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Article

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Gender diversity and publication activity—an analysis of STEM in the UK

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Abstract

Gender diversity in STEM remains a significant issue, as the field continues to be a male dominated one, despite increased attention on the subject. This article examines the interplay between gender diversity on projects funded by a major UK research council, the Engineering and Physical Sciences Research Council, and the publication activity of a project, as measured by the average journal quality of project publication output, over a 10-year period. The proportion of female representation and leadership on these projects remains very low. For the projects examined as part of this study, over 70% of these projects have no female representation, and less than 15% have a female lead. This study does not find a significant relationship between gender diversity and journal quality output. This study highlights that an important avenue for future work is the development of alternative metrics to assess the performance of research projects in a discipline characterized by very low levels of gender diversity, to fully unpack the impact of project team gender diversity on project output activity.

Keywords: gender diversity; STEM; collaboration; network analysis

Introduction

Within the academic labour force, the underrepresentation of females remains a salient issue, one which is particularly prominent in science, technology, engineering, and mathematics (STEM) (Holmes et al. 2008; Riegle-Crumb et al. 2012; Kalpazidou Schmidt and Cacace 2017; Nielsen et al. 2017; Holman, Stuart-Fox and Hauser 2018; Graddy-Reed, Lanahan and Eyer 2019; Greider et al. 2019; Grogan 2019; Hussénius 2020; Black et al. 2021; Bol, de Vaan and van de Rijt 2022). The lack of gender diversity in academia has been examined from numerous perspectives, and in a wide range of settings in recent years (Ceci et al. 2014; Blackburn 2017; Verdugo-Castro, García-Holgado and Sánchez-Gómez 2022). For instance, several scholars note that in doctoral training programs in STEM, the gender pairing between students and advisors can have significant impacts on success (Pezzoni et al. 2016). Gaule and Piacentini (2018) identify that in US chemistry departments, students with an advisor who is the same gender perform better and that this pattern is more noticeable for females, where there are positive career progression benefits. However, they note that the underrepresentation of females in chemistry results in female students often having male advisors, limiting the access to these benefits.

Much of the literature has attributed the disadvantage of women in academia (especially STEM) to a number of key factors (Abramo, D'Angelo and Rosati 2015; Casad et al. 2021), such as disproportionate pressure to balance educational plans with non-academic responsibilities (such as family care) (Aluko 2009; Misra, Lundquist and Templer 2012), the increased likelihood of experiencing isolation and exclusion during their career (Kemelgor and Etzkowitz 2001), and a lack of supportive social networks (Collins and Steffen-Fluhr 2019). A key framework that has emerged to explain the gender gap in STEM is the 'leaky pipeline' approach (Alper and Gibbons 1993; Van Anders 2004; Dubois-Shaik, Fusulier and Vincke 2018). The leaky pipeline is a term used to describe the loss of women in the STEM career progression pathway, from school all the way to senior positions within the field (Pell 1996; Wickware 1997; Resmini 2016). Extant literature drawing on this approach attempts to map the pipeline for a discipline and tries to identify opportunities for promoting gender diversity, and stopping the 'leak' of capable females from the field (Blickenstaff 2005; Goulden, Mason and Frasch 2011; van den Brink and Benschop 2012; Linnenbrink-Garcia et al. 2018; Almukhambetova, Torrano and Nam 2021). Wolfinger, Mason and Goulden (2009) provide a critique of the leaky pipeline framework, noting that it often fails to explain the experiences of women that are remaining in the pipeline, such as those that receive doctorates in the sciences. Windsor, Crawford and Breuning (2021) note that the academic system is not a pipeline that women 'leak' out of, rather it is hierarchical structure with hidden curriculum (the unwritten rules linked to the traditional routes of academic advancement) and hidden shortcuts, which they refer to as a game of 'Academic Chutes and Ladders'. They argue that this system favours men, as they are more likely to have access to shortcuts, or academic ladders, whilst women are more likely to be vulnerable to significant changes in personal and professional circumstances that have a negative impact on their career pathway, such as pregnancy (Maxwell, Connolly and Ní Laoire 2019); bias in hiring or promotion committees (Sheltzer and Smith 2014), and gender harassment (Bondestam and Lundqvist 2020), that they refer to as academic chutes.

The issue of gender diversity has been examined in other settings, where the glass ceiling theoretical framework is utilized (Morley 1994; McCulloch 1997). One example is in corporate governance, where there is extensive literature examining the implications (and policy efforts) of increased gender diversity on boards of directors (Adams and Funk 2012). In this setting, many core interest groups not only emphasize the ethical and moral needs for gender balance, but they also note that there is a business case for gender diversity, noting an increase on firm value and performance (Ali and Shabir 2017; Moreno-Gómez, Lafuente and Vaillant 2018). Many studies show that firms with more female directors reap performance benefits. Arguments similar to the business case have been established (yet to a lesser extent) in the academic setting (Campbell et al. 2013; Kubik-Huch et al. 2020). Furthermore, these arguments have often been utilized to justify the gender gap in the science, suggesting that female academics produce fewer outputs in less prestigious journals (Cole and Zuckerman 1984; Brooks, Fenton and Walker 2014; Jappelli, Nappi and Torrini 2017; King et al. 2017; Lerchenmüller, Lerchenmueller and Sorenson 2018; Thelwall 2018). This has resulted in a further emphasis and imperative being placed on the moral and ethical argument of gender diversity. There is a need to recognize that the underrepresentation of females in STEM is a key contributing factor in the literature noting limited publication successes.

A large amount of empirical work has examined a number of issues regarding gender diversity in STEM. Thelwall et al. (2019) analyse the topics researched by female and male researchers in the USA, to determine whether there are topics preferred by female researchers, and whether this contributes to the lack of female presentation in STEM. Zhang et al. (2021) provide a citation and altmetric analysis of Norwegian researchers and they note differences in the interaction and engagement with journal articles based on author gender. They find that papers with male first authors are cited more often; yet, publications with female first authors receive a higher level of abstract views. They also found within the field that male researcher engages in research that is aimed at contributing to scientific progress, whilst female researchers' work is aimed at contributing to societal progress. Thelwall and Nevill (2019) find in US biochemistry, genetics, and molecular biology research that there is no evidence of a large male citation advantage, contrasting to the findings of Zhang et al. (2021). Others have considered differences in gender diversity across countries, drawing on citation data (Thelwall and Mas-Bleda 2020; Thelwall and Sud 2020; Thelwall 2020a,b; Abramo, Aksnes and D'Angelo 2021). Zhang and Li (2020) consider whether neutral names have an impact on paper citation in STEM subjects; they find papers are cited significantly more if the author's name sounds gender neutral. Su, Johnson and Bozeman (2015) examine the organizational factors within the US academia that impact gender diversity patterns. They find that academic chairs have a significant role in gender diversity efforts within a department.

A number of studies examine the role of gender in the formation of collaborative ties in the sciences (Ozel, Kretschmer and Kretschmer 2014; Akbaritabar et al. 2020; Akbaritabar and Squazzoni 2021). Kwiek and Roszka (2021) study the role of gender homophily in the sciences, they find that homophily underpins many patterns of collaboration amongst male scientists, where male researchers are more likely to collaborate with male scientists. However, they find that this is not the case with female scientists, where they are not likely to collaborate with other females.

Social role theory has been used by a number of scholars to explore the relationship been gender and recognition of expertise in team settings (Joshi 2014). Social role theory argues that in male dominated fields (such as STEM), women are often viewed as less competent by their team members, and can have a less influence on team decision making processes; this is irrespective of their actual knowledge, capabilities and expertise, and rather is a result of women being atypical and underrepresented in these settings (Ridgeway and Smith-Lovin 1999; Carli 2016). Therefore, in STEM, it has been argued that the underrepresentation of women, and atypicality of women in engineer and scientist roles will have an impact on how their expertise is evaluated (Rudman et al. 2012).

There is an additional stream of the extant literautre that considers the interplay between team gender diversity and performance (Joshi and Roh 2009; Niler, Asencio and DeChurch 2020). Yang et al. (2022) demonstrate in the field of medical research, publication teams with mixed gender members tends to produce more novel and higher impact outputs (compared to teams of the same gender of an equivalent size); despite women being underrepresented in this field. Others note that for the positive impact of women on a scientific team to be realized there need to be 'critical mass' of women on the team (Etzkowitz et al. 1994); empirical work has found that women are more likely to participant in scientific teams when there are more women members on the team (Dasgupta, Scircle and Hunsinger 2015). Further empirical work has noted that in male dominated professions (such as STEM), gender diversity can have a negative impact, as women in these areas face even greater integration challenges (Allmendinger and Hackman 1995; Bear and Woolley 2011).

This article seeks to examine the link between the publication success of publicly funded research projects in the sciences and gender; whether increased gender diversity is associated with a project with increased publication success. Funded research projects have been found to be associated with an increased number of publications and in some cases, more highly cited publications, when compared to unfunded research projects (Langfeldt, Bloch and Sivertsen 2015). However, extant work has found that the impact of participating and leading funded research differs for males and females, especially for more junior academics (Pina et al. 2019).

This article aims to investigate how collaborative arrangements impact the publication success of a project. Research projects often consist of collaborative arrangements involving a wide variety of institutions, both academic and non-academic, as collaborative ties represent a salient component of research and innovative activity (Whittington 2018). We examine whether these collaborative arrangements and holding a central position in the research funding space is more important for female academics compared to males. More specifically, whether holding a central position in the collaborative space is more important for female principal investigators (PIs) compared to their male counterparts (given extant research has highlighted the difference between how male and female use and benefit from their networks (Woehler et al. 2021). Therefore, this article will address the following research questions:

1) Is a project with a high proportion of females associated with publishing in journals with a higher journal score?

2) Is a project with a female PI associated with publishing in journals with a higher journal score?
3) Is network centrality associated with a publishing in in journals with a higher journal score?
4) Is network centrality more important for publishing in journals with a higher ranking (as captured by a journal metric) when the project has a female PI?

This work contributes to the extant literature on the gender gap in STEM. It is important to note that the male and female academics working on these projects are chiefly those in the role of PI or co-investigator, therefore they usually reflect individuals that hold more senior roles or are established researchers. This allows us to compare individuals at equivalent stages of their career, in order to unpack differences driven by gender diversity, rather than career stage differences (Lerchenmueller and Sorenson 2018). This study also has implications for how research projects are assessed and evaluated. The impact of gender on research evaluation metrics and measures has been frequently debated in the extant literature (Beck and Halloin 2017). Therefore, this study provides the opportunity to examine whether journal impact score is an appropriate metric to understand project outcomes and detect the impact of gender diversity in a discipline defined by very low levels of female representation (Botella et al. 2019).

Data and methods

In this article, we draw on data from the UK research council database, Gateway to Research (GtR). This dataset has been utilized in previous studies (such as Williams et al. 2017; Smith, Sarabi and Christopoulos 2022) and provides information on projects funded by UK research councils, including level of funding provided, duration, project outputs, team members, and organizational collaborators. As the focus of this article is on STEM, we restrict our analysis to research grants funded by the Engineering and Physical Sciences Research Council (EPSRC). The EPSRC focuses on several disciplines in the sciences, such as healthcare technologies, structural engineering, manufacturing, mathematics, advanced materials, and chemistry. The EPSRC is one of the largest public funders in the UK for scientific research and research related to innovation activities (Owen and Goldberg 2010).

We examine research grant projects ending in a ten-year period; projects with an end date between 2010 and 2019 funded by the EPSRC. This results in 9,961 projects. We make use of a journal metric to capture the citation impact of the publication output of projects. We examine the average citation impact of journals that project output articles were published in. This allows us to go beyond simply counting the outputs. The use of the most appropriate metrics to rank journals and capture journal quality is frequently debated (Csató 2019; Drivas and Kremmydas 2020), and there are a wide range of measures available. The metrics used to capture the quality of a journal in this study is the SCImago journal rank (SJR) indicator (SCImago 2020). The SJR was first proposed González-Pereira, Guerrero-Bote and Moya-Anegón 2010), as a measure of journal prestige, that takes into account both the number of citations a journal receives, and the prestige level of the citing journal (Falagas et al. 2008; Mingers and Leydesdorff 2015). It is an established measure of journal quality that has been utilized in a wide range of empirical studies (Mañana-Rodríguez 2015).

Other measures available to access journal quality include the h-index. The h-index was developed to measure the citation performance of individuals but has adapted to measure journal quality. The original formulation was calculated for an individual, where a scholar would achieve a score of h if they had h publications that had all been cited at least h times (Dettori, Norvell and Chapman 2019). There is much debate regarding the usefulness of the metric in evaluating performance (at either the individual or journal level) (Barnes 2017; Ding, Liu and Kandonga 2020). Limitations of the h-index are that it has limited usefulness when comparing between disciplines (the metric is disproportionally advantageous to scientist working in subfields with higher citation frequencies), it ignores low cited papers and is a measure that can promote self-citation amongst scholars (Bartneck and Kokkelmans 2011). A number of works have investigated gender differences for the h-index (such as Geraci, Balsis and Busch 2015; Roper 2022). Carter, Smith and Osteen (2017) in their study of social work academics in the US, that men had a higher h-index score across faculty ranks, where the gender difference was greatest amongst full professors (and least amongst associate professors). Given the issues surrounding the h-index, in this study, we make use of the SJR indicator to capture journal quality.

We create two networks, which are both two-mode networks,[1] from the research project data extracted from GtR: an individual network and a project network. In the individual network, this is a network of the academics and projects, where a tie indicates that an academic is affiliated with a project (this is chiefly in the role of PI or co-investigator). The second network is an organization—project network; the organization consists of both academic and non-academic institutions, and a tie represents the organizations working on a particular project. Constructing these networks allows us to examine the impact of the network ties on publication performance. Network analysis is an established technique that has been widely applied to understand collaboration (Newman 2001; Dehdarirad and Nasini 2017; Zeng et al. 2017; Šubelj et al. 2019; Anderson 2020), at both individual and organizational levels.

The organization-project and individual-project networks are visualized in Figures 1 and 2, respectively. In Figure 1, the organizations are green, and the projects are coloured on the basis of the gender of the PI. Projects with a female PI are red and projects with a male PI are black. In Figure 2, the projects are blue, females are red, and males are black. In both networks, the issue of gender diversity in STEM is clear, with the majority of projects led by males, and the majority of individuals that are involved in EPSRC funded research projects are also males. In Figure 1,we observe a clear core-periphery structure, with a set of tightly connected projects (representing shared organizations collaborating on these projects), and sparsely connected projects on the periphery (Borgatti and Everett 2000). Many empirical studies of collaboration and co-authorship have also noted a core-periphery structure, with an elite, small set of high connected actors at the centre of collaboration networks (examples include Leydesdorff and Wagner 2008; Choi 2011; Zelnio 2011; Lepori et al. 2013; Gui, Liu and Du 2019). In Figure 2, the network is characterized by multiple components, and many individuals on the periphery; we note that many of the connected components are

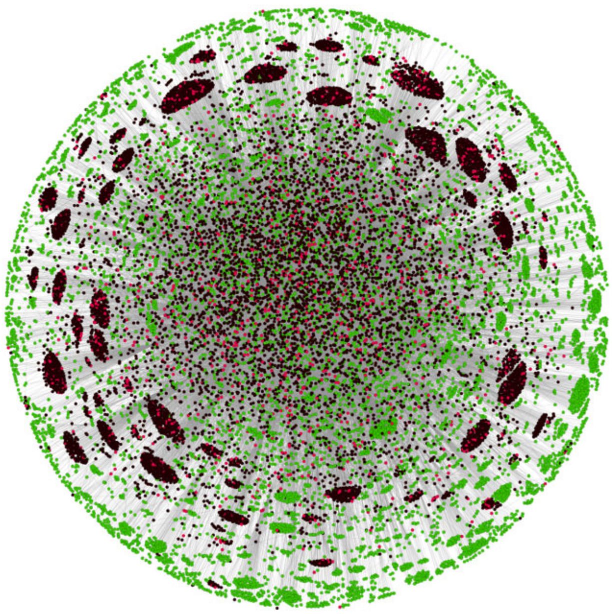

Figure 1. Project—organization network: green nodes—organizations, red nodes—projects with a female PI, and black nodes—projects with a male PI.

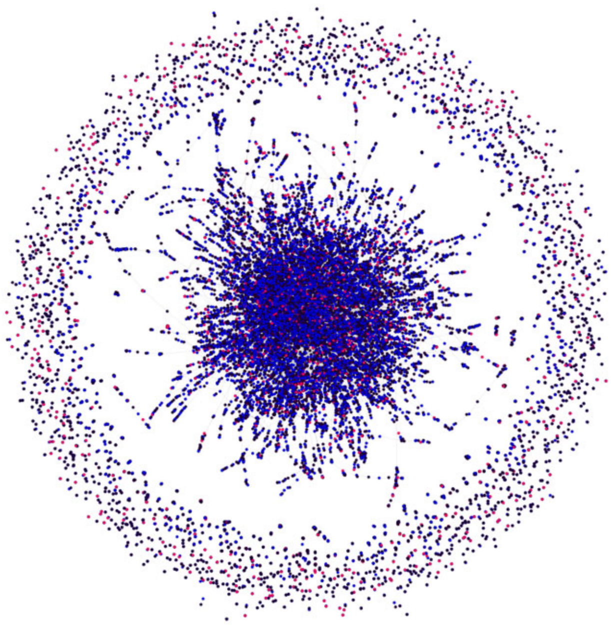

Figure 2. Project—individual network: blue nodes—projects, red nodes—females, and black nodes—males.

often male dominated, with females holding relatively more peripheral positions in this system. These network visualizations are produced by *Gephi* (Bastian, Heymann and Jacomy 2009).

To examine the link between these networks and an indicator of average citation impact of project publications, we draw on two measures of centrality from social network analysis: eigenvector centrality and betweenness centrality. Eigenvector centrality is a measure that captures not only the number of ties an actor has in the network, but also the number of ties of its network partners, a measure of global connectivity. Actors with a high eigenvector centrality are connected to other well-connected actors in the network (Bonacich 1987). In this empirical setting, this measure can be viewed as a measure of individual or project prestige (in line with the work of Bibi et al. 2018). Betweenness centrality refers to the number of times an actor sits on the shortest path between two other actors in a network (Freeman 1977). Betweenness centrality captures an actor's brokerage in the network. In the individual network, high betweenness centrality may indicate that an individual has access to a wide variety of diverse information sources, beneficial for innovation, and research activity (Li, Liao and Yen 2013; Jessani, Boulay and Bennett 2016). The individual centralities calculated using the individual—project network, whilst project centralities are calculated using the project—organization network. In this context, whilst eigenvector centrality can be viewed as a measure of prestige, betweenness can be thought of as a measure of opportunity. The centrality metrics were calculated in R using the *migraph* package (Hollway 2021).

To address the research questions posed by this article, we make use of an ordinary least squares (OLS) regression implemented using the *rms* package in R (Harrell 2015). The analysis is undertaken at the project level with the dependent variable being the average SJR score for journal outputs produced by the project.

There are several independent variables included: project value and project duration are included to control for projects that receive more funding and are active for longer periods. Other independent variables are PI gender; this is a dummy variable, where 1 indicates that the PI is female and 0 male. Proportion of females on the team is also included in the model specification, in order to address the first research question posed by this article.

A further dummy is also included, to capture whether the lead academic organization is a member of the Russell group. The Russell group is a set of UK universities (such as the University of Oxford and the University of Cambridge)[2] (Furey, Springer and Parsons 2014) with a focus on research intensive activities and receives the largest share of government funding (O'Connell 2015). Therefore, this dummy variable is used to examine whether a project's links to an entrepreneurial, research focused university is associated with an increased publication success. We also include the proportion of non-academic organizations (out of all organizations) collaborating on the project, to capture whether a project with a high number of non-academic and potentially private collaborative partners is associated with high quality publication success.

To address the third research question outlined in this article, we specify a number of centrality effects in the model; eigenvector and betweenness centrality for the project network and the individual network. To address the final research question posed by this article, a set of interaction effects are included; interacting network centrality with the female PI dummy variable to examine whether network centrality is more significant for projects with a female lead.

Results

Table 1 presents the descriptive statistics for the key features of these projects. The average number of journal articles is around 12 articles published per project (however, there is a high level of variance). The mean project duration is almost 3 years. A research project has collaborators at the

Table 1. Descriptive statistics

Variable	Mean	Standard deviation
Project value (£)	532,863.09	2,230,563.80
Number of journal article published	12.86	27.41
Project duration (weeks)	147.53	65.08
Proportion of non-academic collaborators	0.38	0.36
Average SJR of published works	1.90	1.91
Proportion female	0.14	0.29
Project betweenness	0.0061	0.031
Project eigenvector	0.0066	0.0075
PI betweenness	0.038	0.082
PI eigenvector	0.0012	0.009

organizational level, these include different universities, but also non-academic organizations. On average out of the total number of institutions working on the project, 38% are non-academic organizations. There is a high level of variation in the average journal quality for project outputs (as indicated by the SJR metrics). A high level of variation is also observed in the network metric scores as indicated by the high standard deviation, suggesting that level of prestige (represented by the eigenvector centrality) and opportunity (represented by the betweenness centrality) are concentrated in a small handful. This confirms what we noted in the network visualizations, where core-periphery structures are observed.

Table 2 presents the output for the first set of regression models, those without interaction effects.[3] We present six models; one without centrality variables or the PI gender variable, another with the PI gender variable included, and the subsequent models examine four metrics of centrality: project betweenness, project eigenvector, PI betweenness, and PI eigenvector. We observe across models, that project value and duration are consistently positive and significant, where longer projects with more funding (more time and resources) are associated with publication in journals with higher SJR scores (which is not a surprising outcome). The Russell group effect, which indicates whether the lead university is a member of the entrepreneurial, research focused set of universities, is positive and significant. This indicates that if a project is led by a Russell group institution, it is associated with outputs in higher ranked journals (according to the SJR metric). This is in line with expectations from the literature, which have often used the Russell group as a proxy for high ranking, innovative, and entrepreneurial universities (Hewitt-Dundas 2013; Guerrero, Cunningham and Urbano 2015; Abreu et al. 2016; Degl'Innocenti, Matousek and Tzeremes 2019; Pickernell et al. 2019; Sánchez-Barrioluengo and Benneworth 2019).

The gender diversity metric is negative and significant across the models (yet only weakly significant). These results are in line with the findings of Bear and Woolley (2011), which suggests that in male dominated fields, the performance benefits of gender diverse teams are not fully realized due to additional integration challenges. From Table 1, we can confidently conclude that the teams arising from projects funded by the EPSRC are male dominated. The female PI effect is non-significant across models, this result may reflect team dynamics proposed by social role theory; that in these male dominated settings, the atypicality of women may results in inaccurate judgements of their skills (and even leadership capabilities) by other team members.

When examining the centrality effects, only project eigenvector centrality is positive and significant, this suggests that central, prestigious projects are more likely to produce output that is published in journals with higher SJR scores. Yet, the PI centrality and the project opportunity (captured by project betweenness centrality) is not associated with the quality of the journal output as measured by the SJR metric. The project centrality is based on the project-organization network; this results suggests that projects linked to well-connected organizations are associated with higher SJR scores. This suggests organizational resources (rather than an individual's personal collaboration network) are more important for publication results (as measured by the SJR metric).

Table 3 presents the results from the regression models with interaction effects, where the centrality metrics are interacted with PI gender. This is to examine whether centrality impacts the project performance in a different way when there is a female PI—are females more likely to tap into their network to increase the average SJR score of the project? For the majority of models, the results are insignificant, for both the baseline and the interaction effects. Project eigenvector centrality is positive and significant (consistent with the main model); yet, the interaction is non-significant. However, there is a negative and significant interaction effect for PI betweenness centrality. This indicates that a project with a female PI with a higher betweenness centrality, is associated with a lower average SJR score for publication outputs. This suggests that female PIs do not necessary gain any advantages or opportunity from their betweenness centrality and brokering positions (compared to their male counterparts). This is a key finding, as it indicates that female PIs do not benefit (in terms of journal performance) from their network position in the UK STEM research funding system.

Discussion and conclusion

This article posed four research questions examining the link between team gender diversity, position in the UK research system, and the average SJR score for publication outcomes of a project. Our findings indicate that gender diversity does not result in higher average SJR scores for publication outputs from publicly funded STEM projects in the UK. However, the gender results are not negative and significant, rather they are insignificant; potentially indicating further work is required to unpack the relationship between female PI and project outcomes EPSRC funded research grant projects. The most notable issue from the descriptive statistics and network visualizations is the lack of female representation on research projects, with over 70% of projects having no female representation, and less than 15% having a female lead. This is in line with the work of Lerchenmueller and Sorenson (2018) who note that female researchers become a PI at a 20% lower rate than male researchers. This finding emphasizes a need for strict policy and recommendations from research councils in the funding criteria, for some female representation on these projects. This finding suggests that for most projects, the number of women on these teams is not at a sufficient level to reach a 'critical mass' to change the team behaviour (and potential outcomes) (Etzkowitz et al. 1994).

The low levels of female representation suggests that there is a need for policies that not only encourage, but guarantee women's equitable participation in all areas of STEM (Bautista-Puig, García-Zorita and Mauleón 2019), in UK

Table 2. Main regression results

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	−0.8289*** (0.0590)	−0.8294*** (0.0590)	−0.8308*** (0.0597)	−0.7340*** (0.0604)	−0.8241*** (0.0599)	−0.8232*** (0.0591)
Project value	0.0863*** (0.0056)	0.0863*** (0.0056)	0.0864*** (0.0056)	0.0807*** (0.0056)	0.0859*** (0.0057)	0.0858*** (0.0056)
Project duration	0.1209*** (0.0107)	0.1209*** (0.0107)	0.1209*** (0.0107)	0.1197*** (0.0106)	0.1211*** (0.0107)	0.1210*** (0.0107)
Proportion of non-academic organizations	−0.0486** (0.0157)	−0.0485** (0.0157)	−0.0482** (0.0158)	−0.0587*** (0.0157)	−0.0487** (0.0157)	−0.0496** (0.0157)
Russell group lead organization	0.1377*** (0.0118)	0.1377*** (0.0118)	0.1376*** (0.0118)	0.1166*** (0.0121)	0.1371*** (0.0119)	0.1371*** (0.0118)
Proportion of females	−0.0618** (0.0190)	−0.0735* (0.0332)	−0.0733* (0.0332)	−0.0770* (0.0331)	−0.0734* (0.0332)	−0.0739* (0.0332)
Female PI		0.0119 (0.0277)	0.0118 (0.0277)	0.0104 (0.0276)	0.0123 (0.0277)	0.0126 (0.0277)
Project betweenness centrality			−0.0009 (0.0056)			
Project eigenvector centrality				0.0403*** (0.0057)		
PI betweenness centrality					0.0029 (0.0056)	
PI eigenvector centrality						0.0094 (0.0055)
Num. obs.	9961	9961	9961	9961	9961	9961
R^2	0.0945	0.0945	0.0945	0.0989	0.0945	0.0948
Adj. R^2	0.0940	0.0939	0.0939	0.0983	0.0939	0.0941

* $P < 0.05$;
** $P < 0.01$;
*** $P < 0.001$.

Table 3. Interaction effect regression results

	Model 7	Model 8	Model 9	Model 10
Intercept	−0.8325*** (0.0598)	−0.7353*** (0.0605)	−0.8267*** (0.0599)	−0.8241*** (0.0591)
Project value	0.0866*** (0.0056)	0.0808*** (0.0056)	0.0866*** (0.0057)	0.0860*** (0.0056)
Project duration	0.1208*** (0.0107)	0.1194*** (0.0106)	0.1197*** (0.0107)	0.1207*** (0.0107)
Proportion of non-academic organizations	−0.0480** (0.0158)	−0.0584*** (0.0157)	−0.0494** (0.0157)	−0.0492** (0.0157)
Russell group lead organization	0.1376*** (0.0118)	0.1167*** (0.0122)	0.1379*** (0.0119)	0.1374*** (0.0118)
Proportion of females	−0.0727* (0.0332)	−0.0750* (0.0332)	−0.0911** (0.0335)	−0.0773* (0.0332)
Female PI	0.0113 (0.0277)	0.0085 (0.0277)	0.0142 (0.0277)	0.0135 (0.0277)
Project betweenness centrality	−0.0023 (0.0062)			
Project betweenness centrality × female PI	0.0069 (0.0137)			
Project eigenvector centrality		0.0381*** (0.0062)		
Project eigenvector centrality × female PI		0.0139 (0.0151)		
PI betweenness centrality			0.0090 (0.0058)	
PI betweenness centrality × female PI			−0.0730*** (0.0196)	
PI eigenvector centrality				0.0111* (0.0056)
PI eigenvector centrality × female PI				−0.0327 (0.0245)
Num. obs.	9961	9961	9961	9961
R^2	0.0945	0.0990	0.0958	0.0949
Adj. R^2	0.0938	0.0983	0.0950	0.0942

* P < 0.05;
** P < 0.01;
*** P < 0.001.

research council funded projects. As these projects do not only represent research interests, but represent key, potentially career defining, opportunities in the workplace, that can be a steppingstone to upper management positions. Such a practice could result in an increase in the representation of females in key positions within STEM and may be a first step in patching the 'leaky pipeline'. In addition, this could help overcome other issues in STEM, such as the male-dominated culture (Smith et al. 2013; Baird 2018; Kelley and Bryan 2018), and help to reduce the barriers preventing females from reaching top academic positions (Best et al. 2013).

In our regression results, we do not find support for the business case of gender diversity on projects, as there is no positive relationship between project publication success and proportion of females. However, this is not necessarily a surprise, given the low number of females in this system. This suggests that there is a need to increase the number of females involved in these projects before properly unpacking the potential publication related benefits (Xu 2008; Van Miegroet et al. 2019). Rather the results support the work of Bear and Woolley (2011), which highlight that in male dominated profession team gender diversity may not have positive performance impact. These results also suggest that there is some support for social role theory, which states that in male dominated settings, the atypicality of women may result in their team members inaccurately judging their capabilities, which can restrict the contribution female team members can make to project outcomes (Joshi 2014).

To address the fourth research question posed by this article, a set of centrality variables were included in the model, along with a set of interaction effects. The results indicates that projects with high eigenvector centrality, linked to well-connected organizations, were more likely to produce higher quality journal output. This indicates that there is a need to further explore the link between prestige and performance in STEM (perhaps going beyond journal citation metrics such as SJR). The interaction effects were chiefly non-significant, however, for PI betweenness centrality the interaction effect was negative and significant. This indicates that projects with a female PI that had a higher betweenness centrality were associated with lower publications with a lower average SJR score. This suggests the current institutional environment of STEM in the UK research system does not allow for female PI to fully utilize and exploit their network position (and network opportunity) for project performance gains. This indicates that further research is needed to identify the barriers that exist preventing females in STEM from benefitting from their network ties.

A point to note is that the total variance explained by the models is rather low (as indicated by the R^2); a potential explanation for this is that the publication success of a project may depend on factors that we do not capture here, such as the overall research and publication experience of the team. For instance, what we do not capture is an actor's other network ties—those outside of the UK research system, that they can draw upon to increase the publication success of a project. Furthermore, publication may not be completely reported to the funder, and it may be published at a later stage.

Whilst this study contributes to the discussion of gender diversity in STEM by providing an empirical investigation of the interplay between project outcomes and team composition, there are a number of limitations to acknowledge. One limitation is that, similar to other empirical work such as Ehrlinger and Dunning (2003) and Park et al. (2011), we treat STEM as a single monolithic category. However, empirical work has demonstrated that different fields within STEM have different cultures (including the extent to which they are associated with masculine stereotypes) (Deemer et al. 2014; Leslie et al. 2015) and different levels of gender diversity (Cimpian, Kim and McDermott 2020). For instance, Cheryan et al. (2017) find in the case of the US undergraduate programmes, female participation in STEM fields is higher in biology, chemistry and mathematics, and much lower in computer science, engineering and physics. In this study research grants awarded by the EPSRC are consider and whilst the EPSRC funds STEM research, is cover a wide range of different disciplines. This may explain some of the insignificant effects in the models, for instance it may explain the non-significant female PI effects or the weakly significant female proportion, where positive female PI effects in more female friendly STEM fields might translate into overall moderate or non-significant effects as a result of the prevailing number of projects in less friendly STEM fields (such as computer science).

A further limitation of this study is that the dependent variable is only linked to the publication outcomes, and in particular the SJR index. Given there is some debate over gender bias in citation metrics, this suggests a need for future research to examine the link between gender diversity on STEM projects and other measures of a project's performance. This indicates a need for the development of metrics that can be better used to unpack the impact of gender diversity on team, performance, even when the representation is low. There is a need to go beyond the so called 'counting and rating' publications system (Good et al. 2015; Sætnan, Tøndel and Rasmussen 2019), as these may limits the career progression benefits of leading on UK research council funded projects for the female leads. Other metrics to explore include intellectual property outcomes, policy influence, and public engagement. A further approach to measure the output of a project would be to develop productivity metrics (Gaughan, Melkers and Welch 2018; Frandsen, Jacobsen and Ousager 2020). The current findings suggest that when evaluating research projects, citation metrics alone should not be utilized, especially when considering the performance of gender diverse teams in the male dominate field of STEM. Reale et al. (2018) discuss alternative options to measure research activity in the case of the social sciences. They discuss alternative metrics, such as those they focus on research impact and transdisciplinary collaborative knowledge exchange that concentrates on policy and society.

Notes

1. Two-mode (or bipartite) networks are networks that consider the links between two sets (or different types of actors) and do not include within set (or type) connections. In this case, for one of the networks, we are examining the linkages between project and organizations (the two sets) and do not consider project-to-project linkages or organization-to-organization linkages. A more in-depth discussion of two-mode (or bipartite) networks is provided by Knoke et al. (2021).
2. The list of Russell Group Universities can be found here: https://russellgroup.ac.uk/about/our-universities/.
3. An inspection of the Q–Q plot and the histogram of the residuals from the estimated models indicate consistency with normality, in line with the assumptions required for OLS.

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