.17***	-0.11***	-1614.97***	-59.70***
2015	16.64***	-0.12***	-2000.25***	-64.59***
2016	18.15***	-0.13***	-2268.46***	-68.52***
2017	17.48***	-0.13***	-2653.15***	-73.45***
2018	22.76***	-0.14***	-3199.91***	-83.00***
2019	22.15***	-0.15***	-3820.74***	-89.74***
2020	23.40***	-0.17***	-4232.95***	-95.17***
2021	24.37***	-0.18***	-5292.16***	-105.49***

P-value sig: 1% (***), 5% (**), and 10% (*),
1=Publications, 2=Research Productivity,
3=Citations, 4=Citation per publication

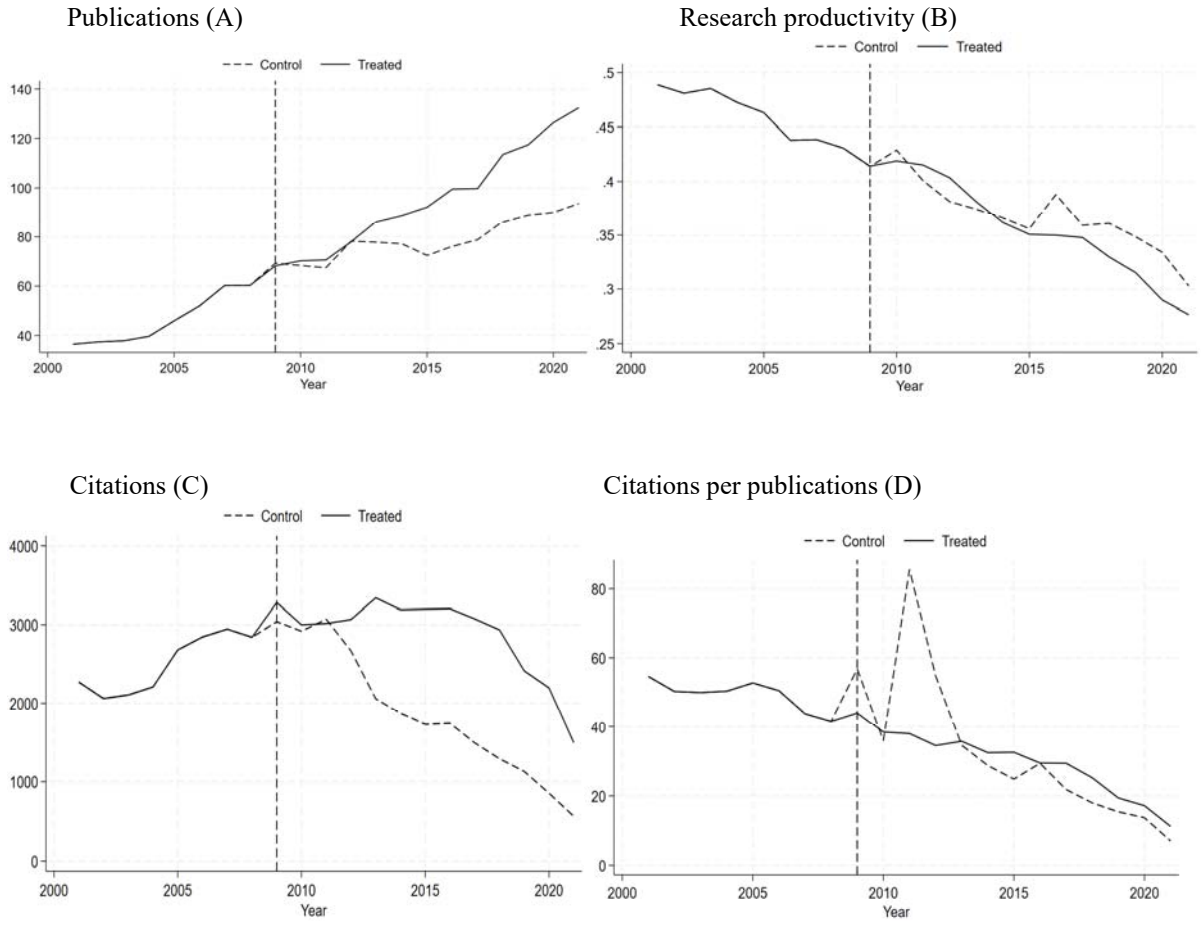

Fig 2. Synthetic DiD Analysis: Research Outcomes for All Publications under REFs

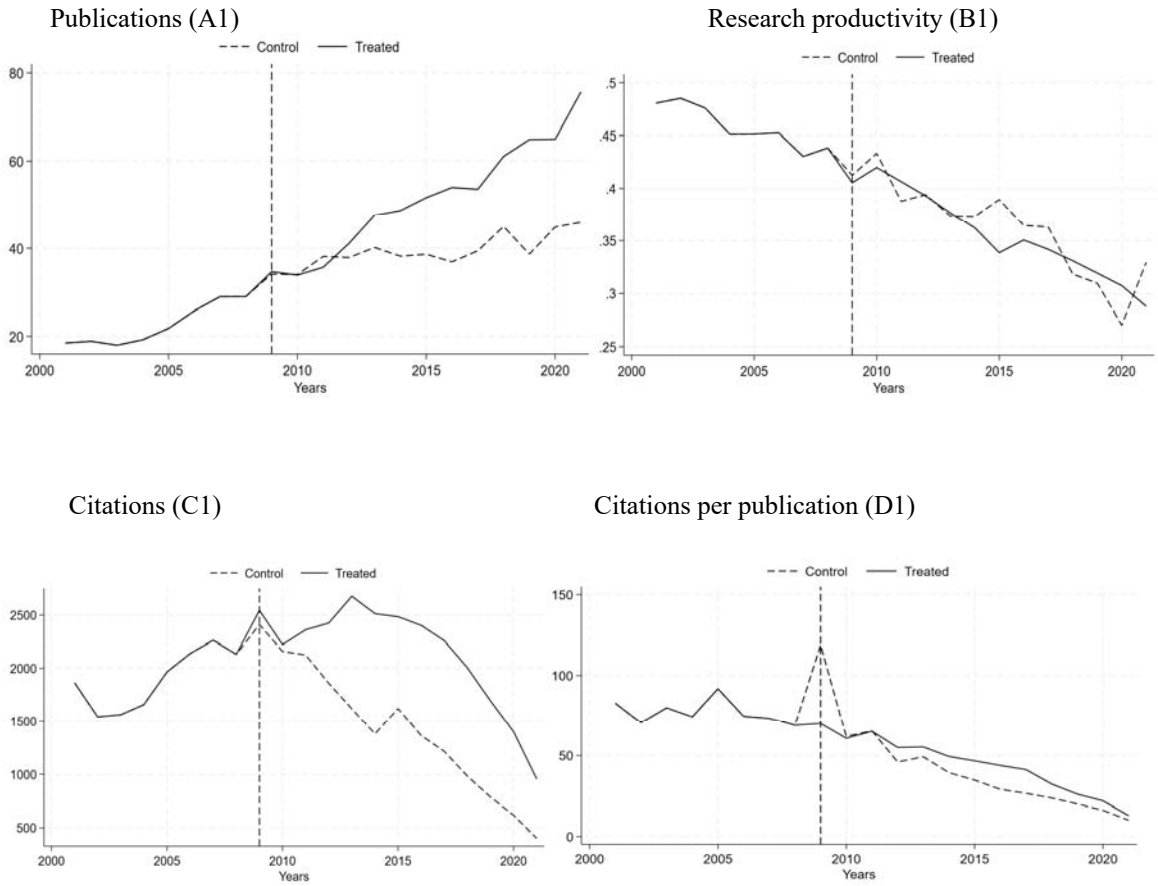

Fig 2A. Synthetic DiD Analysis: Research Outcomes for Top Publications under REF

5.1 Propensity Score Analysis: Assessing additionally the Impact of the REF on Research Outcomes

We investigate the influence of the REFs on research outcomes by analysing publications in different journals using various propensity score methods (PSM). The goal is to understand the ATT for both publications: "All" and "Top" publications. To ensure the robustness of our findings, we employ different PSM techniques, namely Probit, Logit, Probit with Neighbour Matching, Probit with Radial Matching, Probit with Kernel Matching, and Bootstrapping. The PSM estimates, and their implications can be found in Table 4 below.

Table 4 PSM Estimates: Impact of REF on Research Outcomes

ATT "All"	1	2	3	4	5	6
Publications	23.34***	22***	23.34***	23.34***	20.97***	23.34***
Res_productivity	-0.03***	-0.03***	-0.03***	-0.03***	-0.03***	-0.03***
Citations	-292.36	-363.74	-292.36	-292.36	-344.81	-292.36
Cit_Per_Pub	-15.48***	-16.3***	-15.48***	-15.48***	-15.47***	-15.48***
ATT "Top"	1	2	3	4	5	6
Publications	12.88***	14.33***	12.88***	11.94***	12.42***	12.88***
Res_productivity	-0.02***	-0.02***	-0.02***	-0.02***	-0.02***	-0.02***
Citations	-457.85	-308.62	-457.85	-457.85	-491.64**	-457.85
Cit_Per_Pub	-29.76***	-29.99***	-29.76***	-29.76***	-28.29***	-29.76***

P-value sig: 1% (***), 5% (**), and 10% (*); PSM methods: 1) Probit, 2) Logit, 3) Probit with Neighbour Matching, 4) Probit with Radial Matching, 5) Probit with Kernel Matching, and 6) Bootstrapping.

The results reveal statistically significant effects across all PSM methods for the number of publications in 'All' journals, with ATT estimates ranging from 20.97 to 23.34. Similarly, for "Top" publications, the estimates range from 11.94 to 14.33, indicating a considerable impact of the REFs on increasing research output. This aligns with previous studies that have demonstrated the positive influence of funding allocation mechanisms on research productivity (Checchi et al., 2019; Banal-Estañol et al., 2023). The findings suggest that the REFs have encouraged UK universities to produce more publications, particularly in prestigious journals, contributing to overall research excellence.

Furthermore, the research productivity results consistently show negative effects, with ATT estimates ranging from -0.02 to -0.03. This indicates that while the REFs have stimulated higher publication rates, it has also led to an increase in the number of authors per publication. This aligns with existing literature, which suggests that funding schemes like the REFs may foster more collaboration among researchers, diluting individual research productivity (Zhang et al., 2020; Banal-Estañol et al., 2023). Regarding citations, the results vary depending on the PSM method used. For 'All' publications, the ATT estimates range from -292.36 to -363.74, while for 'Top' publications, they range from -308.62 to -491.64. The difference in citation impact can be attributed to the time lag between publishing and citing papers. The acceleration in the rate of publications since the REF's initiation may have led to fewer citations per publication over the years, affecting the citation rate.

Additionally, the ATT estimates for citations per publication range from -15.48 to -16.30 for 'All' publications and from -28.29 to -29.99 for 'Top' publications. This suggests that the REFs

have motivated researchers to produce more publications, leading to higher citation rates but also indicating that citations typically take longer to accumulate.

Overall, our propensity score analysis demonstrates the substantial impact of the REFs on research outcomes in the UK higher education system. The statistically and economically significant results highlight the effectiveness of REFs in promoting research excellence and increasing scholarly output across various academic disciplines and journals.

5.2 Exacerbating Inequalities: An Analysis of Elite vs. Non-Elite Dynamics

PRFS are national incentive schemes that may have varying effects on individuals and organisations within the same field (Carli et al., 2019). The UK higher education system comprises around 130 universities, with diverse histories ranging from medieval establishments to more recent institutions. Among them, the Russell Group (see Appendix A) stands out as a set of 24 research-intensive universities (Banal-Estañol et al., 2023). As previously demonstrated, these universities exhibit superior research performance across all disciplines, including our two fields of interest.

In this section, we examine whether the PRFS in the UK contributes to reducing or exacerbating inequalities. While exceptional researchers may already possess the skills to produce high-quality publications and might not derive significant benefits from the incentive schemes, researchers at the other end of the spectrum, despite their efforts, may not be significantly impacted by these schemes if they fail to reach excellence standards. Additionally, the response to a PRFS is influenced by the extent to which organisations internally deploy incentives at the individual level and by the researchers' sense of belonging and identification with their organisation's objectives.

To investigate whether the REFs have contributed to the concentration of research in fewer universities, we conduct a separate analysis for universities belonging to the elite, research-intensive Russell Group and universities outside this Group, using a subsampling approach. The results of this analysis are presented in Table 5.

Table 5 Russel Vs Non-Russel ATTs (REF)

		1	2	3	4
Non-Russel	All	14.46***	-0.08***	-50.09	-16.05***
Russel	All	43.32***	-0.09***	-517.49**	-22.94***
Non-Russel	Top	12.99***	-0.09***	256.62	-25.02***
Russel	Top	24.41***	-0.07***	-418.56**	-35.20***

P-value sig: 1% (***), 5% (**), and 10% (*)
1=Publications, 2=Research Productivity,
3=Citations, 4=Citation per publication

Russell Group universities have experienced a substantial increase in the number of publications in both 'All' and 'Top' journals, surpassing non-Russell Group universities by nearly three times (ATTs: Russell: 43.32 and non-Russell: 14.46) and two times (ATTs: Russell: 24.41 and non-Russell: 12.99), respectively. The research productivity of both groups exhibits similar negative and significant ATTs, indicating an increase in publications relative to the number of authors due to the influence of the REFs initiatives. Regarding citations, Russell Group universities show negative and significant ATTs, while the effect is insignificant for non-Russell Group universities. Additionally, citations per publication display negative and significant ATTs for both groups. Notably, the ATTs for the Russell Group are significantly higher than the non-Russell Group, suggesting a greater volume of publications and more time required for citations to accumulate.

Our findings reveal a significant impact of the REFs on the number of publications in both 'All' and 'Top' journals for both Russell Group and non-Russell Group universities. However, the number of publications was notably higher among Russell Group universities, indicating that they have derived greater benefits from the REFs compared to non-Russell Group universities. In summary, the REFs have widened the gap between the Russell Group and non-Russell Group in terms of the number of publications in 'All' and 'Top' journals. This concentration of research excellence in a few elite universities has the potential to exacerbate existing inequalities within the higher education landscape.

6. Conclusion

Our results show that REFs promoted research performance in terms of quantity and quality. Compared to a synthetically created control group of US universities, the UK universities have demonstrated a sustained and consistent improvement in both the quantity and quality of research performance following the introduction of REF. UK universities experienced a

substantial rise in research output, primarily during the REFs treatment period (2009-2021). These findings support the claim that the REFs have influenced universities' hiring decisions, as we observe an increase in the number of active researchers, likely driven by universities' hiring policies (La Manna, 2008). Our findings show a decline in research productivity per author, essentially due to high collaboration among researchers leading to an increased number of authors per publication. As a result, individual research productivity declined, but overall research output improved. Citations increase significantly overall in response to the REFs, but yearly trends show declines, likely due to publication-citation lag and increased publication rates. However, the citation impact remains positive and significant.

Finally, our analysis reveals disparities between Russell Group and non-Russell Group universities in terms of the influence of REFs on research outcomes. Russell Group institutions have seen a substantial increase in publications, especially in prestigious journals, while non-Russell Group universities have experienced a relatively more modest growth. Both groups, however, have observed a decrease in research productivity per author due to increased collaboration. Citations have been negatively affected for Russell Group institutions, while there has been no significant change for non-Russell Group universities. Furthermore, both groups have experienced a decline in citations per publication.

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Appendix 1: Additional Tables

Table 1A A brief overview of global PRFS

Country	Year	PRFS Name	Assessment Type	Assessment Level	Key Assessment Aspects
Australia	1995–2009	CI Composite Index	Bibliometric	University	Quantity and quality of research publications (Geuna and Piolatto, 2016)
Australia	2010-present	ERA Excellence in Research	Peer-review	Department	Research outputs vis a vis national and international benchmarks (Soderlind et al., 2019)
Belgium	2003-present	BOF-key	Bibliometric	University	Master degrees, defended doctorates, gender diversity, publications, citations (Geuna and Piolatto, 2016)
Canada	2006-present	RPT Research Performance	Peer-review	University	Research output, training of highly qualified personnel, knowledge and technology transfer (Schimanski and Alperin, 2018)
Croatia	2013-present	Scientific Production	Bibliometric	University	Scientific production, citations, doctoral graduates, research projects, commercialization (Geuna and Piolatto, 2016)
Czech Republic	2013-present	NERO National Evaluation	Bibliometric	University	Publications (impact factor), grants, patents (Geuna and Piolatto, 2016)
Denmark	2009-present	BFI Bibliometric	Bibliometric	University	External research funding, PhD production, student throughput (Geuna and Piolatto, 2016)
Estonia	2012-present	Research Excellence (RE)	Bibliometric	University	High-level publications, research monographs, patents, funding, doctoral graduates (Zacharewicz et al., 2019)
Finland	2010-present	National Research Indicator	Bibliometric	University	Educational and research performance, external funding, PhD production (Zacharewicz et al., 2019)
France	2008-present	Quality Assessment	Peer-review	Department	Research quality indicators, citations, grants, societal openness (Soderlind et al., 2019)
Italy	2001–2010	VTR Valutazione Triennale	Peer-review	Department	Output assessment (Geuna and Piolatto, 2016)
Italy	2011-present	VQR Valutazione della Qualità	Peer-review	Department	Quality assessment (publications, citations, funding, international collaboration) (Soderlind et al., 2019)
Japan	2003-present	QAP Quality Assessment	Peer-review	Department	Research quality, significance, productivity, and effectiveness (Japan Society for the Promotion of Science)
Lithuania	2009-present	Research Performance	Bibliometric	University	Quality and quantity of research publications (Geuna and Piolatto, 2016)
Netherlands	2010-present	Evaluation Quality in Science	Peer-review	Department	Quality and societal relevance of research, knowledge transfer (Netherlands Organization for Scientific Research (NWO))
New Zealand	2003-present	PBRS Performance-Based	Peer-review	University	Research quality, peer esteem, research degree completions, external research income (Soderlind et al., 2019)
Norway	2005-present	Performance-Based	Bibliometric	University	Teaching and research indicators, PhDs, research council funding (Soderlind et al., 2019)

Poland	2008-present	Parametric Evaluation	Bibliometric	Department	Publications (impact factor), patents, funding, scientific awards, PhD degrees (Geuna and Piolatto, 2016)
Portugal	2015-present	Research Unit Evaluation	Peer-review	Department	Academic performance, strategic plan submission (Soderlind et al., 2019)
Singapore	2007-present	APH A*STAR Performance	Peer-review	Research Agency	Research output, impact, strategic alignment (Agency for Science, Technology and Research (ASTAR))
Slovakia	2013-present	Research Output Quality	Bibliometric	Department	Publications, citations, research monographs, international patents (Geuna and Piolatto, 2016)
South Korea	2011-present	KEF Knowledge Evaluation	Peer-review	University	Research impact, outcome, and relevance (Soderlind et al., 2019)
Sweden	2009-present	FOKUS Forskningskvalitetsutvärdering	Bibliometric	University	Publication and citation counts, external funding (Soderlind et al., 2019)
Switzerland	2013-present	SNSF National Research	Peer-review	Research Agency	Research quality, originality, significance, methodology (Swiss National Science Foundation (SNSF))
United Kingdom	1986–2008	RAE Research Assessment	Peer-review	Department	Research output assessment (Hicks, 2012)
United Kingdom	2009-present	REF Research Excellence	Peer-review	Department	Output, impact and environment (Hicks, 2012)

Table 2A: List of Russell Group Universities in the UK

No.	University	Location
1	University of Oxford	Oxford
2	University of Cambridge	Cambridge
3	Imperial College London	London
4	University College London (UCL)	London
5	University of Edinburgh	Edinburgh
6	University of Manchester	Manchester
7	University of Birmingham	Birmingham
8	University of Bristol	Bristol
9	University of Leeds	Leeds
10	University of Sheffield	Sheffield
11	University of Warwick	Coventry
12	King's College London	London
13	Queen Mary University of London	London
14	University of Nottingham	Nottingham
15	University of Southampton	Southampton
16	University of Exeter	Exeter
17	University of Liverpool	Liverpool
18	Durham University	Durham
19	Newcastle University	Newcastle upon Tyne
20	Queen's University Belfast	Belfast
21	Cardiff University	Cardiff

22	University of Glasgow	Glasgow
23	University of Bath	Bath
24	London School of Economics and Political Science (LSE)	London

Table 3A. List of selected UK and US universities

No	UK Universities	No	USA Universities
1	Anglia Ruskin University	1	Harvard University
2	Aston University	2	Massachusetts Institute of Technology
3	University of Bath	3	University of California-Berkeley
4	University of Bedfordshire	4	University of Chicago
5	Birmingham City University	5	Stanford University
6	Bournemouth University	6	Princeton University
7	University of Bradford	7	Columbia University
8	University of Brighton	8	Yale University
9	Birkbeck College	9	New York University (NYU)
10	University of Birmingham	10	Brown University
11	University of Bristol	11	University of Pennsylvania
12	Brunel University London	12	Boston University
13	University of Cambridge	13	University of Southern California
14	University of Central Lancashire	14	University of California-San Diego
15	University of Chester	15	Northwestern University
16	City University London	16	University of California-Los Angeles (UCLA)
17	Coventry University	17	University of Michigan
18	Cranfield University	18	Columbia University
19	University of Cumbria	19	University of California-Davis
20	University of Derby	20	Duke University
21	University of Durham	21	University of Wisconsin-Madison
22	University of East Anglia	22	Michigan State University
23	University of East London	23	Cornell University
24	University of Essex	24	Vanderbilt University
25	University of Exeter	25	University of Maryland
26	University of Greenwich	26	University of California-Irvine
27	University of Hertfordshire	27	Johns Hopkins University
28	University of Huddersfield	28	Georgetown University
29	University of Hull	29	University of Texas-Austin
30	Imperial College London	30	Pennsylvania State University
31	Keele University	31	University of California-Santa Barbara (UCSB)
32	University of Kent	32	University of Notre Dame
33	King's College London	33	University of Virginia
34	Kingston University	34	University of Minnesota
35	Lancaster University	35	New York University
36	University of Leeds	36	University of California-Santa Cruz (UCSC)
37	Leeds Beckett University	37	Ohio State University
38	University of Leicester	38	Washington University in St. Louis
39	University of Lincoln	39	University of Washington
40	University of Liverpool	40	University of Colorado
41	University College London	41	Arizona State University

42	London Business School	42	George Washington University
43	London School of Economics and Political Science	43	Georgia State University
44	London Metropolitan University	44	George Mason University
45	London South Bank University	45	Texas A&M University
46	Loughborough University	46	University of Pittsburgh
47	University of Manchester	47	Iowa State University
48	Manchester Metropolitan University	48	University of Southern California
49	Middlesex University	49	Purdue University
50	Newcastle University	50	Chapman University
51	University of Northampton	51	Indiana University
52	University of Northumbria at Newcastle	52	California Institute of Technology
53	University of Nottingham	53	University of Oregon
54	Nottingham Trent University	54	University of Arizona
55	Open University	55	University of Rochester
56	School of Oriental and African Studies	56	Tufts University
57	University of Oxford	57	University of Connecticut
58	Oxford Brookes University	58	University of Kentucky
59	University of Plymouth	59	Brandeis University
60	University of Portsmouth	60	Clemson University
61	Queen Mary University of London	61	University of Illinois at Urbana-Champaign
62	University of Reading	62	University of Houston
63	Roehampton University	63	University of Missouri
64	Royal Holloway, University of London	64	Drexel University
65	University of Salford	65	University of Georgia
66	University of Sheffield	66	University of North Carolina-Chapel-Hill
67	Sheffield Hallam University	67	Tulane University
68	University of Southampton	68	Rice University
69	Staffordshire University	69	University of Wyoming
70	University of Sunderland	70	Florida State University
71	University of Surrey	71	University of Delaware
72	University of Sussex	72	University of Miami
73	Teesside University	73	City University of New York (CUNY)
74	University of Warwick	74	Southern Methodist University
75	University of the West of England, Bristol	75	University of Illinois at Chicago
76	University of Westminster	76	Carnegie Mellon University
77	University of Wolverhampton	77	Johns Hopkins University
78	University of Worcester	78	University of Michigan
79	University of York	79	State University of New York-Binghamton
80	York St John University	80	Northwestern University
81	University of Aberdeen	81	University of Hawaii-Manoa
82	University of Dundee	82	University of Wisconsin
83	University of Edinburgh	83	American University
84	Edinburgh Napier University	84	University of Texas-Dallas
85	University of Glasgow	85	Stony Brook University – SUNY
86	Glasgow Caledonian University	86	University of Kansas
87	Heriot-Watt University	87	Appalachian State University
88	University of St Andrews	88	University of Massachusetts-Amherst

89	University of Stirling	89	North Carolina State University
90	University of Strathclyde	90	Indiana University
91	University of the West of Scotland	91	West Virginia University
92	Aberystwyth University	92	Utah State University
93	Bangor University	93	Auburn University
94	Cardiff University	94	University of Florida
95	University of South Wales	95	University of California-Merced
96	Swansea University	96	University of South Carolina
97	Queen's University Belfast	97	Santa Clara University
98	University of Ulster	98	Colorado State University
		99	University of Tennessee-Knoxville
		100	Louisiana State University
		101	Duke University
		102	Indiana University-Purdue University (IUPUI)
		103	Oklahoma State University
		104	University of Richmond
		105	University of North Carolina-Greensboro
		106	University of New Mexico
		107	University of Nevada-Reno
		108	Virginia Commonwealth University
		109	University of Maryland-Baltimore County
		110	Baylor University
		111	Georgia Institute of Technology
		112	City University of New York (CUNY)
		113	Sam Houston State University
		114	Florida International University
		115	Colorado School of Mines
		116	University of Nebraska-Omaha