Working Papers in Economics & Finance
No. 2024-08

Research Excellence Framework (REF), International Research Collaborations and Female Participation

Ajab Khan, University of Portsmouth

Ali Sina Önder, University of Portsmouth

Sercan Ozcan, University of Portsmouth

Portsmouth Business School
https://www.port.ac.uk/about-us/structure-and-governance/organisational-structure/our-academic-structure/faculty-of-business-and-law/portsmouth-business-school

Research Excellence Framework (REF), International Research Collaborations and Female Participation

Ajab Khan
University of Portsmouth
Solent University

Ali Sina Önder
University of Portsmouth
Uppsala Center for Fiscal Studies

Sercan Ozcan
University of Portsmouth

Abstract

This study investigates the causal effects of the United Kingdom's (UK) Research Excellence Framework (REF) on international research collaborations and female participation in these collaborations in peer-reviewed journal publications in Economics and Business. Using synthetic difference-in-differences and propensity score matching, we analyze data from 98 UK universities (treated) and 116 US universities (control) from 2001 to 2021. Our results show that REF has significantly increased international collaborations by 20.4 percentage points and female participation in these collaborations by 5.6 percentage points across UK universities. Our results also reveal disparities between Russell Group and non-Russell Group universities, with Russell Group universities experiencing a more pronounced effect on fostering female participation in international collaborations. This study contributes to the existing literature by providing causal evidence on the effects of performance-based research funding systems on international collaborations and gender diversity in these collaborations.

JEL codes: I23; O38; J16; O32

Keywords: Performance-Based Research Funding; International Research Collaborations; Female Participation

1. Introduction

Gender disparities in the academic labor market persist, particularly in economics and business fields. Despite initial progress, women's advancements in academic economics have stagnated since the 1990s (Lundberg and Stearns, 2019). Such disparities exist in various forms, including career progression, publishing rates, and collaboration patterns (Ginther and Kahn, 2004; Hengel, 2022; Ductor et al., 2021). Within this context, international research collaborations (IRC) and female participation in international research collaborations (FIRC) have emerged as crucial factors in academic productivity and career advancement. Despite promising trends (Önder et al., 2021), male researchers dominate IRC. This disparity persists because women face 'glass fences,' invisible barriers that obstruct their participation in international collaborations due to societal expectations, lack of support structures, and gender biases (Uhly et al., 2017; Kwiek and Roszka, 2021). Furthermore, women tend to coauthor with other women, which may prevent their access to broader networks of male collaborators (Boschini and Sjögren, 2007) and thus persist their networks' vulnerability to research that has high uncertainty (Lindenlaub and Prummer, 2021).

Many countries[1] have implemented performance-based research funding systems (PRFS) to incentivize high-quality research by prioritizing IRC as a key metric (Abramo and D'Angelo, 2023). However, the impact of PRFS on IRC and FIRC remains a subject of debate in the academic community. We address this gap by estimating the causal effects of the United Kingdom's (UK) Research Excellence Framework (REF), one of the large-scale implemented PRFSs, on IRC and FIRC in the fields of economics and business. Building on Ductor et al.'s (2021) work on gender and collaboration networks and our earlier work that examines the causal effects of REF on the overall research productivity (Khan et al., 2023), we investigate how PRFS impacts collaboration networks and potentially alters gender diversity in international collaborations.

The REF, implemented in 2014 as a successor to the Research Assessment Exercise (RAE), serves as a plausible case study for examining the impacts of PRFS on research practices and outcomes. As a system that assesses research quality and determines funding allocation, the REF creates strong financial incentives that may influence researchers' behaviour, including

[1] See Table A1 in Appendix A for a comprehensive overview of countries with PRFS and the associated literature.

their propensity to engage in IRC and their choices of collaborators (Stern, 2016). To estimate the causal effects of the REF, we employ synthetic difference-in-differences (SDiD) (Arkhangelsky et al., 2021) complemented with propensity score matching (PSM). This approach allows us to address issues such as time-varying confounders and potential selection biases, providing a robust framework for causal inference. We collect publication and institutional data from 98 UK universities (treated group) and 116 United States (US) universities (control group) in economics and business fields from 2001 to 2021, encompassing both the REF 2014 and REF 2021 cycles. Since there is no nationwide PRFS in the US, we use US universities to establish a suitable counterfactual to the UK ones using the SDiD by assigning weights to US universities based on their similarity to UK institutions.

Our findings reveal that the REF has had a significant and positive impact on IRC and FIRC across UK universities. Specifically, we find that the average treatment effect (ATT) of 0.204 for IRC, corresponding to an increase of 0.55 standard deviations, demonstrates a higher intensity of IRC among UK universities post-REF. Furthermore, we also observed a statistically significant ATT of 0.056 for FIRC, equivalent to an increase of 0.49 standard deviations due to REF. Importantly, our results indicate a substantial enhancement of FIRC within the Russell Group compared to non-Russell universities, providing valuable insights into the effects of the REF on different types of institutions.

Our study contributes to the existing literature in several ways. First, we extend the work on gender disparities in academic publishing by providing causal evidence on how PRFS, like the UK REF, affect IRC and FIRC. Second, we demonstrate how institutional policies can shape collaboration patterns, potentially mitigating the 'Publishing Paradox' identified by Hengel (2022). Our results imply that policies like the REF can significantly alter collaboration networks and potentially counteract some of the biases in academic publishing. Third, our analysis of disparities between Russell Group[2] and non-Russell Group universities contributes to the discussion on inclusivity in research evaluation, highlighting how PRFS can have differential effects on elite and non-elite institutions. These insights advance our understanding of how institutional policies can address gender disparities not only in academic publishing but also in academia in general and offer valuable guidance for policymakers seeking to promote both research excellence and inclusivity in higher education.

[2] Russell Group. (n.d.) https://russellgroup.ac.uk/about/our-universities/

The remainder of this paper is structured as follows: Section 2 provides the context and motivation. Section 3 presents a comprehensive literature review and development of hypotheses. Section 4 describes our data and methodology in detail. Section 5 presents the estimation methodology. Section 6 provides results and analysis. Section 7 presents disparities between Russell and non-Russell Group universities. Finally, section 8 concludes with policy recommendations and directions for future research.

2. The Academic Context and Motivation

In the rapidly evolving global research landscape, IRC and FIRC have become critical factors in advancing scientific knowledge and innovation. IRC has significantly enhanced research quality, impact, and citation rates (Wagner et al., 2018). These collaborations foster diverse expertise and perspectives, leading to more innovative and robust research outcomes (Adams, 2013).

Simultaneously, the importance of gender diversity in research teams has gained increased recognition. Studies suggest that diverse research teams produce higher-quality scientific outputs and more creative problem-solving approaches (Nielsen et al., 2017a). However, women remain underrepresented in many scientific fields, particularly in international collaborations (Uhly et al., 2017).

In this context, the UK's REF, a PRFS, plays a pivotal role in shaping the country's research landscape, including patterns of international collaboration and gender dynamics in academia. Evolved from the Research Assessment Exercise (RAE) initiated in 1986, the REF was introduced in 2014, focusing on outputs, impact, and research environment (Stern, 2016).

Recent studies indicate that the REF has not only encouraged high-quality research but also promoted effective international collaborations (Marques et al., 2017). This aligns with broader research on the relationship between government funding and international collaboration in scientific research (Zhou et al., 2020), which has found that funding can significantly influence patterns of international cooperation. The impact component of the REF, in particular, has fostered engagement with international partners and wider society, aiming to bring about positive socio-economic change. This emphasis on global partnerships and knowledge

exchange fosters a sense of optimism and global connectedness among researchers (Guthrie et al., 2013).

Furthermore, research has shown that funding can have complex effects on research collaboration and impact. Álvarez-Bornstein and Bordons (2021) found that funding is related to higher research impact, with collaboration playing a mediating role. Similarly, Davies et al. (2022) examined how research funding influences collaboration patterns, providing insights that may be applicable to the international context of our study.

The REF encourages institutions to consider impact beyond academia, signifying the global reach and importance of their research. Consequently, UK HEIs have enhanced their reputation worldwide, attracting international researchers and facilitating more effective collaborations (Elezi and Bamber, 2018). Moreover, the REF has prompted UK institutions to adopt international best research practices, further facilitating collaborations with overseas authors (Marques et al., 2017).

Despite these positive outcomes, the influence of REF on equality in research is complex and challenging. The policy framework of REF emphasizes promoting equality, diversity, and inclusion (EDI) in research (Arnold et al., 2018). A comprehensive understanding of the REF's influence on female researchers is crucial, as it underlines the complexity of the system and the challenges it presents. Evidence suggests that PRFS may inadvertently widen gender gaps in research performance. The Bibliometric Research Indicator in Denmark by Nielsen (2017b) found female researchers at a disadvantage due to gender differences in collaborative networks. This implies that PRFS may not suffice to adequately capture or reward the collaborative patterns among female researchers especially. Furthermore, women and early career researchers face hurdles in collaborative research due to less extensive networking. For instance, Kim and Bak (2017) found that women researchers are at a disadvantage in the collaboration-based incentives in South Korea, which redirected researchers away from solo work. These findings align with broader research on the relationship between funding, productivity, and gender in science. Lawson et al. (2021) found that funding can have different impacts on male and female researchers, potentially exacerbating existing gender disparities. Moreover, Johnson et al. (2014) demonstrated that changes in research funding policies can significantly impact the integration of gender considerations in research. These studies raise important questions about how funding systems like the REF might affect FIRC specifically.

Interestingly, while women tend to collaborate in most forms, their presence in international collaborations remains relatively low compared to their male counterparts (Abramo et al., 2013). This suggests that there may be unique barriers for FIRC, which require further investigation in the context of the REF. Understanding these barriers is crucial for designing funding systems that can enhance research excellence through international collaborations while promoting gender equity.

The mixed findings underscore the need to examine REF's role in influencing female researchers in UK universities to participate in international collaborations. This understanding of the intricate dynamics of REF is not only crucial but also inspiring, as it is key to designing REF that may bring further research excellence through IRC and promote FIRC.

3. Literature Review

The economics literature has extensively examined gender disparities in academic labor markets, particularly in economics and business fields. Despite initial progress, women's progress in academia has relatively stagnated since the 1990s (Lundberg and Stearns, 2019), with persistent gaps in various aspects of academic careers, including collaborative endeavours on research projects.

Bayer and Rouse (2016) provide a comprehensive overview of the state of diversity in economics. Their study highlights the persistent underrepresentation of women and minorities in economics, emphasizing the need for systemic changes to address these longstanding issues. Ginther and Kahn (2004) provided a seminal analysis of gender differences in economics careers. Using data from the Survey of Doctorate Recipients, they used linear probability regressions to examine gender gaps in promotion rates. Their findings revealed substantial disparities, with women 21% less likely to be promoted to tenure when controlling for productivity. This work highlighted the structural barriers facing women in academia, the potential role of statistical discrimination, and differences in institutional support.

Hengel (2022) investigated implicit biases in the publishing process, a crucial determinant of academic career progression. She analyzed readability scores of published articles in top economics journals using a differences-in-differences approach. Her results showed that female-authored papers are held to higher standards, taking three to six months longer in peer

review despite being better written. This "publishing paradox" demonstrates how subtle biases in evaluation processes can accumulate to create significant career disadvantages for women.
Collaboration patterns play a critical role in academic productivity and career advancement. Boschini and Sjögren (2007) examined gender homophily in economics collaborations, finding that women are more likely to coauthor with other women. While potentially beneficial for mentorship, this tendency may limit access to broader networks and resources. Abramo et al. (2013) further explored gender differences in research collaboration, providing additional context on how these patterns vary across fields and career stages.

Ductor et al. (2021) provided deeper insights into the network dynamics underlying research collaboration. They developed a theoretical model of coauthorship formation and tested it using a comprehensive dataset of economics publications. Through pooled OLS, they found that women have fewer collaborators and are more likely to form new collaborations with coauthors of coauthors. This network structure can perpetuate existing gender gaps and limit women's access to high-impact collaborations.

The allocation of credit for collaborative work presents another challenge. Sarsons et al. (2021) used observational data on economists' CVs to show that women receive less credit for coauthored work, especially when collaborating with men. This "attribution bias" can significantly impact career progression. Similarly, Hussey et al. (2022) found that female economists experience lower returns to coauthorship in terms of tenure and promotion outcomes.

These disparities extend beyond publication to other aspects of academic visibility. Hospido and Sanz (2021) analyzed submissions to economics conferences, finding significant gender gaps. They showed that all-female-authored papers are less likely to be accepted, even after controlling for quality indicators. This reduced conference participation can limit networking opportunities and visibility, which are crucial for career advancement. Similarly, Doleac et al. (2021) examined gender disparities in invited talks at economics seminars. Their study revealed a significant underrepresentation of women among invited speakers, further highlighting women's challenges in gaining visibility and recognition in the field.

In the context of international collaborations, Kwiek and Roszka (2021) employed an analytical, linear logistic model to analyze a large-scale dataset of Polish university professors

from 85 universities. They found that gender disparities in international research collaboration increase with age and academic position, suggesting cumulative disadvantages for women throughout their careers. This is particularly relevant given the growing importance of international collaborations in academia, as highlighted by Leydesdorff and Wagner (2008).

The impact of PRFS on these collaboration patterns and gender disparities remains an open question. While PRFS aim to incentivize research excellence, this may inadvertently exacerbate existing inequalities. Nielsen (2017) compared publication counts to bibliometric indicator points in Denmark, finding that the new system widened gender gaps in research performance. However, some studies have found positive impacts of funding systems on female participation (Zhang et al., 2020; Bührer and Frietsch, 2020), highlighting the complex relationship between funding mechanisms and gender equity in research.

Furthermore, the link between international collaborations and research performance has been established by studies such as Cimini et al. (2016) and Eisend and Schmidt (2014), underscoring the importance of understanding how PRFS might influence these collaboration patterns.

Our study builds on this literature by providing causal evidence on how PRFS, specifically the UK's REF, affects IRC and FIRC. We employ novel methodological approaches - SDiD and PSM - to address endogeneity concerns and isolate the causal effects of the REF.

Drawing on resource dependence theory (Pfeffer and Salancik, 2015) and institutional theory (DiMaggio and Powell, 1983), we posit that the REF incentivizes universities to foster IRC and promote FIRC. However, the differential effects on elite versus non-elite institutions may exacerbate existing inequalities.

4. Methodology and data

To estimate the incremental impact of REF schemes (i.e., REF 2014 and REF 2021) on IRC and FIRC in research teams, our study considers 2001-2008 as the 'pre-treatment' period and 2009-2021 as the 'treatment' period. The 'pre-treatment' period refers to the time before the significant transition from the RAE to the REF in 2009, while the 'treatment' period is the time after this transition. This unique approach allows us to observe and measure the changes in IRC and FIRC that can be attributed to the introduction of the REF.

Our dataset is derived following our previous work (Khan et al., 2023), which is based on extending Banal-Estañol et al.'s (2023). Our study includes 461,861 unique publications authored by 237,216 individuals and published in 2,519 journals between 2001 and 2021. While Banal-Estañol et al. focused on the impact of REF 2014, and our previous study extended this to analyze overall research productivity through REF 2021, the current study leverages this rich dataset to specifically examine the causal influence of REF on IRC and FIRC in research teams.

Our sample includes 98 UK HEIs and 116 US universities as a control group, consistent with both Banal-Estañol et al. (2023) and our previous study (Khan et al., 2023) approach. The US universities serve as a control group as they are not subject to any PRFS systems, providing a counterfactual group that closely matches the characteristics of the UK universities. In the UK context (treated group as the UK universities are subject to UK's PRFS-i.e., REF since 2009), we utilize the data collected in the fields of Economics and Econometrics (Panel 18) and/or Business and Management (Panel 19). For the US universities, we consider top-quartile economics departments and business schools to establish a comparative benchmark based on the December 2018 RePEc rating. By doing so, we can compare the performance of universities that follow the REF with a counterfactual group, the US universities, thereby enhancing the validity of our causal inferences.

Additionally, in our analysis, we utilize the genderize.io web service, a tool known for its precision and accuracy, to identify the gender of researchers based on their first names. This service provides a confidence score for each prediction, ensuring the reliability and accuracy of our gender identification process. With this reliable tool, we were able to study the gender makeup of authorship teams involved in international collaborations and examine changes in female participation over time, especially after the introduction of the REF, with a high degree of confidence in our results.

PRFS encourages HEIs to foster a culture of research excellence. In response, most universities collaborate globally to produce high-quality research, leveraging diverse resources and researchers' distinct expertise in various fields (Leydesdorff and Wagner, 2008; Zhou et al., 2020). Female participation, in particular, is paramount in such collaborations as women often bring unique perspectives to problem-solving and idea generation (Abramo et al., 2013;

Restrepo et al., 2021). Several theoretical frameworks underscore why the UK's REF is crucial in understanding its influence on IRC and FIRC. For instance, institutional theory implies that organizations adapt to external pressures and expectations to establish legitimacy and acquire resources (DiMaggio and Powell, 1983). This adaptability of organizations is a reassuring sign that they can align with the set criteria by the funding bodies, potentially affecting the patterns of IRC and FIRC. Additionally, resource dependence theory (RDT) posits that organizations' behaviours are influenced by their need to secure critical resources from the external environment (Pfeffer and Salancik, 2015). In this context, the HEIs' reliance on PRFS may necessitate collaboration with other researchers to secure more expertise and resources, primarily through IRC and FIRC in research teams.

In the UK context, REF's emphasis on fostering research quality, impact, and the environment by promoting IRC and upholding a commitment to equality, diversity, and inclusion (EDI) in academia may influence IRC and FIRC patterns. However, as our literature review has shown, the effects of PRFS on IRC and FIRC are not uniformly positive across different contexts. Some studies have found negative or neutral effects, highlighting the complexity of these relationships.

The influence of PRFS on IRC and FIRC warrants immediate and thorough empirical investigation to isolate the effects of the UK's REF on these collaborations. Based on these theoretical foundations and the mixed findings in the literature, we propose the following hypotheses:

Hypothesis 1: The implementation of the UK's REF has significantly increased the international research collaborations among the UK HEIs.
Hypothesis 2: The UK's REF has significantly increased female participation in international research collaborations among the UK HEIs.

We control for income and expenditure following the approach of Banal-Estañol et al. (2023) and our previous study (Khan et al., 2023), as these factors significantly impact universities' research capabilities and outcomes. Income sources include grants, investment income, and donations, while expenditure covers staff costs, operating expenses, and other financial outlays. These variables help align UK and US universities, creating more comparable groups and enhancing our ability to isolate the causal impact of the REF.

In the SDiD method, these variables help in constructing a more accurate synthetic control group (Arkhangelsky et al., 2021). For the PSM approach, we use these variables to calculate propensity scores, ensuring that we compare UK universities with US counterparts that have similar resource profiles (Rosenbaum and Rubin, 1983; Dehejia and Wahba, 2002).

By controlling for these financial factors, we can more confidently attribute observed differences in IRC and FIRC to the implementation of the REF rather than to disparities in institutional resources. This enhances the validity and robustness of our causal inferences about the impact of PRFS on IRC and FIRC in academia.

5. Estimation Strategy

According to our data, the average IRC and FIRC in both UK universities (treated group) and US universities (control group) increased during both REF (i.e., 2014 and 2021) assessment periods. This increase may be attributable to the commencement of REF. However, it may also be associated with other factors, such as publications in indexed journals (Hammarfelt and de Rijcke, 2015) due to IRC among researchers and the involvement of FIRC, as well as increases in universities' revenues, excluding research funding and/or journals covered by Scopus. Including US universities in the study serves as a control group, allowing us to isolate the effects of the REF on UK universities. Interestingly, the number of IRC and FIRC also increased for US HEIs despite being unexposed to any PRFS, which indicates that the productivity of UK, as well as US universities, may have been subject to similar trends that are driven by factors other than the explicit incentives provided by the REF. Hence, the analysis necessitates a method that distinguishes between the outcomes (IRC and FIRC) that would have occurred independently of the implementation of the REF and those directly attributable to the intervention. Below, we illustrate our method for making empirical estimates.

Our research relies on the detailed SDiD methodology (Arkhangelsky et al., 2021) to assess the causal impact of the REF on IRC and FIRC at UK universities. This method involves creating a synthetic control group to enhance the reliability of our findings. We begin by identifying a pool of potential control units (US universities) and then use a sophisticated matching algorithm to assign weights based on universities' income and expenditure

(Arkhangelsky et al., 2021). This produces a synthetic control group that accurately reflects the pre-treatment (2001-2008) outcomes of the treated UK universities. This meticulous approach reduces the need for a strict parallel trend assumption, ensuring that the synthetic control group effectively represents the scenario in which UK university outcomes would have evolved without the REF.

The SDiD methodology incorporates time weights to consider changes over time in outcomes (Arkhangelsky et al., 2021). These weights are assigned to each time period and help to align the periods before treatment (2001-2008) and after treatment (2009-2021) for both the treated and synthetic control groups. By focusing on periods where the treatment effect is expected, time weights enhance the creation of a strong comparison scenario. The adaptability of the SDiD methodology ensures its effectiveness in various research contexts, highlighting its versatility and broad applicability, which provides reassurance about its robustness.
Finally, we use a two-way fixed-effects regression model with a constructed synthetic control group to estimate the REF's causal effect on IRC and FIRC. This model considers unit and time weights to estimate the REF's Average Treatment Effect (ATT) on research outcomes (IRC and FIRC) at UK universities. What makes this model unique is its 'local' approach, which focuses on units and time periods that are most similar to the treated universities. This tailored approach, specific to the context of UK universities, is crucial as it enables us to concentrate on the most relevant comparisons, resulting in more accurate estimates and providing a high level of confidence in the validity of our results.

In line with our approach, we have developed a step-by-step process to identify a smaller, more reliable set of control units for matching. We initially used the synthetic control approach for all 98 treated units, leveraging all 116 US universities as potential control units for each outcome. Afterwards, we refined our control set by removing US universities that did not significantly contribute to creating optimal synthetic units for any of the outcomes. We repeated this process iteratively until we identified a consistent set of 23 US universities, ensuring robust controls that could shape the synthetic unit for at least one UK university and one outcome.

We also use the PSM method to complement the SDiD for assessing the causal impact of the REF on IRC and FIRC within UK universities. This method is particularly suitable for our

study as it allows us to control for factors that might influence a university's propensity to engage in IRC or promote FIRC in research teams.

We follow several steps in PSM tailoring to focus on estimating the REF on IRC and FIRC. First, we compute the propensity scores for each UK university based on factors such as income and expenditure that might influence IRC and FIRC in research teams (Rosenbaum and Rubin, 1983). These scores are crucial because they ensure the comparability of the universities during pre-REF in the treated group to those in the control group. Second, we pair UK universities with US counterparts that have similar propensity scores. This matching is crucial for creating comparable groups, particularly in terms of their pre-existing tendencies towards IRC and FIRC. We conduct tests to ensure that the matched groups are similar in terms of covariates. Third, we compare IRC and FIRC outcomes between matched groups (i.e., the treated universities and the synthetic control group before (2001-2008) and after (2009-2021) the REF. This comparison allows us to isolate the REF's impact on IRC and FIRC in the research landscape. While it is challenging to control for all potential time-varying unobserved differences completely, we minimize potential biases by including relevant control variables such as income and expenditure. Fourth, we employ 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 to ensure the robustness of our findings related to IRC and FIRC. We utilize common support to ensure that we compare UK universities affected by the REF with US institutions with similar propensities for IRC and FIRC. Focusing on this overlapping subset strengthens the reliability of our analysis and improves the credibility of our findings (Smith and Todd, 2005).

6. Results and analysis

6.1 Descriptive statistics

To evaluate IRC, we examine publications involving authors affiliated with institutions from multiple countries based on the authors' listed addresses. Furthermore, we assess female participation in these collaborations, a key aspect of our study, by computing the ratio of female authors involved in such collaborative works. This allowed us to analyse not only the extent to which institutions engaged in IRC but also the level of gender diversity and inclusion within these cross-border collaborative efforts.

Table 2 presents descriptive statistics for IRC, FIRC, income, and expenditure for US and UK universities before and after the implementation of REF. A notable observation is the substantial increase in IRC for UK universities post-REF, with the mean rising from 0.406 to 0.878, outpacing the increase seen in US universities. Similarly, FIRC shows a more pronounced increase in UK institutions than their US counterparts post-REF. These trends imply the potential effects of the REF on both IRC and FIRC, setting the stage for our subsequent causal analysis. In terms of financial metrics, the mean income and expenditure for US universities are higher than those for UK institutes. However, UK universities experienced a more substantial percentage increase in both income and expenditure from pre- to post-REF periods. For instance, mean income for UK universities nearly doubled, while US universities saw a more modest increase.

Table 2 Descriptive statistics

Category	Variable	Mean	Std. dev.	Min	Max
US: Pre-REF	IRC	0.357	0.191	0	1.277
US: Post-REF	IRC	0.609	0.266	0	2.479
UK: Pre-REF	IRC	0.406	0.238	0	1.333
UK: Post-REF	IRC	0.878	0.372	0	2.164
US: Pre-REF	FIRC	0.089	0.057	0	0.414
US: Post-REF	FIRC	0.148	0.077	0	0.542
UK: Pre-REF	FIRC	0.105	0.072	0	0.509
UK: Post-REF	FIRC	0.229	0.115	0	0.592
US: Pre-REF	Income	1,345,060	1,471,562	12,715	14,400,000
US: Post-REF	Income	1,696,618	1,663,029	102,154	14,600,000
US: Pre-REF	Expenditure	1,156,476	1,195,913	31,186	9,165,160
US: Post-REF	Expenditure	1,497,472	1,358,304	32,757	1,290,000
UK: Pre-REF	Income	165,213	134,456	8,706	1,139,897
UK: Post-REF	Income	294,172	289,424	7,774	2,536,312
UK: Pre-REF	Expenditure	164,592	136,353	8,736	1,155,422
UK: Post-REF	Expenditure	286,190	280,148	10,200	2,582,239

Note: Income and Expenditure values are reported in thousands of pounds sterling (£'000).

Our causal analysis in Table 3 confirms the significant and positive influence of REF on IRC and FIRC. The substantial increase in yearly effects and average treatment effects (ATTs) of

REF on IRC and FIRC is primarily attributed to the consistent rise observed during all years of the treatment period (2009–2021).

The ATT for IRC is 0.204, showing a 20.4 percentage point (correspond to an increase of 0.55 standard deviations) increase in IRC intensity after REF implementation in the UK HEIs, confirming our first hypothesis. Our results are consistent with extant studies (such as Abramo and D'Angelo, 2023; Ubfal and Maffioli, 2011; European Commission, 2021; Mali et al., 2017). This positive influence can be attributed to several factors inherent in the REF schemes. The focus of REF on fostering research excellence drives the UK HEIs to prioritize high-quality research, particularly through IRC. As suggested by RDT, the REF encourages institutions to harness diverse expertise and resources. One key way it does this is by creating international alliances, which play a crucial role in facilitating knowledge exchange and enabling UK HEIs to take advantage of global best practices. Moreover, economies of scale through international partnerships significantly enhance the intensity of the IRC after the implementation of REF, demonstrating the global impact of such systems on research behaviours and outcomes in UK HEIs.

Accordingly, the ATT for FIRC in these collaborative endeavours is 0.056, indicating a 5.6 percentage point (equivalent to 0.49 standard deviations) increase in gender diversity due to REF, supporting our second hypothesis. Our results are partially in line with Abramo et al. (2013). This finding can be attributed to a few factors. The UK funding bodies, including REF, started recognizing equality, diversity, and inclusion (EDI) as crucial ingredients for the research landscape, possibly contributing to fostering more FIRC. The impact component of REF may encourage wider society engagement and international partnership, potentially encouraging female researchers to participate in global collaborations. Moreover, as suggested by Zhang et al. (2020), female scientists can benefit more from international collaborations, which may motivate women to participate in such partnerships.

These findings are not only consistent with our expectations but also highlight the fact that UK universities experienced faster growth in the IRC and FIRC compared to their US counterparts after the introduction of REF in 2009. This trend is further substantiated by the solid lines representing UK universities in Figure 1 and Figure 2, which present consistently significant and positive effects of REF on IRC and FIRC from 2009 onwards, respectively.

The yearly data in Table 3 reveals a consistent and significant increase in both metrics. The IRC metric, for instance, rose from 0.112 in 2009 to 0.260 in 2014, representing a 132% increase. This implies that the IRC has more than doubled during the first five years post-REF. In practical terms, this means that for every 100 research outputs pre-REF, approximately 11 involved IRC. By 2014, this number had more than doubled to 26. The upward trend continued consistently through 2021, when IRC increased to 0.733, marking a total 554% increase from 2009. This substantial rise indicates that by 2021, on average, 73.3% of UK institutions' research involved IRC, compared to just 35.7% before the REF. This increase has significant implications for the research landscape, highlighting the growing importance of collaboration in research outputs.

Similarly, the growth in FIRC from 0.022 in 2009 to 0.076 in 2014, highlighting an increase of 245%. To contextualize this change, if we interpret these numbers as proxies for participation rates, it suggests that for every 1000 IRC in 2009, approximately 22 involved female researchers, and by 2014, this number increased to about 76. The metric continued to improve, reaching 0.213 by 2021, a total increase of 868% from 2009. By 2021, the data suggests that for every 1000 IRCs, about 213 involved female researchers.

The data strongly suggests that successive REF cycles have had a cumulative effect, reaffirming the REF's pivotal role in fostering IRC and enhancing FIRC within research teams.

Table 3 REF: yearly effects and ATTs of IRC and Gender Diversity

	IRC	**FIRC**
ATT09-21	0.204***	0.056***
2009	0.112***	0.022***
2010	0.057**	0.029***
2011	0.109***	0.031***
2012	0.126***	0.049***
2013	0.185***	0.061***
2014	0.260***	0.076***
2015	0.289***	0.099***
2016	0.317***	0.095***
2017	0.334***	0.108***
2018	0.379***	0.131***
2019	0.461***	0.153***
2020	0.695***	0.193***
2021	0.733***	0.213***

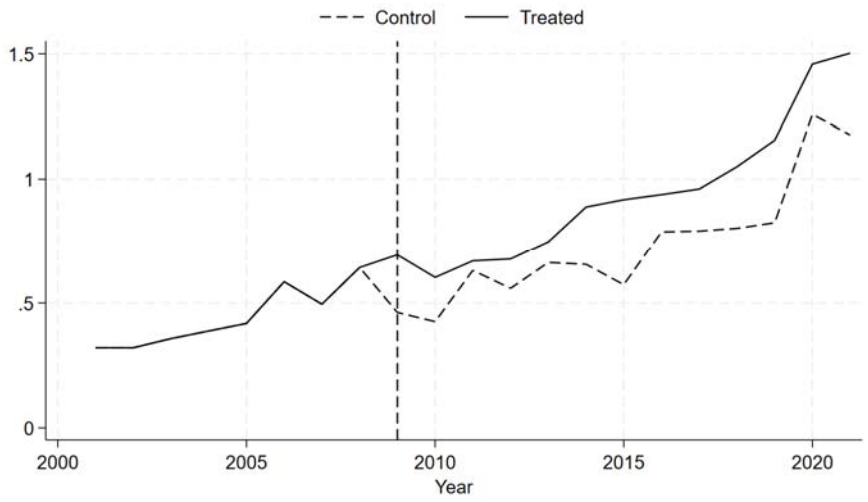

Fig 1. Synthetic DiD Analysis: International Research Collaborations under REF schemes

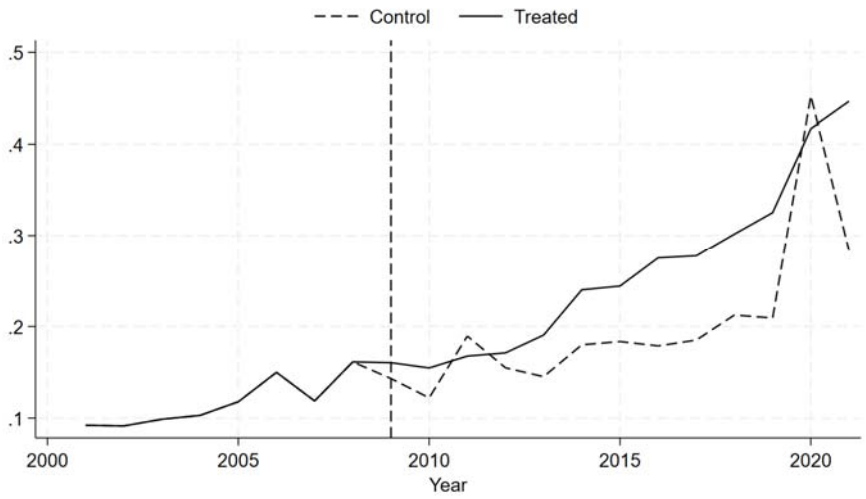

Fig 2. Synthetic DiD Analysis: Female Participation in International Research Collaborations under REF schemes

We conduct additional robustness checks using various PSM techniques to validate our main findings further. The results, presented in detail in Appendix B (Table B1), consistently support our primary conclusions. The PSM estimates show that the REF has a positive and statistically significant impact on both IRC and FIRC. The ATT for IRC ranges from 0.285 to 0.316 across different PSM methods, indicating an increase of approximately 28.5 to 31.6 percentage points. For FIRC, the ATT estimates range from 0.078 to 0.082, suggesting an increase of about 8 percentage points. These results are consistent across multiple PSM techniques and provide additional support for the robustness of our main findings.

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

The descriptive statistics in Table 4 show that Russell Group (RG) and Non-Russell Group (NRG) universities experienced substantial increases in IRC and FIRC post-REF. However, RG universities consistently outperformed NRG institutions in both metrics across all periods. Notably, RG universities have substantially higher mean income and expenditure. Despite this financial disparity, both groups demonstrate the positive influence post-REF, albeit to varying degrees.

Table 4 Descriptive statistics presenting NRG and RG

Category	Variable	Mean	Std. dev.	Min	Max
NRG: Pre-REF	IRC	0.368	0.212	0	1.333
NRG: Post-REF	IRC	0.695	0.331	0	2.479
RG: Pre-REF	IRC	0.457	0.206	0.083	1.146
RG: Post-REF	IRC	0.944	0.346	0.261	1.848
NRG: Pre-REF	FIRC	0.063	0.057	0.014	0.481
NRG: Post-REF	FIRC	0.165	0.141	0.067	2.75
RG: Pre-REF	FIRC	0.078	0.048	0.005	0.313
RG: Post-REF	FIRC	0.219	0.136	0.015	1.454
NRG: Pre-REF	Income	329,367	149,315	88,877	862,478
NRG: Post-REF	Income	658,741	377,601	23,370	2,536,312
RG: Pre-REF	Income	1,002,606	1,505,356	12,715	1,440,000
RG: Post-REF	Income	1,097,905	1,344,763	14,590	1,460,000
NRG: Pre-REF	Expenditure	324,457	149,190	88,943	866,865
NRG: Post-REF	Expenditure	635,688	361,564	21,812	2,582,239
RG: Pre-REF	Expenditure	865,392	1,264,739	32,757	1,110,000
RG: Post-REF	Expenditure	955,564	1,024,593	32,859	1,290,000

Note: Income and Expenditure values are reported in thousands of pounds sterling (£'000).

The analysis in Table 5 shows the potential exacerbation of inequalities within the UK higher education system due to the REF. We can draw several insights by comparing the ATTs for IRC and FIRC between universities belonging to the elite Russell Group and those outside of it.

Firstly, the ATTs for IRC are positive and statistically significant at the 1% level for both Russell Group (0.361) and non-Russell Group (0.353) universities. This indicates that the REF has successfully fostered IRC, a significant achievement regardless of institutional prestige. However, the slightly higher ATT for Russell Group universities suggests they may have experienced a marginally greater boost in IRC than their non-Russell counterparts.

Secondly, a more pronounced difference emerges when examining the ATTs for FIRC. While both groups exhibit positive and statistically significant effects, the ATT for Russell Group universities (0.103) is notably higher than that of non-Russell universities (0.062). This finding is a testament to the substantial enhancement that the REF has brought to female participation in international collaborations within the elite Russell Group institutions, marking a significant step forward in gender equality in the field of research.

Table 5 Russel Vs Non-Russel ATTs (REF)

Category	IRC	FIRC
Russel	0.361***	0.103***
Non-Russel	0.353***	0.062***

P-value sig: 1% (***), 5% (**), and 10% (*)

The discrepancy in the ATTs for FIRC between the two groups may be attributed to several factors. Russell Group universities, being research-intensive and well-resourced (Table 4 shows RG universities with substantially higher mean income and expenditures than NRG institutions), may have been better positioned to implement targeted initiatives and allocate resources toward promoting gender diversity and inclusivity in their research endeavours. Additionally, these prestigious institutions may have a stronger incentive to prioritise gender equity and diversity, as it aligns with their pursuit of research excellence and global recognition.

On the other end, Non-Russell Group (NRG) universities face challenges in addressing gender disparities within their research programs, as evidenced by their lower ATT for FIRC. This disparity can be attributed to several structural factors: First, resource limitations, as shown by significantly lower mean income and expenditure than Russell Group (RG) universities in Table 4, likely constrain NRG institutions' ability to implement comprehensive diversity initiatives. Second, fewer established international partnerships, indicated by lower pre-REF IRC means, may restrict their capacity to attract diverse international collaborators. Third, a more teaching focus in many NRG institutions may result in higher teaching loads, leaving less time for developing IRC. Finally, the prestige of RG universities may give them an advantage in attracting diverse international talent. These factors collectively contribute to the structural barriers that NRG universities face in responding to the REF's emphasis on diversity and inclusivity, as reflected in the lower ATT for FIRC (0.062 vs. 0.103 for RG). While the REF has positively impacted the sector, its effectiveness in promoting FIRC has been more limited for NRG institutions.

8. Conclusion

Our study shows the significant and positive impact of the UK's REF on both IRC and female participation in international collaborations within the UK HEIs. Using novel methodological approaches such as SDiD and PSM, this study effectively demonstrates a clear causal effect of

REF on these key metrics. The overall average treatment effect (ATT) of 0.204 for IRC indicates a substantial increase in collaboration intensity by 20.4 percentage points after the implementation of REF in the UK HEIs. To contextualize this change, if a UK institution had 100 research projects pre-REF, of which 30 were international collaborations, post-REF (after 2009 onwards), we would expect around 50 international collaborations out of 100 projects, all else being equal. This substantial increase reassures the effectiveness of the REF in promoting IRC. This finding strongly supports our first hypothesis, which we fail to reject. Similarly, our results show an ATT of 0.056 for female participation in international collaborations, indicating a 5.6 percentage point increase in FIRC post-REF. This indicates that if women made up 30% of researchers in international collaborations pre-REF, this proportion has increased to roughly 35.6% following post-REF. This supports our second hypothesis, which we also fail to reject. The consistency of results across multiple analytical approaches, including various PSM techniques, reinforces the robustness of these findings and instils confidence in their validity. Notably, our analysis reveals a disparity in the impact of REF between Russell Group and non-Russell Group universities, particularly in terms of female participation in international collaborations. This implies that the REF may exacerbate existing inequalities between Russell and non-Russell Group universities.

These findings strongly suggest the effectiveness of PRFS, like the UK's REF, in bringing positive changes in research practices and outcomes. With its focus on outputs, impact, and environment, REF has successfully promoted UK universities in developing international alliances through collaborations on research projects and simultaneously fostering gender diversity within research teams, aligning with its objectives of bringing research excellence and inclusivity. However, the highlighted unintended consequence of REF in fostering disparities between Russell Group and non-Russell universities underscores the urgent need for policymakers to consider targeted support mechanisms for non-elite institutions. Support could be a more equitable distribution of resources, dedicated funding streams for capacity building in non-Russel universities, and encouraging collaborating researchers between these different institution types. This is crucial to ensure a more equitable distribution of resources across HEIs in the UK.

References

Abramo, G. and D'Angelo, C.A. (2023) The impact of Italian performance-based research funding systems on the intensity of international research collaboration, Research Evaluation, 32, 47-57.

Abramo, G., D'Angelo, C.A., and Murgia, G. (2013) Gender differences in research collaboration, Journal of Informetrics, 7, 811-22.

Adams, J. (2013) The fourth age of research, Nature, 497, 557-60.

Aksnes, D.W., Piro, F.N., and Rørstad, K. (2019) Gender gaps in international research collaboration: A bibliometric approach, Scientometrics, 120, 747-74.

Álvarez-Bornstein, B. and Bordons, M. (2021) Is funding related to higher research impact? Exploring its relationship and the mediating role of collaboration in several disciplines, Journal of Informetrics, 15, 101102.

Arkhangelsky, D., Athey, S., Hirshberg, D.A., Imbens, G.W., and Wager, S. (2021) Synthetic difference-in-differences, American Economic Review, 111, 4088-118.

Arnold, E. (2018) Review of the research excellence framework: evidence report.

Austen, S. (2008) Australia's research quality framework and gender equity, International Education Journal: Comparative Perspectives, 9.

Banal-Estañol, A., Jofre-Bonet, M., Iori, G., Maynou, L., Tumminello, M., and Vassallo, P. (2023) Performance-based research funding: Evidence from the largest natural experiment worldwide, Research Policy, 52, 104780.

Bayer, A. and Rouse, C.E. (2016) Diversity in the economics profession: A new attack on an old problem, Journal of Economic Perspectives, 30, 221-42.

Boschini, A. and Sjögren, A. (2007) Is team formation gender neutral? Evidence from coauthorship patterns, Journal of Labor Economics, 25, 325-65.

Bührer, S. and Frietsch, R. (2020) How do public investments in gender equality initiatives and publication patterns interrelate? The case of Germany, Evaluation and Program Planning, 79, 101769.

Cimini, G., Zaccaria, A., and Gabrielli, A. (2016) Investigating the interplay between fundamentals of national research systems: Performance, investments and international collaborations, Journal of Informetrics, 10, 200-11.

Curtis, B. (2016) The performance-based research fund, gender and a cultural cringe, Globalisation, Societies and Education, 14, 87-109.

Davies, B., Gush, J., Hendy, S.C., and Jaffe, A.B. (2022) Research funding and collaboration, Research Policy, 51, 104421.

Dehejia, R.H. and Wahba, S. (2002) Propensity score-matching methods for nonexperimental causal studies, Review of Economics and Statistics, 84, 151-61.

DiMaggio, P.J. and Powell, W.W. (1983) The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields, American Sociological Review, 48, 147-60.

Doleac, J.L., Hengel, E., and Pancotti, E. (2021) Diversity in economics seminars: who gives invited talks?, AEA Papers and Proceedings, 111, 55-59.

Ductor, L., Goyal, S., and Prummer, A. (2021) Gender and collaboration, Review of Economics and Statistics, 1-42.

Eisend, M. and Schmidt, S. (2014) The influence of knowledge-based resources and business scholars' internationalization strategies on research performance, Research Policy, 43, 48-59.

Elezi, E. and Bamber, C. (2018) Knowledge management factors affecting educational partnerships within the British HE/FE sector, International Journal of Knowledge Management Studies, 9, 243-59.

European Commission (2021) Horizon Europe—THE EU RESEARCH & INNOVATION PROGRAMME 2021–27, European Commission, Brussels. Available online: https://research-and-innovation.ec.europa.eu/system/files/2022-06/ec_rtd_he-investing-to-shape-our-future_0.pdf

Ghiasi, G., Beaudry, C., Larivière, V., St-Pierre, C., Schiffauerova, A., and Harsh, M. (2021) Who profits from the Canadian nanotechnology reward system? Implications for gender-responsible innovation, Scientometrics, 126, 7937-91.

Ginther, D.K. and Kahn, S. (2004) Women in economics: Moving up or falling off the academic career ladder?, Journal of Economic Perspectives, 18, 193-214.

Guthrie, K.L., Jones, T.B., Osteen, L., and Hu, S. (2013) Cultivating leader identity and capacity in students from diverse backgrounds: ASHE Higher Education Report, 39: 4, John Wiley & Sons, Hoboken.

Hammarfelt, B. and De Rijcke, S. (2015) Accountability in context: Effects of research evaluation systems on publication practices, disciplinary norms, and individual working routines in the faculty of Arts at Uppsala University, Research Evaluation, 24, 63-77.

Hengel, E. (2022) Publishing while female. Are women held to higher standards? Evidence from peer review, The Economic Journal, 132, 2951-91.

Hengel, E., Sevilla, A., and Smith, S. (2024) Measuring research quality in a more inclusive way: Evidence from the UK Research Excellence Framework, Research Evaluation, rvae013.

Hospido, L. and Sanz, C. (2021) Gender gaps in the evaluation of research: Evidence from submissions to economics conferences, Review of Economics and Statistics, 103, 898-911.

Hussey, A., Murray, S., and Stock, W. (2022) Gender, coauthorship, and academic outcomes in economics, Economic Inquiry, 60, 465-84.

Johnson, J., Sharman, Z., Vissandjée, B., and Stewart, D.E. (2014) Does a change in health research funding policy related to the integration of sex and gender have an impact?, PloS One, 9, e99900.

Khan, A., Önder, A.S., and Ozcan, S. (2023) Does Performance-based Public Funding Pay off? UK's Research Excellence Framework (REF) and Research Productivity, Available at SRN: https://ssrn.com/abstract=4624285 or http://dx.doi.org/10.2139/ssrn.4624285

Kim, D.H. and Bak, H.J. (2017) Incentivizing research collaboration using performance-based reward systems, Science and Public Policy, 44, 186-98.

Kwiek, M. (2020) Internationalists and locals: international research collaboration in a resource-poor system, Scientometrics, 124, 57-105.

Kwiek, M. and Roszka, W. (2021) Gender disparities in international research collaboration: A study of 25,000 university professors, Journal of Economic Surveys, 35, 1344-80.

Lawson, C., Geuna, A., and Finardi, U. (2021) The funding-productivity-gender nexus in science, a multistage analysis, Research Policy, 50, 104182.

Leydesdorff, L. and Wagner, C.S. (2008) International collaboration in science and the formation of a core group, Journal of Informetrics, 2, 317-25.

Leydesdorff, L., Bornmann, L., and Wagner, C.S. (2019) The relative influences of government funding and international collaboration on citation impact, Journal of the Association for Information Science and Technology, 70, 198-201.

Lindenlaub, I. and Prummer, A. (2021) Network structure and performance, Economic Journal, 131, 851-98.

Lundberg, S. and Stearns, J. (2019) Women in economics: Stalled progress, Journal of Economic Perspectives, 33, 3-22.

Mali, F., Pustovrh, T., Platinovšek, R., Kronegger, L., and Ferligoj, A. (2017) The effects of funding and co-authorship on research performance in a small scientific community, Science and Public Policy, 44, 486-96.

Marques, M., Powell, J.J., Zapp, M., and Biesta, G. (2017) How does research evaluation impact educational research? Exploring intended and unintended consequences of research assessment in the United Kingdom, 1986–2014, European Educational Research Journal, 16, 820-42.

Nielsen, M.W. (2017b) Gender consequences of a national performance-based funding model: New pieces in an old puzzle, Studies in Higher Education, 42, 1033-55.

Nielsen, M.W., Alegria, S., Börjeson, L., Etzkowitz, H., Falk-Krzesinski, H.J., Joshi, A., Leahey, E., Smith-Doerr, L., Woolley, A.W., and Schiebinger, L. (2017a) Gender diversity leads to better science, Proceedings of the National Academy of Sciences, 114, 1740-42.

Nygaard, L.P., Piro, F.N., and Aksnes, D.W. (2022) Gendering excellence through research productivity indicators, Gender and Education, 34, 690-704.

Önder, A.S., Schweitzer, S., and Yilmazkuday, H. (2021) Specialization, field distance, and quality in economists' collaborations, Journal of Informetrics, 15, 101222.

Pfeffer, J. and Salancik, G. (2015) External control of organizations—Resource dependence perspective, in Organizational Behavior 2, Routledge, London, 355-70.

Restrepo, N., Unceta, A., and Barandiaran, X. (2021) Gender diversity in research and innovation projects: The proportion of women in the context of higher education, Sustainability, 13, 5111.

Rosenbaum, P.R. and Rubin, D.B. (1983) The central role of the propensity score in observational studies for causal effects, Biometrika, 70, 41-55.

Sarsons, H., Gërxhani, K., Reuben, E., and Schram, A. (2021) Gender differences in recognition for group work, Journal of Political Economy, 129, 101-47.

Smith, J.A. and Todd, P.E. (2005) Does matching overcome LaLonde's critique of nonexperimental estimators?, Journal of Econometrics, 125, 305-53.

Stern, N. (2016) Building on success and learning from experience: An independent review of the Research Excellence Framework.

Ubfal, D. and Maffioli, A. (2011) The impact of funding on research collaboration: Evidence from a developing country, Research Policy, 40, 1269-79.

Uhly, K.M., Visser, L.M., and Zippel, K.S. (2017) Gendered patterns in international research collaborations in academia, Studies in Higher Education, 42, 760-82.

Wagner, C.S., Wagner, C.S., and Graber (2018) Collaborative era in science, Palgrave Macmillan, London.

Zacharewicz, T., Lepori, B., Reale, E., and Jonkers, K. (2019) Performance-based research funding in EU Member States—a comparative assessment, Science and Public Policy, 46, 105-15.

Zhang, M., Zhang, G., Liu, Y., Zhai, X., and Han, X. (2020) Scientists' genders and international academic collaboration: An empirical study of Chinese universities and research institutes, Journal of Informetrics, 14, 101068.

Zhou, P., Cai, X., and Lyu, X. (2020) An in-depth analysis of government funding and international collaboration in scientific research, Scientometrics, 125, 1331-47.

Appendix A:

Table A1 Impact of PRFS on IRC and FIRC

Country/Region	Impact on International Collaboration	Impact on Female Participation	Methodology	Source
Australia	Not directly addressed	Likely to exacerbate gender inequity in universities	Analysis of publication records and promotion patterns	Austen (2008)
Canada	Not directly addressed	Negative - underrepresentation of women	Analysis of research chair data	Ghiasi et al. (2021)
China	Positive for both genders, more so for women	Female scientists benefit more from international collaboration than males	Bibliometric analysis of research outputs	Zhang et al. (2020)
Denmark	Not directly addressed	PRFS widens gender gap in researcher performance	Analysis of bibliometric data and funding patterns	Nielsen (2017b)
EU Member States	Varies widely across countries	Varies widely across countries	Comparative analysis of national R&D funding data	Zacharewicz et al. (2019)
Europe	Not directly related to PRFS	Negative - gender disparity increases with age	Bibliometric study of 25,000 professors	Kwiek and Roszka (2021)
Germany	Not directly addressed	Increased women's publication rates and quality indicators	Bibliometric analysis and evaluation of funding programs	Bührer and Frietsch (2020)
Global	Not directly related to PRFS	Negative - women face more barriers	Analysis of international survey data	Uhly et al. (2017)
Global	Positive effect of international collaboration	Gender differences diminish when controlling for other factors	Bibliometric analysis of Web of Science data	Leydesdorff et al. (2019)
Global	Not directly related to PRFS	No significant gender differences	Analysis of international collaboration data	Aksnes et al. (2019)
Global	Positive	Not directly addressed	Analysis of international collaboration data	Cimini et al. (2016)
Italy	Positive	Not directly addressed	Interrupted time series analysis	Abramo et al. (2023)
New Zealand	Potential negative impact on local collaborations	May exacerbate gender inequalities	Mixed methods	Curtis (2016)
Norway	Positive	Negative - amplifies gender gaps by ~10%	Analysis of Norwegian Publication Indicator data	Nygaard et al. (2022)
Poland	Positive for those involved	Negative - women less likely to be internationalists	Survey of 3,704 Polish university professors	Kwiek (2020)
UK	Not directly addressed	Positive - when using broader quality measures	Analysis of REF data	Hengel et al. (2024)

Appendix B: Propensity Score Matching Analysis

Table A1 presents the results of our PSM analysis as a robustness check for our main findings on the impact of the REF on IRC and FIRC. The consistent positive and statistically significant ATT estimates across all PSM methods strongly support the robustness of our main findings, reinforcing the conclusion that the REF has a substantial positive impact on IRC and FIRC.

Table B1 PSM Estimates: Impact of REF on Research Outcomes

ATTs	**1**	**2**	**3**	**4**	**5**	**6**
IRC	0.287***	0.285***	0.285***	0.316***	0.312***	0.285***
FIRC	0.082***	0.082***	0.082***	0.078***	0.080***	0.082***

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.