Cross-disciplinary research: What configurations of fields of science are found in grant proposals today?

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Considering the complexity of the world problems, it seems evident that they do not fit straight-forwardly into a disciplinary framework. In this context, the question arises as to whether and how frequently several disciplines cooperate on research projects. Cross-disciplinary cooperation in research might be difficult for two reasons. On one hand, many researchers feel that efforts to achieve methodological rigour, exactness, and control are only possible in the circumscribed area of a discipline. On the other hand, it is claimed that funding organizations, with their rigid disciplinary classification systems, impede cross-disciplinary research in the context of their selection and evaluation procedures. For a total of N = 8,496 grant proposals submitted to the Austrian Science Fund (FWF) from 1999 to 2009, detailed codings of the subdisciplines involved were available for the statistical analysis. Latent class analysis produced 12 latent classes or configurations of fields of science. Mono-disciplinary projects are very well represented in physics/astronomy/mechanics, geosciences, and clinical medicine. Cross-disciplinarity is found particularly in research project proposals of fields of science with clearly overlapping content (e.g. preclinical and clinical medicine) and mainly in research proposals submitted by fields of science within the humanities and social sciences.

Keywords: latent class analysis; cross-disciplinarity; research evaluation; coding system.

1. Introduction

Considering the complexity of the world problems, it seems evident that they do not fit straightforwardly into a disciplinary framework. 'This is true, in particular, of those problems...rendered clear in the fields of environment, energy and health' (Mittelstrass 2011: 330–31). Cross-disciplinary research has become an established concept in science policy. Metzger and Zare (1999: 642) and Rafols and Meyer (2007: 634) even speak of it being a 'mantra of science policy'. Numerous monographs and anthologies underline the importance of cross-disciplinary research (e.g. Hirsch Hadorn et al. 2008; Friedeman et al. 2010; Lyall et al. 2011; Repko et al. 2013). According to Rafols and Meyer (2007: 633), 'we use the term *cross-disciplinary* to denote all forms of research that cut across disciplinary borders in some way; *interdisciplinary* is reserved for very integrated cross-disciplinary research'. A more elaborated concept of interdisciplinarity can be found in Klein (2010).

The Future & Emerging Technology (FET) Flagships funded by the European Commission can be seen as prototypes of cross-disciplinary projects: 'FET Flagships are science-driven, large-scale, multidisciplinary research initiatives oriented towards a unifying goal, with a transformational impact on science and technology and substantial benefits for European competitiveness and

society' (http:/cordis.europa.eu/fp7/ict/programme/fet/flag ship/). The EU Framework Programme for Research and Innovation Horizon 2020 (http://ec.europa.eu/progra mmes/horizon2020) emphasizes the cross-disciplinary character of research projects to be funded during the period 2014–2020.

However, there is also some doubt as to the value of cross-disciplinarity in the sciences. Weingart (2000) speaks of a 'paradoxical discourse' in connection with cross-disciplinarity: 'Interdisciplinarity (or transdisci-plinarity and similar derivatives) is proclaimed, demanded, hailed, and written into funding programs, but at the same time specialization in science goes on un-hampered, reflected in the continuous complaint about it' (Weingart 2000: 26). Weingart's thesis is that different interests can be identified in the discussion on cross-disciplinarity. Whereas science policy calls for cross-disciplinarity in research, using terms like 'frontier research' or 'research at the border' to promote innov-ations, research itself aims for methodological rigour, exactness, and control of errors, which many researchers think is only possible in the circumscribed area of a dis-cipline: 'Both interdisciplinarity and disciplinarity are, thus, given positive evaluations for different functions: in-novation on the one hand and rigour and control of error on the other' (Weingart 2000: 29). Woelert and Millar (2013) identify what they say can be called the 'paradox of interdisciplinarity' in Australian research governance. They find a significant mismatch between the discourse of cross-disciplinary in government reports and govern-ment policy as guarantee for innovation and applicability and what actually happens in the evaluation of research proposals. In the case of cross-disciplinary grant pro-posals, rigid and hierarchical discipline-based classification systems are used, and proposals are reviewed by experts in individual disciplines:

> For instance, such proposals may be evaluated mainly by experts from the individual disciplines listed in the application who may not have a proper understanding of those methodologies and conceptions that are borrowed from another disciplinary context . . ., one of the challenges with assessing interdisciplinary research is that an adequate assess-ment requires taking seriously the integrated whole, and not just the individual disciplinary components . . . (Woelert & Millar 2013: 764)

Woelert and Millar conclude: '. . . there is a significant mismatch between the discourse of interdisciplinarity and associated conception of knowledge on the one hand, and current, relatively inflexible governmental research funding and evaluation practices on the other hand' (Woelert & Millar 2013: 755). In a similar way, Lyall et al. (2013) criticize the role of funding agencies in the United Kingdom, in particular the Research Councils UK (RCUK).

Overall, with regard to cross-disciplinarity, three differ-ent, not necessarily exhaustive, positions are distinguished in our article. The first position is that cross-disciplinary research is in fact possible and represents no real problem (e.g. EU FET Flagships). A second view is that cross-disciplinary research is rather rare due to an indissoluble 'paradox' (Weingart 2000). The interests of policy in in-novation collide with the interests of science in a defined discipline-specific research. In the end, it is science itself that hinders cross-disciplinary research. And the third standpoint is that research funding organizations prevent cross-disciplinary research, in that they, for example, use selection and evaluation procedures that follow rigid hier-archical classification systems (Lyall et al. 2013; Woelert & Millar 2013).

In light of the above, this study analyses empirically the extent to which submitted grant proposals—independently of whether they receive funding or not —show configur-ations of cooperating disciplines that indicate that the research projects are cross-disciplinary. If configurations of cooperating fields of science are frequent in grant pro-posals, this would speak against Weingart's (2000) thesis that science itself is interested only in mono-disciplinary research.

The Austrian Science Fund (FWF) is Austria's central funding organization for basic research (www.fwf.ac.at). The body responsible for funding decisions at the FWF is the board of trustees, made up of 26 elected reporters and 26 alternates (Fischer & Reckling 2010; Sturn & Novak 2012). Each grant proposal submitted must be coded regarding the relevant research disciplines. On the application form, the principal investigator lists up to four subdisciplines that are relevant for the project (following Statistik Austria, www.statistik.at). According to the information supplied by the FWF, the multitude of disciplines are summed up in 22 fields of science (see *Österreichische Systematik der Wissenschaftszweige* [Austrian Classification of Science and Technology Fields], http://www.fwf.ac.at/de/applica tions/general/wiss-disz-201002.pdf). These subdisciplines agree with the field of science classification in the interna-tional Frascati Manual (OECD 2002) and form the basis of this study. The classification system itself, its structure, and granularity will not be queried.

In the following, we use the statistical method of latent class analysis (LCA) to analyse these codings, whereby the clusters or latent classes reflect the configurations of the cooperating fields of science.

2. Methods

2.1. Data and variables

The data, generated by the normal review procedure at the FWF and provided for our study, consisted of all grant proposals (N = 8,496) for individual research projects called 'Stand-Alone Projects' (Fischer & Reckling 2010)

across all fields of research from 1999 to 2009. The 'Stand-Alone Projects' are one of the FWF funding instruments (the others are 'Special Research Programs', 'Awards and Prizes', and 'Transnational Funding Activities'). The stand-alone projects account for 60% of all funded FWF proposals (Fischer & Reckling 2010: 6). External reviewers (N = 18,357) (about two to three reviewers for each proposal on average) rated the proposals on a scale from 0 to 100 (from poor to excellent) in 23,977 reviews (ex ante peer evaluation). Due to missing values in the variables included in the data analysis, the effective sample (case-wise deletion) consisted of 8,329 proposals with 23,414 reviews.

The FWF uses a coding system by which the principal investigator makes a highly precise coding (from a list of 1,244 subdisciplines) of the disciplines involved. However, the analyses in this study are restricted to the 22 fields of science that the FWF also uses. For one thing, a higher resolution than that does not make much sense for purely statistical reasons, considering the mismatch between the large number of variables (subdisciplines) and the number of proposals. For another, it does not make much sense for a research funding organization to make its policy-strategic decisions at the level of 1,244 individual subdisciplines. In its own discussion papers, the FWF therefore also breaks down the data at the level of the 22 fields of science.

For the statistical analysis, the fields of science were coded in dummy variables (0/1). With 22 fields of science, 21 dummy variables are sufficient for complete coding of the grant applications with regard to the disciplines involved in the proposed research project.

2.2. Statistical methods

For clustering the proposals according to the coded disciplines, LCA was performed. In its basic idea, LCA can be defined as a statistical approach that extracts clusters or types of individuals (latent classes, LCs) that are homogenous with respect to the observed nominal variables (McCutcheon 1987; Bornmann et al. 2013; Mutz et al. 2013). Similar to the factor analysis, LCs are extracted in such a way that correlations between the observed variables should vanish completely within each LC (local stochastic independence). The basis of the data analysis is the 22 fields of science that were coded in 21 dummy variables with 'Law' as reference category (zero on all dummies). The dummy coding allows a proposal to be coded in multiple disciplines. The fields of science thus form the variables in the LCA. The latent classes extracted by the LCA can be seen as types of proposals, which can be classified as either mono-disciplinary or cross-disciplinary.

Suppose that the data consist of four binary 0/1-variables or disciplines A, B, C, and D, and two latent class variables LC. Then, the LCA model can be defined by two kinds of probabilities of a proposal (Rindskopf 2009: 200): First, the *unconditional probabilities* of belonging to each of the two latent classes LC (latent class probability), and, second, the *conditional probabilities* of belonging to each of the four disciplines A, B, C, and D, given the status on LC (response probabilities). For example, proposals belonging in a mono-disciplinary latent class have a high response probability in only one of the disciplines/variables, otherwise it is zero. In order to estimate these probabilities, it will be assumed that the responses to A, B, C, and D are independent conditional on each latent class. Whereas the conditional response probabilities do not sum necessarily to one across latent classes, the unconditional probabilities do. That is, disciplines as variables might contribute to different latent classes with moderate till high conditional probabilities. With four binary variables, 16 possible empirical patterns of proposals can be defined ranging from 0000 to 1111. With the information of the observed frequencies of these different response patterns, the two kinds of probabilities (unconditional and conditional probability) can be estimated using maximum likelihood (ML). With ML, the parameters of the model are estimated in such a way that the probability of the entire observed data will be maximal. LCA is favoured towards cluster analysis due to the fact that fewer pre-decisions are required than in common cluster analysis procedures. Whereas LCA models observed data directly, in ordinary cluster analysis, one of the several distance measures (e.g. Euclidean distance) must be chosen first. Besides the choice of the distance measure, a decision on the aggregation algorithm (simultaneous or hierarchical) must be made. Whereas LCA uses ML as one of the most efficient estimation procedure, ordinary cluster analysis uses the less efficient least-squares method. Therefore, the results of a cluster analysis might depend more or less on this set of pre-decisions (Vermunt & Magidson 2005).

To compare models and identify the number of latent classes, we used information criteria, especially the Bayesian information criterion (BIC) instead of the ML value. In the literature, it is recommended to use Akaike information criterion (AIC) and BIC together in model selection (Bozdagon 1993; Lukočienė & Vermunt 2010; Lukočienė et al. 2010; Dziak et al. 2012). LCA assumes local stochastic independency of the variables. Given the latent classes, the residual correlations between variables are zero, i.e. the correlations among variables are completely explained by the latent classes, an assumption that cannot be fully held in most empirical applications. Four direct effects from one variable to the other were admitted to approximate local stochastic independency (technical science–mathematics, psychology–zoology, linguistic/literary science–philosophy/theology, and botany–zoology). The analysis was performed using Latent GOLD (Vermunt & Magidson 2005).

3. Results

A first impression of the frequency of cross-disciplinary and mono-disciplinary proposals is gained from the number of disciplines named by the principal investigators in their codings of their grant proposals. The principal investigators are allowed to name a maximum of four relevant subdisciplines (Table 1). According to the numbers, about 10% of the submitted grant proposals qualify as mono-disciplinary; the remaining proposals named two or more cooperating subdisciplines.

A deeper insight into cross-disciplinary cooperation is gained from analysis of the configuration of fields of science by means of LCA. To identify the number of latent classes or types of cross-disciplinary projects, we calculated models with 1–16 latent classes and compared them using information criteria (AIC, BIC) (Fig. 1). The smaller the value of an information criterion, the better the model is. According to both criteria, a model with 12 latent classes was chosen.

To interpret the results of a latent class model, the response probabilities (see Table 2) are usually used instead of the more or less abstract estimated statistical parameters from which the response probabilities are calculated. A conditional or response probability is the probability that a proposal that was assigned to a certain latent class belongs to a certain field of science. For example, the probability that a proposal in LC1 belongs to clinical medicine is 0.41, and the probability that it belongs to preclinical medicine is 1.00. This example shows that conditional probabilities need not sum to 1.0 and, therefore, clinical medicine contributes to more than one latent class. Probabilities can also be given as percentages (e.g. 41% of the sample), if the sample size is assumed to go to infinity. If in a latent class a response probability of 1.0 is observed in a field of science in combination with clearly lower probabilities in other disciplines, this would indicate that in this field of science, research proposals are mono-disciplinary. Probabilities of 0.00/0.01 in a field of science indicate that there are actually no collaborations with other fields of science in the particular latent class. The more nulls there are in a column in Table 2, the more that cross-disciplinarity refers to just few cooperating fields of science and in the extreme case to just one. The columns show information on the importance of the latent class and field of science, and the rows show the connections of a field of science with various other fields of science and latent classes.

The marginal frequencies in Table 2 indicate how frequently (in per cent) a field of science was coded in all N = 8,329 proposals. The sum of the frequencies in the column does not equal 100% due to multiple codings. The most frequently coded fields of science were biology (22%) and preclinical medicine (22%), and the least frequently coded ones were law (2%) and economic science (3%). The explained variance R^2 shows the extent to which the latent classes can distinguish between the individual fields of science. For instance, there are clear differences

Table 1. Number of coded subdisciplines with respect to a proposal (N = 8,329 proposals)

Number of coded subdisciplines	Frequency	Per cent	Cumulative frequency	Cumulative per cent
0	19	0.21	19	0.21
1	891	10.02	910	10.23
2	1,847	20.76	2,757	30.99
3	2,940	33.05	5,697	64.04
4	3,199	35.96	8,896	100.00
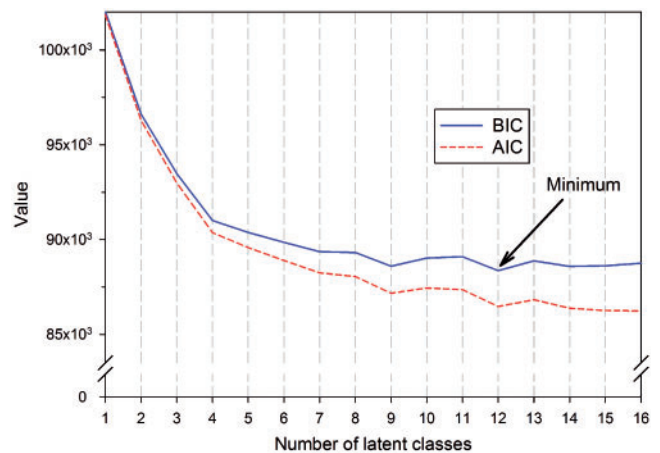
Figure 1. Identifying the number of latent classes using information criteria.

($R^2 > 0.70$) in the response probabilities (e.g. 0/1) for the latent classes in mathematics, physics/astronomy/mechanics, biology, geosciences, and preclinical medicine, which means that these fields of science are decisive for the interpretation of the content of a latent class (marker variables). In contrast, for agriculture/forestry/veterinary medicine and other natural sciences, there is hardly any difference in the response probabilities between the latent classes ($R^2 = 0.03$), which means that these fields of science do not mark any of the latent classes. This can also be traced back to the small per cent involvement of these fields of science in the total volume of grant proposals.

The four central results of the LCA can be stated as follows:

(1) The 12 latent classes can be subsumed, according to content (not statistical) affinity, in the following six broad fields, sorted in descending order according to sample size proportion (in brackets):

(a) *Biomedical sciences* (0.40): LC1 medicine (preclinical and clinical); LC2 biology in a narrower sense (biology and preclinical medicine); LC5 biology in a broader sense (biology, botany and zoology); LC12 clinical medicine

(b) *Humanities* (0.18): LC3 history (history, art history, other humanities, and social sciences)

Table 2. Response probabilities of the LCA (N = 8,329 proposals)

Fields of science	LC1	LC2	LC3	LC4	LC5	LC6	LC7	LC8	LC9	LC10	LC11	LC12	FREQ	R^2
Mathematics	.01	.00	.00	.10	.00	.00	.00	.00	.00	.01	**1.00**	.00	.07	.81
Computer sciences	.01	.02	.02	.10	.00	.03	**.47**	.00	.08	.02	**.40**	.05	.08	.26
Physics/ astronomy / mechanics	.03	.01	.00	**1.00**	.00	.00	.05	**.22**	.00	.03	.06	.00	.12	.75
Chemistry	.05	.15	.00	.09	.04	.00	.00	**1.00**	.00	.06	.01	.00	.11	.62
Biology	.13	**1.00**	.00	.02	**.71**	.00	.00	.07	.00	.08	.02	.04	.22	.71
Botany	.00	.00	.01	.00	**.57**	.00	.00	.01	.00	.07	.01	.00	.06	.47
Zoology	.01	.00	.01	.00	**.49**	.00	.02	.00	.00	.04	.01	.02	.05	.39
Geosciences	.00	.01	.02	.05	.07	.01	.04	.02	.02	**1.00**	.02	.00	.08	.73
Other natural sciences	.01	.06	.04	.10	.09	.00	.06	.09	.02	.16	.04	.00	.05	.04
Technical sciences	.02	.00	.08	.16	.00	.00	**.54**	.14	.08	.15	.15	.00	.10	.21
Preclinical medicine	**1.00**	**.36**	.00	.01	.02	.00	.03	.09	.01	.01	.00	.15	.22	.74
Clinical Medicine	**.41**	.04	.00	.01	.01	.02	.07	.02	.01	.00	.03	**1.00**	.12	.50
Agriculture / forestry/ veterinary medicine	.03	.09	.01	.01	.11	.00	.04	.02	.06	.04	02	.00	.04	.04
Social sciences	.00	.00	**.22**	.00	.01	.17	.00	.00	**.58**	.05	.02	.08	.08	.30
Psychology	.01	.00	.01	.00	.02	.05	.04	.00	.19	.00	.02	.17	.03	.10
Law	*.00*	*.00*	*.05*	*.00*	*.00*	*.02*	*.05*	*.00*	*.09*	*.00*	*.00*	*.00*	*.02*	-
Economic sciences	.00	.00	.01	.00	.00	.00	.01	.00	**.35**	.01	.07	.00	.03	.26
Philosophy / theology	.00	.00	.05	.01	.00	**.43**	.00	.00	.04	.00	.02	.02	.04	.31
History	.00	.01	**.77**	.00	.02	**.26**	.03	.01	.02	.05	.00	.01	.11	.55
Linguistic / literary science	.00	.00	.00	.00	.00	**.67**	.01	.00	.01	.00	.00	.02	.06	.62
Art history	.00	.00	**.23**	.00	.00	.11	.05	.01	.00	.00	.00	.00	.04	.14
Other humanities	.00	.00	**.25**	.00	.00	**.31**	.01	.00	.03	.00	.00	.01	.05	.22
Class sizes	.15	.12	.10	.09	.09	.08	.07	.07	.07	.06	.05	.04		

Notes: FREQ = marginal frequency, R^2 = variance explained by the latent classes. Response probabilities ≥0.20 are printed in bold face. Law (shown in italics) was not included in the LCA.

and LC6 linguistic/literal sciences (philosophy/theology, linguistic/literal sciences, history, and other humanities)

(c) *Physical sciences* (0.16): LC4 physics/astronomy/mechanics, LC8 physical sciences (physics/astronomy/mechanics, chemistry)

(d) *Formal and technical sciences* (0.12): LC7 computer and technical sciences, LC11 mathematics and computer sciences

(e) *Social sciences* (0.07): LC9 social sciences (social sciences, psychology, economic sciences)

(f) *Geosciences* (0.06): LC10 geosciences

Biomedical sciences are the most strongly represented in the sample (at 40%), followed by the humanities (18%) and physical sciences (16%).

(2) The response probabilities reveal a great difference between the humanities and social sciences on the one hand and the physical sciences and formal and technical sciences on the other. High response probabilities of fields of science on the one side are coupled with low response probabilities on the other side, and vice versa. This shows that between the two groups there is no, or only sporadic, cross-disciplinary research cooperation.

(3) In physical sciences and formal and technical sciences, mono-disciplinary projects are strongly predominant (response probabilities = 1.0); see physics/astronomy/mechanics in LC4. Cross-disciplinarity is mainly found in the fields of science that have clearly overlapping content, such as preclinical medicine and clinical medicine (LC1), biology and preclinical medicine (LC2), chemistry and physics (LC8), and computer sciences and technical sciences (LC7). Research projects with unusual combinations of fields of science are observed only rarely (that is, with a low percentage). For instance, proposals in LC10, which were coded as geosciences, also involve technical sciences with a probability of 0.15.

(4) Cross-disciplinarity in the true sense is found mainly in the humanities and social sciences. In LC3 and LC6, we find a broad spread of fields. LC3 is dominated by history and LC 6 by linguistic/literary science. In LC3, even the technical sciences have a response probability of 0.08.

4. Discussion

With regard to cross-disciplinarity denoting 'all forms of research that cut across disciplinary borders in some way'

(Rafols and Meyer 2007: 633), three different, not necessarily exhaustive, positions were distinguished in the sense: The first position with respect to the EU FET Flagships is that cross-disciplinary research is in fact possible and represents no real problem. The second view is that cross-disciplinary research is rather rare due to an indissoluble 'paradox' (Weingart 2000). The interests of policy in innovation collide with the interests of science in well-defined discipline-specific research. It is science itself that hinders cross-disciplinary research. And the third standpoint is that research funding organizations prevent cross-disciplinary research, in that they, for example, use selection and evaluation procedures that follow rigid hierarchical classification systems (Lyall et al. 2013; Woelert & Millar 2013).

In our study of the disciplinary coding of research grant proposals submitted to the FWF, the result was a large number of latent classes, or configurations of fields of science in research projects. The latent classes can be assigned to six groups: biomedical sciences, humanities, physical sciences, formal and technical sciences, social sciences, and geosciences. According to the results of the LCA, cross-disciplinary research tends to be the exception rather than the rule in the grant proposals examined here. When several relevant subdisciplines are named in a grant proposal, they are usually fields within the humanities and social sciences that are cooperating cross-disciplinarily on the research project (latent class 3 and 6). In biomedical sciences, physical sciences, formal and technical sciences (latent class 1, 2–4, 7–12), cooperation is mainly between fields that have a strong content affinity (e.g. preclinical medicine and clinical medicine). In other words, in the physical sciences and formal and technical sciences, grant proposals with a mono-disciplinary orientation predominate. Cooperation between these fields of science and the humanities and social sciences was seldom found in the proposals (see Table 2, for example LC3 and LC6).

The FWF's classification system is relatively flexible; it allows the principal investigator to list in the proposal the subdisciplines involved in the research project; and all submitted proposals (rejected and accepted for funding) were included in the analysis. In view of these points, Lyall et al.'s (2013) thesis that the research funding organization itself is decisively responsible for the low extent of cross-disciplinary research is therefore not very plausible by investigating all proposals, irrespective of whether they were funded or not. Our finding that mainly fields of science with overlapping content are involved in cross-disciplinary research proposals also speaks against Lyall et al.'s thesis. Our findings are in agreement with Mittelstrass's (2011: 331) observation that cross-disciplinary research is most often realized in the context of neighbouring scientific fields, for instance with sociological elements in the work of the historian, chemical elements in the work of the biologist, or biological elements in the work of the medical researcher.

From our study findings, the following implications for both the Austrian Science Fund (FWF) and the research on cross-disciplinarity altogether can be derived:

– For the FWF, it would be worth asking the principal investigator to indicate on the grant application what form of cooperation the research project has, e.g. mono-disciplinary, multi-disciplinary, or transdisciplinary. This would make it possible to further differentiate the cross-disciplinary types that were found empirically. Perhaps the classification system, which is not queried here, is too rough to detect different kinds of cross-disciplinarity.
– In view of the results, the FWF should check whether cross-disciplinary research should be stimulated through special research funding programs.
– In the research on cross-disciplinarity, coding systems for disciplines should be further developed, supported by empirical evidence. LCA can be useful in developing that kind of empirically based coding systems.
– As the coding system used by the FWF is based on an international standard (the Frascati Manual), future studies could investigate whether the findings for FWF can be replicated for other funding organizations in other countries.
– A further question for future research on cross-disciplinarity could be, whether mono-disciplinary research proposals have a greater probability to be funded than cross-disciplinary ones? The answer to this question requires that a certain number of cross-disciplinary and mono-disciplinary proposals exists. Regarding the FWF such a comparison is not possible due to the low number of cross-disciplinary proposals.

Finally, it should be mentioned that the findings for the FWF are not necessarily generalizable to other research funding organizations. In addition, it cannot be excluded that applicants pursue disciplinary research, because they expect that this kind of research has more success in the approval procedure of a funding organization.

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