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Is funding related to higher research impact? Exploring its relationship and the mediating role of collaboration in several disciplines

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Abstract

The funding process is increasingly under scrutiny in order to ensure the effectiveness of research investments. This paper contributes to improve our understanding of the effects of funding on research performance through the analysis of the scientific publications of Spain-based researchers in seven disciplines during a five-year period. Funding data are extracted from the "Funding acknowledgment" field of the WoS database. Firstly, funded research is compared to the non-funded one regarding impact and collaboration through bivariate analyses. Funded research is published in more prestigious journals, attains higher citation rates and is developed in teams of greater size in all disciplines, but only in a few of them is associated to greater extra-mural collaboration. Secondly, a logistic regression model is used to explore whether funding contributes to explain the likelihood of papers to attain citation rates above world average controlling for other variables such as prestige of publication journal and collaboration. Thirdly, funding shows direct and indirect effects on the citation rate of papers. Indirect effects are mediated through the publication of more complete papers, in more prestigious journals and with more extensive collaboration, although the presence and magnitude of these effects vary by discipline. The results are discussed in the context of their interest for research policy.

Keywords: Research funding, Scientific collaboration, Research impact, Funding acknowledgments, Mediation analysis.

1.Introduction

Research is an important driver of social and economic development of countries, but achieving an adequate level of R&D investment is hindered by the rising costs of research and the scarcity of economic resources. As a result of the latter, the funding process is more and more under scrutiny and the evaluation of research funding has become a great concern for governments and agencies (Lane and Bertuzzi, 2011). Thus, measures of the returns of R&D investment are increasingly demanded as a way to demonstrate the efficient allocation of R&D funds. Both quantitative and qualitative techniques have proved useful to study the impacts of funding and bibliometric indicators may play an important role among the former (Bloch et al. 2014). The inclusion of funding acknowledgments in different bibliographic databases such as Web of Science (since 2008) and Scopus (since 2013) has contributed to enhance funded-related studies, since it enables funding agencies to track the results of their investment and explore whether funding affects knowledge production in terms of quantity and impact of scientific publications (Rigby, 2011).

The **relationship between funding and research impact** has been studied in the literature from a bibliometric perspective at different levels of analysis. Some studies focus on the results of specific funding organizations or programs while others analyse the presence of funding in the scientific publications of specific centres, scientific domains and countries. Funded research was more cited than the non-funded one in a study dealing with world publications collected by WoS (Costas and Van Leeuwen, 2012) as well as in several studies focused on different fields such as medicine (McAllister and Narin, 1983; Lewison and Dawson, 1998), economics (Peritz 1990), library and information science (Zhao 2010) and nanotechnology (Wang and Shapira 2015). Moreover, a positive significant association between funding and citations was observed in seven disciplines of science, technology and mathematics (Yan, Wu and Song, 2018). Considering other levels of analysis, such as centre or country, research funding has been also associated with higher impact publications (e.g. Zhao et al, 2018; Gok, Rigby and Shapira, 2016, respectively) while in a number of studies focused on specific funding agencies, grant funded publications show higher citations than non-grant sponsored papers (Trochim et al. 2008; Campbell et al. 2010). In spite of the former, no clear relationship between funding and citations has been also described, for example in specific journals (Harter and Hooten, 1992; Rigby, 2013), fields (Haslam et al. 2008) or funding agencies (Langfeldt, Bloch and Sivertsen, 2015). Differences in the scope of the study (national or supranational), unit of analysis (centres, disciplines, countries, funding schemes..) and methodological approach hinder comparisons among studies, while differences between disciplines may also exist.

In fact, several reasons would lead us to **expect higher quality for funded research**. On the one hand, funding is usually awarded through a review process, so funded papers might be of higher quality because they have successfully undergone an evaluation process (Lewison and Dawson, 1998). Besides, funding may have a positive influence on research because economic resources may allow scientists to improve their infrastructures and access to data (Katz and Martin, 1997) as well as to conduct more rigorous studies (Reed et al. 2007), which may result in higher quality papers. Moreover, funding may foster collaboration, which may turn out in higher quality research because it enables scientists to share skills and ideas, to use resources more efficiently and to produce more creative and relevant research (Katz and Martin, 1997) so, from this point of view, collaboration could play the role of a mediating factor between funding and research impact.

The effects of funding on collaboration have been addressed in a number of studies. A greater degree of collaboration –measured through the number of authors per paper- has been described for the best supported fields by some authors (Beaver and Rosen, 1979), while funded scientists seem to have larger teams (Gullbrandsen and Smeby, 2005; Heffner, 1981; Ebadi and Schiffauerova, 2015), a higher number of different co-authors and greater embeddedness into the scientific community (Ubfal and Maffioli, 2011). In a study in seven disciplines, Yan et al (2018) noted that funding had a positive effect on papers´s impact and that it was magnified by multiple authorship and multiple institutions, thus suggesting a moderator function for collaboration. Although a positive association between funding and number of authors was observed in a recent study on two biomedical fields in Spain, funded papers show a higher number of institutions only in one of the disciplines, which raises the issue of to what extent funding fosters extra-mural collaboration (Álvarez-Bornstein, Díaz-Faes and Bordons, 2019). Given that research dependence on funding, collaboration practices and the relationship between funding and collaboration may vary by discipline, extending the analysis to other domains seems to be necessary to make comparisons across disciplines. Accordingly, this study aims at characterize funded research and explore the relationship between research funding and impact, with special focus on the role of some influential variables such as collaboration. With this purpose, the scientific publications of Spain-based scientists in seven disciplines during a five-year period are analysed.

The interest of this study is to contribute to understand the effects of research funding on research performance with the aim of providing agencies useful information in their effort to make more efficient and informative decision about funding allocation.

2.Objectives

In this context, this study seeks to answer the following questions:

a) Is funded research published in more prestigious journals than the non-funded one? Does funded research obtain higher citation rates? A positive answer is expected assuming that funding is usually awarded after an evaluation and, once it is granted, allows scientists to improve their infrastructures, access to data and mobility, which may result in higher quality research (Question 1)

b) Is funded research more collaborative? One might expect higher collaboration since, on the one hand, collaboration is sometimes formed in answer to funding opportunities and, on the other hand, economic support may allow scientists to enlarge their social networks (e.g. through conference attendance, stays in foreign centres, etc.) (Question 2).

c) Is funding more often acknowledged in internationally co-authored papers? Higher funding rates could be expected for internationally co-authored papers assuming the greater complexity of cross-country relationships which may require more often a formal agreement and economic support (Question 3)

d) Is funded research more likely to be cited above world average? Does funding contribute to explain the citation rate of papers considering the simultaneous effect of other potential influential variables such as collaboration and publication journal prestige? To what extent do these influential variables play a mediating role between funding and research impact? (Question 4)

Since the answer to these questions may vary by field, these issues are analysed in seven different disciplines to make cross-disciplinary comparisons possible.

3.Methods

3.1. Data

Scientific publications of Spain-based scientists in seven selected disciplines during 2010-2014 were downloaded from the Web of Science (WoS) database, produced by Clarivate Analytics. For the delimitation of disciplines, the WoS classification of journals into subfields was considered. Disciplines were selected according to different criteria: a) one discipline from each of the seven broad research areas considered in ACUTE studies (see table 1) based on the aggregation of WoS subject categories, in order to include fields with different patterns of knowledge production; b) selected disciplines should have a collaboration pattern representative of its reference area, since we assume that funding may have an influence on collaboration and it may vary by research area; c) disciplines of similar size (number of publications) were selected to make balanced comparisons possible. According to these criteria, the following disciplines were studied: Biodiversity Conservation (BIOD), Cardiovascular System (CARD), Polymer Sciences (POLYM), Spectroscopy (SPEC), Statistics & Probability (STAT), Telecommunications (TELEC) and Virology (VIROL) (table 1). No discipline was selected from Social Sciences and Humanities because in these two areas funding acknowledgments were only collected in Web of Science since 2015 and 2017, respectively. During the period 2010-2014 a total of 12,461 papers were published in the seven disciplines, which differ in their basic/applied nature, national/international orientation and collaboration patterns/intensity.

Table 1. Disciplines selected by research area

Research area	Selected discipline
Agriculture, Biology and Environment	Biodiversity Conservation (BIOD)
Biomedicine	Virology (VIROL)
Clinical Medicine	Cardiovascular System (CARD)
Chemistry	Polymer Science (POLYM)
Engineering & Technology	Telecommunications (TELEC)
Mathematics	Statistics and Probability (STAT)
Physics	Spectroscopy (SPEC)

Note: see Bordons et al (2018) for a detailed description of the composition of the research areas

Only articles were considered[1]. Other types of documents such as reviews, editorials or letters were excluded because they are generally less likely to be written with funding support. The study is limited to papers written in English because acknowledgments should be written in this language to be collected by WoS (Álvarez-Bornstein, Morillo & Bordons, 2017).

3.2. Funding

Funding data were extracted from the "Funding acknowledgment" (FA) field of the WoS database. The agencies included in the Funding Agency section were normalized and classified with a web application created for this purpose. For each discipline, its funding rate, that is, the percentage of articles with funding acknowledgments, and the average number of agencies per paper were calculated.

[1] A slightly lower number of papers is analysed in this study, as compared with Álvarez-Bornstein et al. 2019, where articles and reviews were considered.

By “funded paper” we mean research that explicitly acknowledges the support of a research sponsor or grant award to develop the research. We consider “non-funded paper” that without funding acknowledgments, although we are aware that it might be supported by internal core funding. Higher quality can be assumed for external grants since they are more often awarded through a peer review process within competitive calls (Rigby, 2011).

3.3. Collaboration indicators

The following indicators were obtained for the analysis of collaboration:

- Number of authors per paper
- Number of institutions per paper
- Collaboration type. Percentage distribution of papers by different categories: (a) non collaborative papers (only one institution), (b) only national collaboration (two or more Spain-based institutions), (c) only international collaboration (one Spanish institution and at least one foreign institution), and (d) national & international collaboration.

3.4. Impact indicators

Different indicators based on the prestige of the publication journal (%Q1 and %D1 papers) and the citations received by the papers (share of uncited papers, relative citation rate and share of highly cited papers) were used.

- Share of papers in first quartile journals (%Q1). Percentage of articles published in the 25% of journals with the highest impact factor within each discipline, following the Journal Citation Reports (JCR) in the publication year of the article.
- Share of papers in first decile journals (%D1). Percentage of articles published in the 10% of journals with the highest impact factor within each discipline, also following the JCR in the publication year of the article.
- Relative citation rate (RCR). Number of citations received by each article since its publication until 2017, divided by the average number of citations received by the world in the corresponding discipline and during the same period. A value above 1 indicates a citation rate higher than the world average, while values below 1 point to the opposite situation. This indicator is used to account for different citation patterns across disciplines (Moed, 2005). The variable RCR_c was also built. This is a categorical variable, which takes two possible values: 1(RCR >1, that is, above world average) or 0 (RCR<=1, at or below world average).
- Share of non-cited articles. Percentage of articles which have not received any citation since their publication year to 2017.
- Share of highly cited papers (%HCP). Percentage of articles among the world 10% most cited within each discipline. The citation window ranges from the publication year to 2017.
- Impact funding advantage. Ratio between the share of Q1 papers in funded papers and the share of Q1 papers in the non-funded ones. In the same way, the impact funding advantage was calculated for %D1, %HCP and RCR_c indicators. An impact funding advantage greater than one denotes the higher impact of funded papers.

Main indicators of impact, as well as the number of publications and collaboration indicators by discipline, are shown in table A.1 (Appendix A). The disciplines differ in average team size (number of authors per paper), presence of inter-institutional collaboration (share of papers with more than 1 institution) and international orientation (papers with at least one foreign partner). The highest team size is observed in SPEC, CARD and VIROL, while the lowest corresponds to STAT. The highest share of inter-institutional collaboration is observed in CARD, VIROL and BIOD (more than 80% of papers with two or more centres), while TELEC shows the highest share of single-centre papers (around 1/3). Internationally co-authored papers range from 45% (STAT, TELEC) to 60% (BIOD).

3.5. Statistical methods

In order to respond to the research questions posed in this paper, different types of statistical analyses were used:

Firstly, to study whether there are significant differences between funded and non-funded papers in terms of impact (question 1) and collaboration (questions 2 and 3) the Mann-Whitney test for non-parametric distributions and the Chi^2 test were used (SPSS, version 25). For each statistical test, the differences were considered significant at $p<0.05$.

Secondly, a logistic regression analysis was applied to explore to what extent funding contributes to explain the likelihood of papers to attain citation rates above world average considering the simultaneous effect of different independent variables such as journal quartile and collaboration (question 4). As dependent variable the RCR_c was used, which is a categorical variable with two possible outcomes: citation rate below world average (RCR=<1) and citation rate above the world average (RCR >1). Journal quartile, collaboration type (4 categories: 1 centre, national collaboration, international collaboration, national & international collaboration) and number of references were used as independent variables. These variables were selected according to their relationship with research impact as described in the literature. The number of authors and number of institutions were not included in the model due to multicollinearity problems.

Thirdly, to investigate indirect effects of funding on impact (RCRc), a mediation analysis was conducted using the model 4 of the PROCESS bootstrapping macro for SPSS (v.3.4) developed by Hayes (2013). Indirect effects of funding onto RCRc through three different mediators (journal quartile, collaboration type and number of references) were analysed.

4.Results

The share of papers with FA ranges from 58% in CARD to more than 90% in VIROL. On average, 2-3 funding sources were acknowledged in each paper, showing CARD and VIROL the highest average number of sources per paper (almost 4) (table 2).

Table2. Funding rate and average number of funding agencies by discipline

	BIOD	CARD	POLYM	SPEC	STAT	TELEC	VIROL
No.Articles	1157	2473	2315	1269	1590	2515	1142
% Funded articles	88.76	58.35	90.80	85.89	83.14	83.42	91.94
No.Agencies (av)	2.85	3.65	2.61	2.89	2.36	2.43	3.82

The comparison between funded and non-funded articles regarding number of references, collaboration and impact indicators is shown in Table 3. The number of references of funded articles is higher than that of papers without funding acknowledgments in all the seven disciplines, with differences being statistically significant in six of them. This suggests that funds may contribute to the development of more comprehensive publications.

Table 3. Main features of funded vs non-funded articles by discipline

	BIOD		CARD		POLYM		SPEC		STAT		TELEC		VIROL	
	FA	No FA	FA	No FA	FA	No FA	FA	No FA	FA	No FA	FA	No FA	FA	No FA
No.Articles	1027	130	1443	1030	2102	213	1090	179	1322	268	2098	417	1050	92
No.References/article	55.36[a]	48.16	35.45[a]	27.39	41.19[a]	35.69	31.95[a]	29.23	29.47	29.25	26.57[b]	26.18	43.33[a]	32.21
Collaboration														
No.Authors (av)	5.77[a]	5.11	11.16[a]	8.06	5.10[b]	4.71	14.63[b]	8.48	3.10[b]	2.78	4.36[b]	4.17	8.87	8.10
No.Institutions (av)	4.01[a]	3.38	6.90[a]	4.36	2.62	2.52	4.52	3.34	2.37[a]	2.07	2.14[c]	2.33	5.02	4.67
% Total int. coll. papers	60.86[b]	47.69	57.93[a]	32.23	46.15[b]	56.81	52.39	51.96	45.69	41.04	43.8[c]	49.4	50.57[b]	35.87
Collaboration pattern														
%Non col.papers	15.00	24.62	6.65	24.76	24.22	22.54	24.50	21.23	24.81	36.94	36.70	33.09	12.95	2.17
%Only nat.col.papers	24.15	27.69	35.41	43.01	29.64	20.66	23.12	26.82	29.50	22.01	19.49	17.51	36.48	61.96
%Only int.col.papers	36.81	34.62	32.50	22.33	30.45	44.60	35.14	43.02	32.07	34.70	33.27	40.53	28.86	25.00
%Nat.& int.col.papers	24.05	13.08	25.43	9.90	15.70	12.21	17.25	8.94	13.62	6.34	10.53	8.87	21.71	10.87
Impact														
%D1 Articles	23.41[c]	14.17	31.56[a]	15.94	38.21[a]	26.07	2.42	1.69	30.13[a]	18.49	16.03	16.88	20.92[b]	10.99
%Q1 Articles	56.81[b]	44.17	56.05[a]	31.78	68.99[a]	46.92	25.00[b]	16.85	42.03[a]	26.79	42.36[b]	35.52	51.58[a]	17.58
Relative Citation Rate (RCR)	1.23[a]	0.92	1.61[a]	1.04	1.00[a]	0.73	1.22[a]	0.90	0.94[a]	0.57	1.01[c]	1.11	1.09[a]	0.71
%RCR>1	40.60[a]	26.92	46.02[a]	24.76	36.39[a]	19.72	40.73[b]	30.17	26.25[a]	17.16	30.46[b]	24.70	36.67[a]	20.65
% Uncited articles	4.38[c]	8.46	2.43[a]	11.26	3.66[b]	7.98	6.06[b]	11.17	14.60[a]	23.88	12.39[b]	17.75	1.81[b]	7.61
% HCP	13.53	9.23	22.11[a]	10.78	10.85	7.98	20.00	18.44	14.37[b]	8.58	12.44	10.79	11.52	5.43

Note: shaded cells denote that funded values are significantly higher than non-funded ones. Mann-Whitney test is used for the comparison of continuous variables (mean ranks are compared) and Chi^2 test for categorical ones.

[a] $P<0.001$; [b] $P<0.01$; [c] $P<0.05$

4.1. Impact and funding status of research

Concerning research impact, it is interesting to note that funded research presents on average a significantly higher RCR than the non-funded one in all disciplines (table 3, figure 1). Besides, funded papers are more likely to become HCP, although the differences are statistically significant only in two disciplines (CARD and STAT).

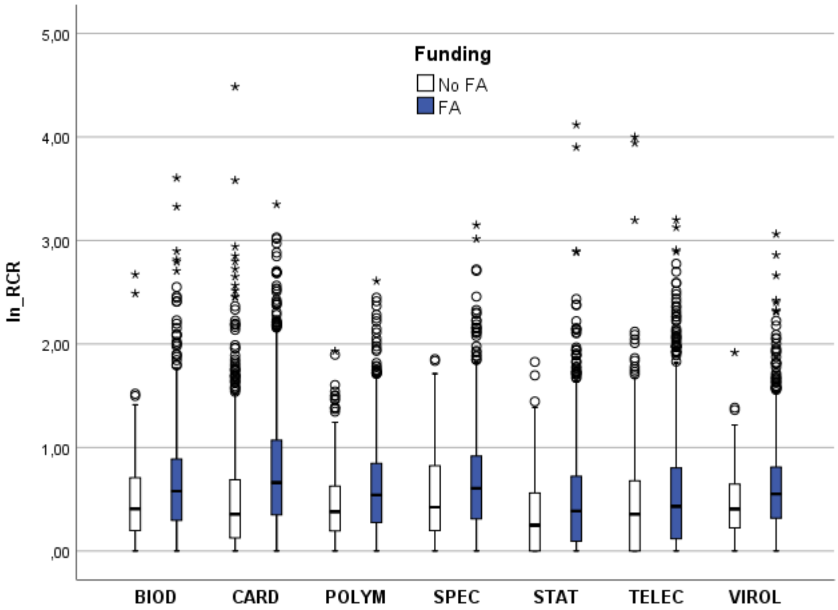

Figure 1. RCR by funding status and discipline
Note: RCR was transformed (ln) to improve visualization of data

In fact, funded papers tend to surpass non-funded ones in most of the impact indicators, that is, share of Q1 papers, share of D1 papers, share of papers cited above world average (RCR>1) and share of HCP (table 3). The funding advantage for each of these indicators, measured through the ratio between the value attained by each indicator in funded papers and the corresponding value in the non-funded ones is greater than 1 in most of the cases (figure 2). The most outstanding results are observed in VIROL and CARD since the share of HCP and the share of D1 papers are around two times greater in the case of funded papers. Besides, the share of Q1 papers in VIROL is almost three times greater in funded papers than in the non-funded ones. An advantage above 50% can be observed also in all impact measures in STAT, and in Q1 publications in BIOD. The least funding advantage in impact is found in TELEC, where the impact of funded papers surpasses non-funded values in 20% at best.

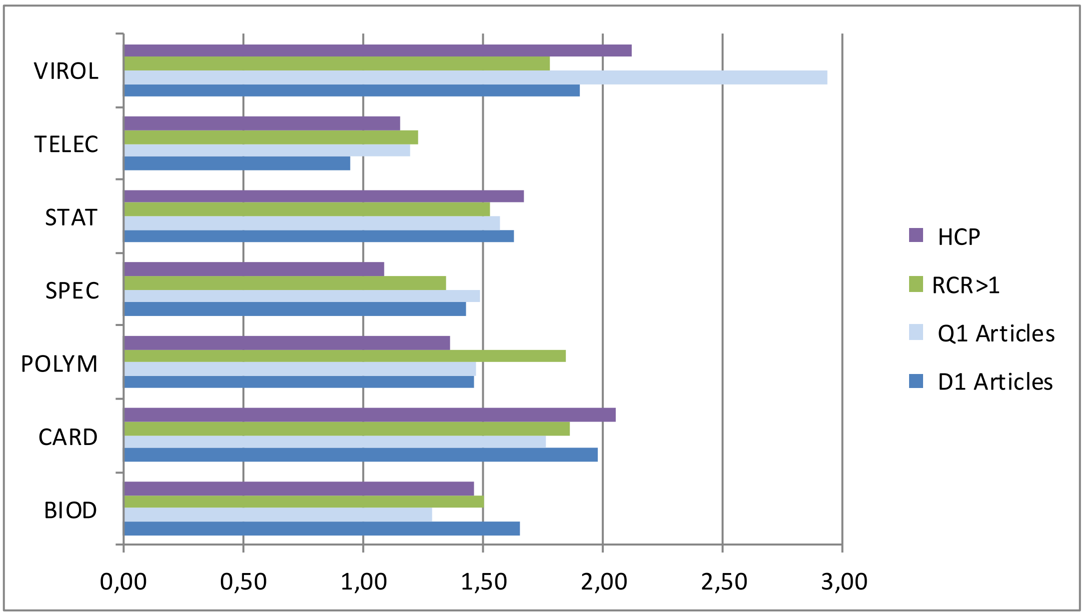

Figure 2. Impact funding advantage by discipline

4.2.Collaboration and funding

Funded articles show a higher number of authors than the non-funded ones (differences significant in all fields except in VIROL), which might support the hypothesis of funding as enhancer of collaboration among authors. Concerning the collaboration among centres, it tends to be higher in funded papers, but only in three fields the differences were statistically significant (BIOD, CARD, STAT), whereas funded papers in TELEC show a lower number of centres than the non-funded ones (table 3). Figures 3a and 3b show the distribution of the number of authors and centres per paper by discipline and funding status. It is interesting to note that outliers with an extremely high number of authors /centres are more often found in funded papers in most of the fields.

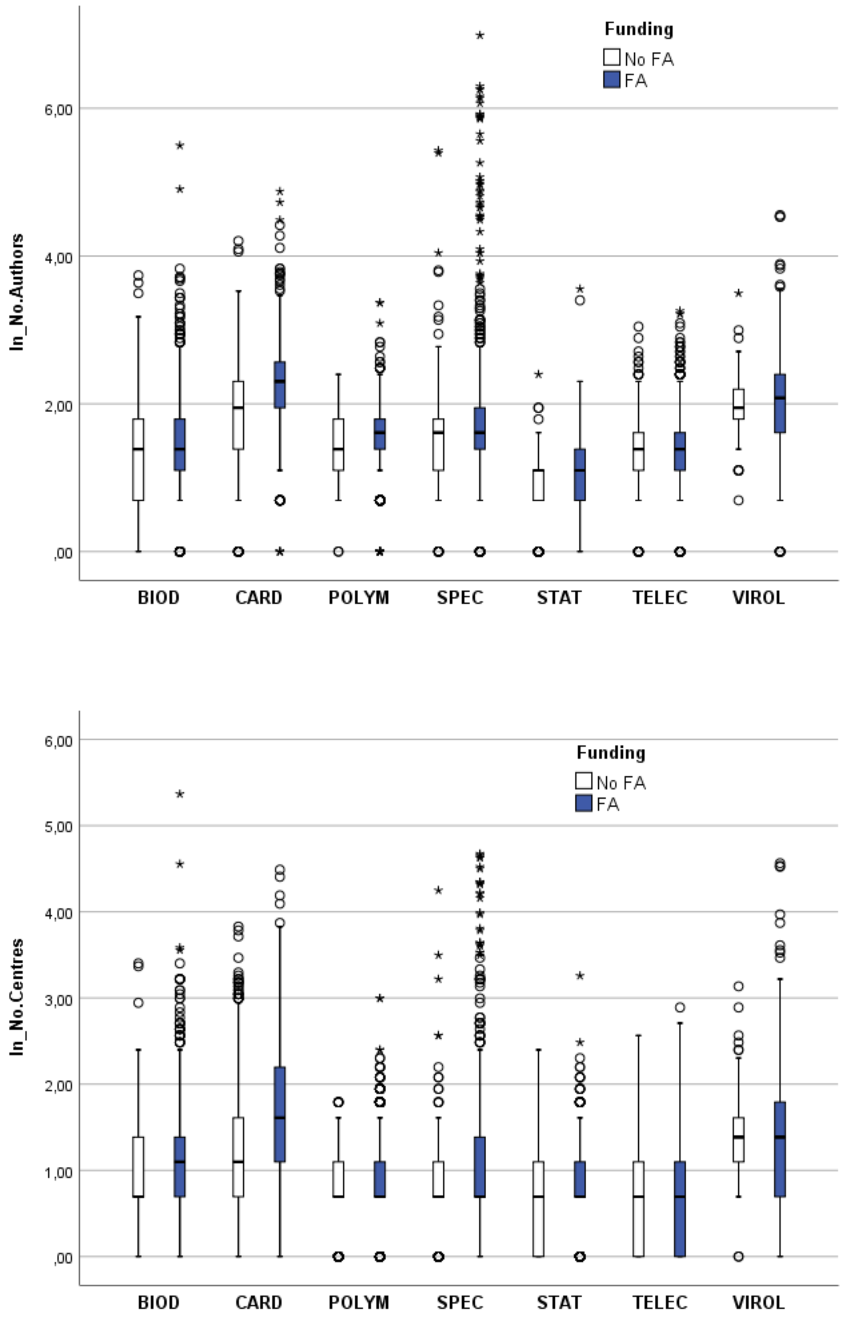

Figure 3. Distribution of the number of authors and number of centres per paper by discipline and funding status

Note: number of authors and number of centres are transformed (ln) to improve visualization of data

Although we expected to find a higher share of papers with funding among those internationally co-authored, this was observed only in three disciplines. It was very evident in CARD, and less evident but also significant in BIOD and VIROL (figure 4). Interestingly, these three fields have in common a high share of collaborative papers (more than 1 centre in at least 80% of the papers) and, more importantly, a high share of highly-collaborative ones (at least 5 centres in more than 20% of the papers) (table A.1.) (Appendix A). This suggests that funding might be especially needed to make these broad collaborations possible, but that some kind of internationally co-authored research can be developed without specific funding support, maybe enhanced by the increasing online interaction of scientists via web.

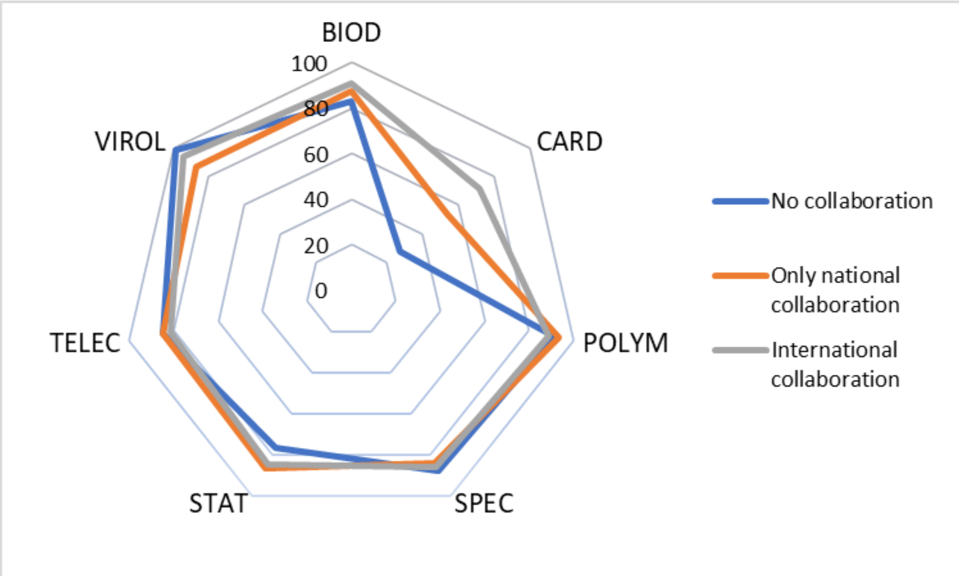

Figure 4. Funding rate of papers by type of collaboration and discipline

Not surprisingly, in the set of funded papers, the number of funding agencies tends to increase with the number of authors and with the number of centres (table 4), probably because different authors and teams may have different grants for the development of the research. Even if there is a common funded project shared by all the participants (which not always exists), some researchers may have their own grants or personal fellowships that have enhanced their participation in a given paper and therefore are acknowledged. As the number of authors and centres increases, and different teams are involved in the research, the diversity of agencies acknowledged also grows, and it is mostly higher in internationally co-authored papers (figure 5).

Table 4. Spearman correlation between number of funding agencies and number of centres/authors by discipline (N=number of funded papers)

	No. Funding agencies						
	BIOD (N=1021)	CARD (N=1440)	POLYM (N=2091)	SPEC (N=1088)	STAT (N=1278)	TELEC (N=2083)	VIROL (N=1042)
No.Centres	0.225**	0.122**	0.217**	0.266**	0.226**	0.047	0.181**
No.Authors	0.193**	0.178**	0.169**	0.290**	0.175**	0.041	0.236**

Note. **significant differences at p<0.01

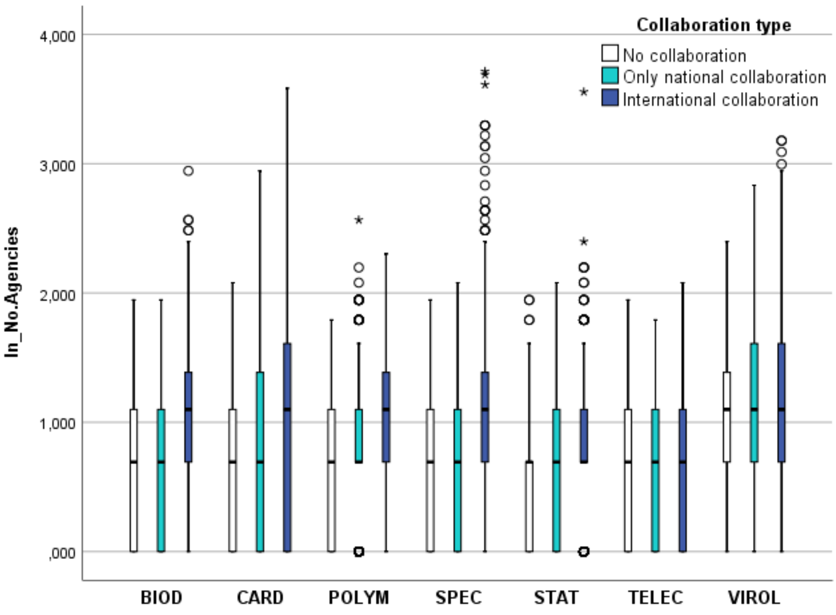

Figure 5. Distribution of the number of funding agencies by type of collaboration and discipline (only funded papers considered)
Note: the number of agencies is transformed (ln) to improve visualization of data

4.3.Funding contribution to research impact

A logistic regression analysis was used to explore to what extent funding contributes to explain the likelihood of papers to attain citation rates above world average (table 5). As dependent variable the RCR_c was used, which is a categorical variable with two possible outcomes: citation rate at or below world average (RCR=<1) (coded as 0) and citation rate above the world average (RCR >1) (coded as 1). In a first step, a significant positive zero-order relationship between FA and RCR_c was observed in all disciplines. Secondly, the effect of funding on RCR_c when considering simultaneously three additional explanatory variables (quartile of publication journal, collaboration type and number of references) was analysed. In this case, 68% of the cases were correctly predicted by the model. As shown in table 5, the three independent variables are significant, while a significant positive association between funding and RCR_c is still observed in four disciplines (CARD, POLYM, SPEC and STAT). The odds of funded research to be cited above world average are greater than for non-funded papers in five disciplines: 30-40% more likely in CARD and SPEC; 51% in STAT and 85% in POLYM.

Interestingly, journal quartile shows the greatest effect in the model in all disciplines (the highest Wald value in all models, p<0.001). The likelihood to be cited above world average decreases as the quartile increases from Q1 to Q4 (negative B coefficients). For example, in BIOD, POLYM and VIROL publications in Q2 journals are 71%, 74% and 69% less likely to be cited above world average than those in Q1 (reference category) (odds ratio= 0.29, 0.26 and 0.31, respectively).The number of references shows a positive influence on the likelihood to become cited above world average (OR>1), so as the number of references increases also do the odds of being cited above the world average. Concerning the type of collaboration, it is also significant, being the higher effect observed in CARD, where international collaboration (only or in combination with national collaboration) increases the likelihood of being cited above world average around 2.6-3 times as compared with papers published by a single centre. We observe that internationally co-authored papers are more likely to be cited above average in all disciplines, while the presence of both national & international collaboration shows the highest positive influence on impact in BIOD, SPEC and TELEC. Moreover, national collaboration does not contribute significantly more than no collaboration at all (1 centre papers) to become cited above world average in any of the disciplines.

Returning to the effect of funding, it is interesting to note that it does not contribute significantly to the model in the case of BIOD, TELEC and VIROL (table 5). Although a positive zero-order relationship was observed between RCR_c and funding also in these disciplines, funding is no longer significant when the other variables are included in the model, which means it does not provide any additional information to that yielded by the rest of the variables. Does it mean that funding does not contribute to the publication of more impactful research in these disciplines? An alternative hypothesis is that funding might have indirect effects on RCR_c enhancing the publication of more comprehensive papers (with a longer reference list) and/or papers in more prestigious journals (lower quartile journals) and/or more extensive collaboration; therefore, once these three variables were included in the model, less or no supplementary effect (depending on the discipline) is due to funding.

Table 5. Results of logistic regression to explain RCR above world average

	BIOD			CARD			POLYM			SPEC			STAT			TELEC			VIROL		
	B	Wald	Exp(B)	B	Wald	Exp(B)	B	Wald	Exp(B)	B	Wald	Exp(B)	B	Wald	Exp(B)	B	Wald	Exp(B)	B	Wald	Exp(B)
Journal Quartile		102.946			164.415			142.606			31.443			94.649			175.887			88.916	
Q2	-1.229***	66.597	0.293	-0.960***	86.303	0.383	-1.349***	115.506	0.259	-0.598***	18.150	0.550	-0.723***	25.099	0.485	-0.942***	76.062	0.390	-1.162***	47.081	0.313
Q3	-2.362***	36.682	0.094	-1.693***	76.224	0.184	-1.756***	36.580	0.173	-0.820**	10.229	0.441	-1.597***	47.916	0.202	-1.598***	110.894	0.202	-1.535***	65.287	0.215
Q4	-3.613***	12.592	0.027	-2.174***	50.163	0.114	-20.693	0.000	0.000	-1.740***	18.397	0.176	-1.677***	53.757	0.187	-1.719***	51.243	0.179	-21.701	0.000	0.000
Col.Type		15.872			70.324			14.206			10.670			8.879			26.022			16.535	
Nat.Col.	0.134	0.340	1.143	0.145	0.682	1.156	-0.176	1.784	0.838	0.056	0.101	1.058	-0.024	0.019	0.976	0.092	0.434	1.097	0.116	0.245	1.123
Int.Col.	0.635**	8.823	1.887	0.961***	28.767	2.613	0.27*	4.596	1.311	0.283	3.133	1.327	0.386**	5.496	1.470	0.485***	18.084	1.624	0.683**	8.379	1.979
Nat&int.Col.	0.644**	7.942	1.904	0.869***	21.047	2.385	0.119	0.626	1.126	0.561**	8.575	1.753	0.251	1.401	1.285	0.594***	13.355	1.811	0.565*	5.317	1.760
No.References	0.017***	28.115	1.017	0.022***	58.448	1.022	0.014***	23.802	1.014	0.017***	20.796	1.017	0.021***	31.388	1.022	0.016***	33.945	1.017	0.016***	24.798	1.016
Funding	0.211	0.776	1.235	0.316**	9.149	1.372	0.615***	10.127	1.850	0.347*	3.624	1.415	0.415*	5.020	1.514	0.251	3.392	1.285	0.120	0.169	1.128
Constant	-1.400	18.460	0.247	-1.340	52.721	0.262	-1.429	36.500	0.239	-0.977	14.080	0.377	-1.682	46.183	0.186	-1.143	44.562	0.319	-1.161	8.950	0.313
Nagelkerke R2		0.257			0.275			0.170			0.091			0.162			0.155			0.215	

Note: The reference category was the first one for all variables (Q1 for Journal Quartile; No collaboration for Collaboration Type; No funding for Funding).
OR= Odds ratio= Exp (B)
*P<0.05; **P<0.01; ***P<0.001

To test the hypothesis of the indirect effects of funding onto impact (RCR_c) through three mediators (journal quartile, collaboration type and number of references), a mediation analysis was conducted on the SPSS PROCESS bootstrapping macro (model 4) developed by Hayes (2013). Figure 6 depicts the mediator model in which the variable funding (X) is modelled as affecting RCR_c (Y) through three mediators (M1, M2, M3). Through the PROCESS macro, several regressions are conducted in each discipline (funding predicting each mediator, each mediator predicting RCR_c and funding and all three mediators predicting RCR_c). It should be noted that journal quartile and collaboration type are considered ordinal variables in this analysis. We explore to what extent funding may have an influence on journal quartile (a1), collaboration type (a2) and number of references (a3), which in turn would affect impact (b1, b2 and b3, respectively) (figure 6). Thus, we have three possible indirect effects of funding on RCR_c (a1b1, a2b2 and a3b3), which are obtained by multiplying a and b, the two effects associated with each mediator. In addition, the direct effect (c`) is calculated, which is the effect of funding on RCR_c while controlling for the mediators. Through the macro PROCESS we determine which effects are significant and the coefficients associated with the various pathways (i.e. a, b, ab, c') -which are unstandardized regression coefficients- are calculated. For the sake of simplicity, only the coefficients concerning the indirect effect (ab) are shown in table 6. An indirect effect was considered significant if its 95% bootstrap confidence interval did not include zero (if the confidence interval includes zero the indirect effect is not significant because zero is in the realm of possible values of the effect).

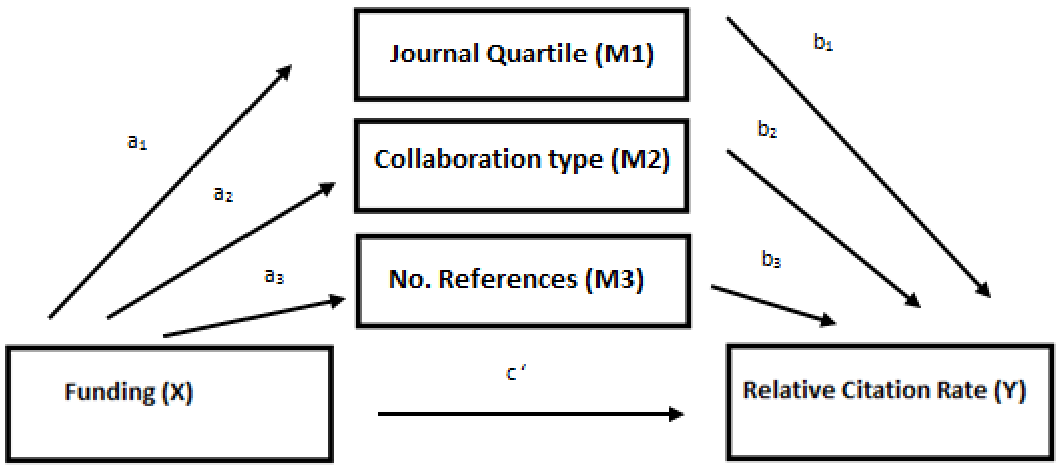

Figure 6. Mediating effects of funding on RCR_c

The indirect effects of funding on RCR_c through publication journal quartile (M1) are significant in all disciplines (table 6). Funded research tends to be published in journals better located in the impact factor ranking within each discipline (lower quartile), and lower quartile publications are subsequently more likely to be cited above world average. However, the indirect effects of funding through collaboration type (M2) are significant only in three disciplines (BIOD, CARD and STAT), in which funded research is associated to broader scope of collaboration, and the latter is related to more citations. Finally, the indirect effects of funding on RCR_c through the number of references (M3) are significant in four disciplines (BIOD, CARD, POLYM and VIROL), where funded research is associated to higher number of references, and a longer reference list increases the probability to be cited above world average. [2]

Table 6. Indirect effects of funding (X) on RCR_c (Y) through Journal Quartile (M1), Collaboration type (M2) and Number of references (M3)

	BIOD	CARD	POLYM	SPEC	STAT	TELEC	VIROL
Indirect effect							
X-->M1-->Y	0.386*	0.428*	0.459*	0.080*	0.162*	0.189*	0.519*
X-->M2-->Y	0.081*	0.220*	-0.008	0.012	0.032*	-0.019	0.038
X-->M3-->Y	0.124*	0.166*	0.077*	0.048	0.002	0.002	0.202*

*P<0.05

In summary: there is at least one significant mediator in all disciplines, while the three mediators proposed are significant only in CARD and BIOD. Moreover, it is worth mentioning that when the effect of mediators is considered, the direct effect of funding on citations disappears in some disciplines such as BIOD and VIROL (complete mediation), while remains significant in other cases (partial mediation), where funding still provides some additional information to explain $RCR_{c.}$ Anyway, the concepts of complete and partial mediation need to be interpreted cautiously. It has been argued that complete mediation is more likely to be obtained with small samples and, on the other hand, even if we find evidence of complete mediation there may be additional variables not included in our study that could be mediating (Hayes and Rockwood, 2017).

5.Discussion

This paper analyses the presence of funding in the scientific publications of Spain-based scientists in seven disciplines to gain insight into the relationship between research funding and impact as well as to explore the mediating role of some variables such as collaboration. Concerning the presence of funding, it is interesting to note that a high rate of funded papers (>80%) is observed in all disciplines but in CARD (58%), which is a clinical field with high activity from hospitals. The fact that hospital papers include funding acknowledgements significantly less often than papers by authors with other affiliations has been also described in cancer research (Lewison, 2003). The reason is that hospital papers may partly derive from clinical practice, funded internally or by sources that do not require explicit acknowledgment (Álvarez-Bornstein, Díaz-Faes and Bordons, 2019).

In answer to the first question addressed in this paper, our study shows that funded research is more often published in **high prestige journals** (first quartile journals) and tends to receive a **higher number of citations** than the research developed without any kind of external funding. These results provide additional evidence to support the positive association between impact and funding suggested by a number of studies in the literature (see Introduction section of this paper). Moreover, an interesting issue is that this positive association between impact and

[2] An additional analysis was conducted using a linear regression to explain RCR (log-transformed to reduce right skewness) (table A.2 in the Appendix). Most of the results were consistent with those of the logistic regression in terms of significance of the variables and sign of the coefficients. The only differences were found in POLYM, where neither funding nor collaboration type was significant. Nevertheless, indirect effects of funding were observed in all the seven disciplines and the same mediators were significant as when using RCR_c as dependent variable (table A.3).

funding is observed in our study in all of the seven disciplines analysed, although they differ in their patterns of knowledge production, as they are located in different points of the basic-applied and the theoretical-experimental spectra.

Concerning the second question, our interest was to explore whether **funded research is associated to higher collaboration**, being the latter measured through different indicators such as number of authors, number of centres and scope of the collaboration (national/international). Our results show that funded research tends to present a higher number of authors per paper (significant differences in all but one discipline), which is consistent with prior studies which describe a positive effect of funding on the number of co-authors (Heffner, 1981; Adams et al. 2005; Zhao, 2010; Ubfal and Maffioli, 2011). In fact, funding agencies may encourage collaboration before and after the allocation of resources. On the one hand, collaboration is pursued by funding agencies under the assumption that it will result in higher achievements and avoid duplication of efforts in research. Accordingly, scientists may develop strategic alliances to increase their chances of getting funding in response to this “ex-ante stimulation of collaboration” (it precedes funding). On the other hand, economic resources allow scientists to incorporate new skilled members into their teams (e.g. contracts) and to enlarge their social networks as a result of increased mobility, therefore an “ex post stimulation of collaboration” (it follows funding), could also take place. Both mechanisms may contribute to explain the higher co-authorship index of funded papers.

However, in our study funded papers only show a significant **higher number of centres** than the non-funded ones in three out of the seven disciplines (BIOD, CARD, STAT). This might suggest a more relevant role of funding in enhancing intramural than extramural collaboration. This is despite the fact that funding agencies usually try to encourage collaboration within teams but also across different teams and centres, as a way to foster cross-disciplinary and cross-sectorial links that may result in more innovative approaches to problem solving. This is the case of EU research projects (Defazio, Lockett and Wright, 2009), and also applies to Spain, where collaboration between teams is pursued by the main public funding agency (http://www.ciencia.gob.es/stfls/MICINN/Prensa/FICHEROS/2018/PlanEstatalIDI.pdf).
Nonetheless, the fact that extra-mural collaboration requires greater effort from scientists than the intramural one, since it has networking and coordination costs (Katz and Martin, 1997; He et al. 2009), may limit its development. Moreover, inter-centre collaboration is in general not mandatory in Spanish research projects, where “quality and adequacy of the research team”, as well as “quality, viability and impact of the research proposal” are the main aspects assessed. (http://www.ciencia.gob.es/stfls/MICINN/Ayudas/PE_2017_2020/PE_Orientada_Retos_Sociedad/FICHEROS/Proyectos_IDI_Retos_Investigacion/Convocatoria_Proyectos_Retos_Investigacion_2018.pdf). The promotion of collaboration between centres takes place in Spain mainly through specific calls (i.e., those oriented to foster public-private cooperation, creation of networks and internationalization), which comprise a limited part of the total R&D funding. Anyway, although funding is not associated to more extensive collaborative networks of centres in several disciplines, we cannot discard other positive effects on collaboration, such as contributing to the consolidation of existing networks (Ebadi and Schiffauerova, 2015; Zhao et al, 2018), whose analysis is beyond the scope of this study.

As put forward in our third question, we expected to find a **higher FA rate in internationally co-authored papers**, assuming the higher complexity of cross-country research, which may require more often a formal agreement to be developed. However, this hypothesis was confirmed only in three disciplines (BIOD, CARD, VIROL), maybe because these are the fields with the most extensive networks, which could be more highly dependent on formal agreements and economic support. In the remaining fields, internationally co-authored papers do not present funding more often than the rest of the papers and even between 11-18% of the papers with international collaboration -depending on the field- do not acknowledge any funding at all. We believe that the increasing mobility of scientists, enhanced by lower travel cost, and the advances in communication technologies may favour interactions between scientists and facilitate collaboration even in the absence of specific economic support, at least in some fields.

In answer to the last question addressed in this paper, a logistic regression analysis was run to explore the contribution of funding to explain the likelihood of papers to be cited above world average considering simultaneously the effect of other independent variables such as number of references, journal quartile and collaboration scope. What we observe is that these three variables significantly contribute to explain a citation rate above world average in all disciplines, while funding remains significant only in four of them (table 5). However, the mediation analysis reveals that funding is relevant in all the seven disciplines, because apart from its direct effects on RCR it shows indirect effects through journal quartile (in all disciplines), number of references (in four disciplines) and collaboration scope (in three disciplines). Thus, depending on the field, funded research is positively associated to publication in more prestigious journals (better located in the impact factor ranking), more complete research papers (longer reference list) and broader scope of collaboration, which are subsequently related to higher RCR.

An interesting finding of the study is the different relevance of mediators depending on the discipline (table 6). Publication quartile is the only mediator shared by all fields; probably enhanced by the high value awarded to papers published in high prestige journals in research evaluation processes at academia. Concerning the number of references, it is interesting to note that it fails to be mediator in three fields, which are the ones with the lowest number of references per paper (table A.1.) (Appendix A), maybe because their papers are usually shorter than in the other fields, so there is less room for differences between funded and non-funded papers. Finally, collaboration scope is a mediator between funding and RCR in two very different types of disciplines: two highly collaborative fields (CARD and BIOD) and one field traditionally considered as low collaborative (STAT). In the first case, collaboration might be especially relevant because it may enhance resource sharing and coordination in the frame of large networks oriented to the development of either clinical trials (CARD) or biodiversity monitoring (BIOD). With regard to STAT, it is not an equipment–based discipline and small size teams are the norm, but funding may promote creative thinking or cross-disciplinary knowledge generation, whose need has been repeatedly pointed out (https://www.amstat.org/asa/files/pdfs/POL-Statistics-as-a-Scientific-Discipline.pdf) and may result in more impactful research.

Concerning policy implications of the research, we would like to mention two main issues. Firstly, our study reveals that funded research is more likely to be cited above world average in all the seven disciplines, which is a result clearly relevant for policy makers, who are increasingly concerned with demonstrating the returns of R&D investments. Moreover, the interest of analysing funding indirect effects on impact needs to be highlighted, since funding contribution to RCR may be underestimated if only direct effects were considered. Secondly, our study provides new insights into the relationship between funding and collaboration. Funded research is developed in teams of greater size in all disciplines, but it is associated to greater extramural collaboration only in three of them, where collaboration scope seems to be a mediating factor between funding and research impact. These results raise the question of to what extent funding policies are effectively promoting a broader scope of collaboration - which, in general, contributes positively to RCR-. Further analyses focused on specific funding schemes could be especially useful to shed light on this issue.

Finally, this study presents several **limitations** that should be taken into account. Firstly, data on funding sources can be incomplete because they are not always acknowledged by authors, although this problem is getting to be less relevant as disclosure of funding support is becoming mandatory in science. Secondly, the fact that the acknowledgment section of papers is a non-structured section which contains varied information (acknowledgment of funding sources, but also of technical and/or intellectual support) including poorly normalized funding agencies, encumber data management and may endanger the precision of final results (Rigby, 2011; Álvarez-Bornstein, Morillo and Bordons, 2017). Moreover, it has been described that WoS is not always able to discriminate between funders and companies mentioned due to conflict of interest in the acknowledgment section, which may lead to overestimate funding sources (Álvarez-Bornstein and Bordons, 2019). The need to improve the way in which authors disclose funding sources in publications as well as the identification and standardization of these sources in WoS has been previously pointed out in order to increase the reliability of the studies. Thirdly, it should be noted that our study mainly deals with external funding, since internal core funding –resources allocated internally within research performing organizations- is rarely acknowledged by authors. However, higher influence of external funding on impact is expected assuming that most of it has surpassed a peer review process. Lastly, our research focuses on the scientific output of a specific country and the results cannot be extrapolated to other countries, which may differ in research funding schemes (Leydesdorff and Wagner, 2009). In addition, there may be differences between disciplines, as shown in this paper, due to differences in their scientific practices and degree of dependence on funding. Accordingly, our findings cannot be generalised and should be interpreted cautiously. Anyway, the methodology here used -including mediating analysis- can be applied in other contexts and to other countries.

6. Conclusions and further research

This study supports the interest of the funding acknowledgment section of the WoS database as a source of information to track funding returns in form of publications and explore the effects of funding on different aspects of research performance. Accordingly, it may offer support for policy makers and research managers in their goal to monitor and optimize the returns from funding investments.

The relevance of funding in the seven disciplines analysed is pointed out in this paper, as far as it is associated to higher impact publications which, in principle, might be more able to contribute to the advance of science. Our study suggests that funding is effectively playing a role in promoting high-impact research, decreasing uncited papers and fostering team work. However, no evidence of greater extramural collaboration in funded research is observed in four out of the seven disciplines, which would require further analysis since collaboration is usually promoted by funding policies. A particularly relevant finding of this study is that funding shows direct and indirect effects on the citation rate of papers and that if only direct effects were considered the contribution of funding could be underestimated. Indirect effects are mediated through the publication of more complete papers, in more prestigious journals and with more extensive collaboration, although the presence and magnitude of these effects vary by discipline. Further research is needed to cope with these issues at a higher level of granularity, that is, a) to make longitudinal studies to analyse the effects of funding within specific programmes and on lower level of analysis such as teams; and b) to distinguish among different types of funding (e.g. personal scholarships, research grants, industry contracts or supported networks) which may have different influence on research performance.

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Appendix A.

Table A.1. Number of papers and collaboration and impact indicators by discipline

	BIOD	CARD	POLYM	SPEC	STAT	TELEC	VIROL
No.Articles	1157	2473	2315	1269	1590	2515	1142
No.References/article	54.55	32.09	40.68	31.57	29.43	26.50	42.43
Collaboration							
No.Authors (av)	5.70	9.87	5.07	13.76	3.05	4.33	8.81
No.Institutions (av)	3.94	5.84	2.61	4.36	2.32	2.18	4.99
%Highly col.papers[a]	21.87	45.0	9.89	15.92	5.09	5.41	35.64
% Total int.col.papers	59.38	47.23	47.13	52.33	44.91	44.73	49.39
Collaboration pattern							
% Non col.papers	16.08	14.19	24.06	24.03	26.86	36.10	12.08
% Only nat.col.papers	24.55	38.58	28.81	23.64	28.24	19.17	38.53
% Only int.col.papers.	36.56	28.27	31.75	36.25	32.52	34.47	28.55
% Nat.& int.col.papers	22.82	18.96	15.38	16.08	12.39	10.26	20.84
Impact							
% D1 Articles	22.41	25.26	37.10	2.31	28.17	16.17	20.12
% Q1 Articles	55.45	46.26	66.96	23.84	39.47	41.23	48.86
Relative Citation Rate (RCR)	1.20	1.37	0.97	1.17	0.88	1.03	1.06
% RCR>1	39.07	37.16	34.86	39.24	24.72	29.50	35.38
% Uncited articles	4.84	6.11	4.06	6.78	16.16	13.28	2.28
% HCP	13.05	17.39	10.58	19.78	13.40	12.17	11.03

[a] Percentage of articles in collaboration among at least 5 institutions

Table A.2. Results of linear regression to explain RCR

	BIOD			CARD			POLYM			SPEC			STAT			TELEC			VIROL		
	B	t	Exp(B)	B	t	Exp(B)	B	t	Exp(B)	B	t	Exp(B)	B	t	Exp(B)	B	t	Exp(B)	B	t	Exp(B)
Journal quartile	-0.208***	-12.945	0.812	-0.191***	-16.635	0.826	-0.198***	-16.735	0.820	-0.115***	-6.135	0.892	-0.127***	-12.476	0.881	-0.166***	-15.881	0.847	-0.135***	-9.564	0.873
Col.type	0.064***	5.059	1.066	0.110***	10.094	1.116	0.013	1.698	1.014	0.062***	4.958	1.064	0.043***	3.898	1.044	0.055***	5.799	1.056	0.083***	6.798	1.087
No.references	0.004***	7.646	1.004	0.005***	15.763	1.005	0.003***	7.014	1.003	0.005***	6.522	1.005	0.005***	6.806	1.005	0.005***	8.995	1.005	0.004***	7.422	1.004
Funding	0.004	0.092	1.004	0.072***	3.387	1.074	0.046	1.637	1.047	0.086*	2.334	1.090	0.081**	2.724	1.084	0.008	0.315	1.008	0.016	0.378	1.017
Constant	0.573	8.550		0.528	1.,222		0.653	14.944		0.482	7.508		0.432	8.936		0.580	13.673		0.455	7.048	
Adj.R^2		0.248			0.291			0.154			0.097			0.146			0.140			0.187	

Note: Dependent variable= Ln(RCR+1)
Journal quartile has four categories with Q1 coded as 1 to Q4 coded as 4. Collaboration type has three categories arranged in order of increasing collaboration scope (1=no collaboration; 2= national collaboration; 3=international collaboration; 4=national & international collaboration).
*P<0.05; **P<0.01; ***P<0.001

Table A.3. Indirect effects of funding (X) on RCR through Journal Quartile (M1), Collaboration type (M2) and Number of references (M3)

	BIOD	CARD	POLYM	SPEC	STAT	TELEC	VIROL
Indirect effect							
X-->M1-->Y	0.0666*	0.0949*	0.0752*	0.0175*	0.0323*	0.0422*	0.0836*
X-->M2-->Y	0.0205*	0.0627*	-0.0011	0.0043	0.0102*	-0.0045	0.0128
X-->M3-->Y	0.0316*	0.0357*	0.0192*	0.0136	0.0005	0.0008	0.0480*

Dependent variable= Ln(RCR+1)
*P<0.05