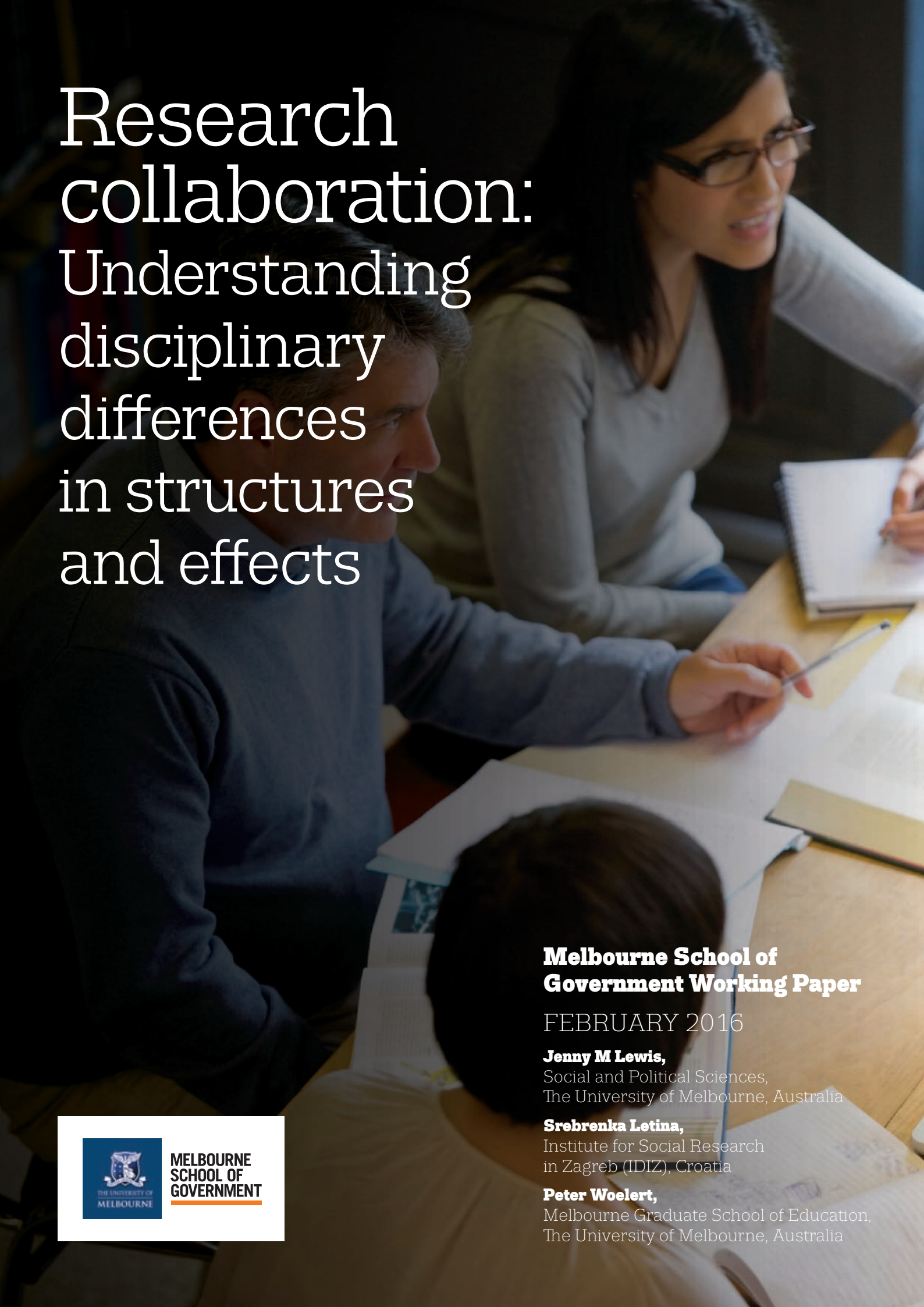
Research collaboration: Understanding disciplinary differences in structures and effects



Melbourne School of Government Working Paper

FEBRUARY 2016

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Acknowledgements:
This work was supported by strategic research funding from the Melbourne School of Government and the Faculty of Arts. The earlier research was funded by an ARC Discovery grant to Lewis. We would like to thank Paul Jensen and Garry Robins for their input at early stages of this project, and Simon Porter for his help with data extraction. Phuc Nguyen and Thom Holden helped with data reformatting and analysis and Jiří Šebek with the analysis of network overlap using name matching. We would also like to thank all the people who agreed to be interviewed for this project.

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Introduction

For the last few decades, research policy in many nations has increasingly focused on stimulating collaboration between researchers, in order to progress nations' ambitions of becoming knowledge economies and accelerating the pace of innovation. Collaboration has been an implicit or explicit focus of government policies on research evaluation and funding in many developed countries.

There is some evidence that research collaboration is linked to better research productivity, but there are significant limitations to much of the work on this topic, including that:

- It is not at all clear what 'collaboration' inludes and what its purpose is in different research contexts and different disciplines;
- Collaboration is often simply measured as co-publication;
- The appropriate form of collaboration for different discipline areas is likely to vary given their disparate approaches, methods and ways of working;
- The vast majority of the literature on research collaboration deals only with the physical and biological sciences;
- The link between collaboration and research productivity (or more correctly research outputs) is uncertain and depends on how publications are counted and how co-authorship is fractioned; and
- There is a widespread but unproven assumption that collaboration produces 'better' research.

This paper examines the structures and effects of research collaboration, and attempts to address the limitations outlined above. Importantly, it compares how these differ in three discipline areas - the (biological and physical) Sciences, and the much less examined Humanities and Social Sciences. It first explores the meaning of research collaboration and its measurement, and then focuses on two different types of collaboration (expressive and instrumental) and examines the overlap between them. It then examines the link between collaboration and research outputs, and collaboration and research quality. The findings provide an insight into the structures and effects of research collaboration in different disciplines. Some recommendations for research policy-making are made in the conclusion.

This paper uses two sources of data based on studies of academics at The University of Melbourne: The first of these examined research collaboration in three discipline areas for 85 academics in 2008–2010 (Lewis 2013). The second is an exploratory study of a small number of Melbourne academics (18), conducted in 2014–15.

The meaning of research collaboration and its measurement

Collaboration is the term usually used in the literature to refer to academics working together. Hara et al. (2003) reviewed definitions of scientific collaboration in the literature and concluded it has two basic elements: working together with the purpose of achieving a common goal, and knowledge sharing. Other authors stress the social aspect as an important feature of collaboration, (Sonnenwald 2007, Lewis 2013), and sharing of competencies and resources (Melin and Persson 1996). Scientists[1] describe their (successful) collaborations with other scientists using metaphors like a good marriage, a successful creative alliance, or a winning team (Baldwin and Austin 1992). Most researchers emphasize that it is a complex phenomenon, influenced by multiple factors (Kronegger et al. 2012). Furthermore, it is a multilevel phenomenon; it could be viewed as an activity between individual scientists, their organizations (see Shrum, Genuth and Chompalov 2007), between disciplines and between countries, and between scientists and other professions/sectors (Katz and Martin 1997).

Much of the literature on research collaboration tends to assume that the best measure of collaboration is through examination of co-authored papers (Frame and Carpenter 1979; Meadows 1974; Newman 2001). Some use authorship and citation records to construct collaborative authorship networks (e.g. Newman, 2001), taking advantage of large databases, and large numbers of multi-authored publications to generate their studies. However, the literature has increasingly acknowledged problems with reliance on publication data as a measure of collaborative activity, including that it is essentially a social activity based on networks. The ties between individual academics may be narrowly instrumental and purely a means of doing research in the short term. Alternatively, they may be friendships linked to long-term working relationships, based on shared intellectual interests (Lewis 2010). This important distinction is invisible in studies of collaboration that are built solely upon co-authorship.

There have also been important acknowledgements of disciplinary differences in collaboration. Newman (2001) distinguished carefully between different disciplines in his study, and Bozeman and Corley (2004) controlled for discipline field in their study of collaboration. However, both of these studies explicitly focused on the building of 'science and technology human capital'. Just as publication data can only yield a partial picture of collaboration, studies of science disciplines alone provide a restricted view of collaborative activity.

Three 'discipline areas' (Humanities, Science and Social Science) are compared in this paper. This typology is used in preference to the four-way discipline classification system distinguishing soft from hard and pure from applied disciplines (Biglan 1973; Del Favero 2005), or mode 1/mode 2 (Gibbons et al. 1994). These cannot fully capture the complex array of discipline fields, including the differences that exist between the ways in which discipline fields are grouped together formally at various institutions. Nevertheless, this typology enables a heuristically valuable comparison across disciplinary areas in line with categories that are intuitively meaningful to most academics and administrators alike.

TWO TYPES OF COLLABORATION

Academics across all disciplines undertake collaborative activity, but not all collaboration has the same level of visibility. To address the problems posed by a tendency for analysis to be biased towards the more visible (and easily measurable) forms of collaboration this report follows Lewis, Ross and Holden (2012) and Lewis (2013) in distinguishing between two types of collaboration. The first type is concrete - researchers formally work together on a project, designing it and/or undertaking it together, and publishing its results together. This form of collaboration is readily observable by research funding and measurement systems, and is often made a direct target of institutional policy initiatives. The second type is expressive – it involves discussion of ideas, intellectual feedback and commentary on research work. These two types of collaboration are not mutually exclusive. All, or almost all, academics are engaged in the expressive type while fewer engage in the concrete type.

This distinction is a simplification, but it is helpful in highlighting that collaboration has multiple meanings. The relationship between expressive (based on the discussion of ideas and exchange of information), and concrete (based on visible research outputs such co-authored publications and joint grants) forms of collaboration is not straightforward, and either can be construed as leading to the other. However, this distinction is a first step in addressing the limitation of assuming that all collaboration is concrete and can be measured as co-publication.

This distinction is also useful for comparing collaborative activities across disciplines. It is assumed that both concrete and expressive

1 Much of this literature refers to academics as scientists – this does not mean they are necessarily natural scientists, although much of the work on this topic deals with academics in the (physical and biological) science disciplines.

types of collaboration will be present and important to varying degrees in different discipline areas. The most important aspect of disciplines that influences the collaboration patterns of researchers is how the research is typically conducted. In disciplines such as history and literature (which are divergent and loosely knit), researchers are more likely to conduct their research alone – or to resort to expressive but not necessarily concrete forms of collaboration. This reflects how they were taught to do research, suits the methods they use, and fits with these disciplines' structures of knowledge and the density of their knowledge production (Lewis 2013).

There are major differences between the discipline areas of humanities, social sciences and sciences, both in collaborative practices and in reasons why people work together or alone (Lewis, Ross and Holden 2012). The social sciences tend to occupy the middle ground between solo researchers and large teams, sometimes working as part of a small team, and sometimes working alone (Lewis 2013). Of course, the pattern varies for disciplines within these three broad areas, and even within a discipline there is diversity in collaboration between sub-disciplines and research approaches. But this does not mean that there are no typical modes of collaborating in discipline areas.

THE LINK BETWEEN COLLABORATION AND RESEARCH QUANTITY AND QUALITY

The most often mentioned motive for collaboration (on every level) is the belief that it will lead to higher productivity and quality of publications. This belief may also explain the focus of collaboration to be commonly found in institutional policies. Some authors have questioned that positive association (e.g. Toomela 2007; Duque et al. 2005; Lee and Bozeman 2005; Rigby and Edler 2005), and others have investigated some possible negative aspects of collaboration (Bozeman et al. 2003; Landry and Amara 1998; Dickens and Sagaria 1997; Fox and Faver 1984). Toomela (2007) estimates that the effect size of collaboration is very small, ranging between one and five per cent. Lee and Bozeman (2005) conclude that some collaborations enhance productivity whereas others inhibit it. Regardless, the prevailing stance reflected in research funding policies is that collaboration is connected with more successful outcomes in regard to quality and for research career development.

Theoretically, He at al. (2009) proposed three general hypotheses for explaining the expected positive association between collaboration and research outputs. These are that collaboration:

1. enables knowledge recombination of specific and different knowledge of collaborators;
2. provides the opportunity for new learning and acquaintance of tacit knowledge; and
3. allows for building of social networks that enable scientists to "catch" valuable information about research opportunities and future (funded) collaborations that could lead to greater productivity.

Collaborations in all disciplines tend to be published in high-impact journals, cited more frequently and cited for longer, and having an international co-author can increase a paper's citation rate (Sonnenwald, 2008; Smith et al. 2014). Andrade, Lopez and Martin (2009) found that the number of high-impact and "quality" science publications produced is related to international partners and to interdisciplinary work. These findings suggest the possibility of a more complex relationship between collaboration and research outputs – not all collaborations lead to more/better research, and the disciplinary and national diversity of collaborators could be important.

However, research that associates collaboration with productivity or quality, when both are measured through the bibliometric data of individual researchers, suffers from some important methodological flaws. These include problems with conceptual operationalization (measurement of co-authorship is a partial indicator of research output and varies depending on which particular measure is used), problems with circularity (using the same data on publications to operationalize activity (collaboration) and the output of that activity (publication), and problems with the selectiveness of the data (collaborations that did not result in a tangible product (a publication) remain invisible).

One additional conceptual difficulty with the analysis of such data is that it indicates little about the particular motivations behind the concrete collaborations that are examined. One may assume that the majority of concrete collaborations resulting in co-authorship are at their core motivated by epistemic concerns and considerations. Then again, co-authorship patterns also reflect the implicit and explicit authority relations and politics that can be found within research organizations (see: Lawrence 2002). Co-authorship activity may also serve a decidedly strategic purpose, as it can also be a convenient means to increase individual productivity rates where systemic and institutional incentive structures make this possible and even desirable.

In summary, collaboration has different meanings and its form varies in scale and scope across disciplines. A distinction into concrete and expressive types of collaboration is helpful in thinking about disciplinary differences. The measurement of collaboration is often based on co-authorship of publications, but this is not the only way that collaboration can be conceptualised and measured. Further, the link between collaboration and research quantity and quality is not well understood.

STUDYING COLLABORATION

This paper uses empirical data from two studies to address some of the gaps in our understanding of research collaboration. A study of academics at three universities in 2008–10 (Melbourne, Birmingham in the UK and Auckland in New Zealand) used interviews to gather information on individuals' discussion networks (Lewis 2013). The number of Melbourne academics interviewed in 2008 was 91, and these were the starting point for this analysis. The second study used two additional approaches:

Co-authorship data: Publication information for all academic staff is centrally held and maintained as an electronic database at The University of Melbourne. Co-authorship data were extracted from Melbourne Research Windows (https://mrw.app.unimelb.edu.au) for each person on the 2008 interviewee list, for the five years from 2009 up to 2013. These extracted data were cleaned and reformatted, so that the overlap between co-authorship and discussion networks (based on informal discussion and sharing of ideas) could be examined. This involves comparing the names of co-authors and those listed as discussion partners (see the section on expressive networks for more information on this).

Interviews: In 2014–15, interviews were conducted with 18 of the individuals who had been interviewed in 2008 and 2010 for the earlier study (split across the Humanities, Sciences, and Social Sciences) and who were still working at The University of Melbourne. The questions focused on eliciting the perceived importance of discussion networks, concrete networks (grants), and also institutional settings for producing high-quality research in the three fields. For the purposes of this paper, our analyses of the interview data focus on a) the participating academics' understanding of what constitutes high quality research, and b) on their views concerning the specific role various forms of collaborative activity play in producing such high quality research.

CONCRETE AND EXPRESSIVE COLLABORATION

Two different types of research collaboration (expressive and concrete) were examined, as well as the overlap between them. Both expressive networks (based on discussion of ideas and exchange of information), and concrete networks (based on visible research outputs such co-authored publications and joint grants), are seen as vital to producing research. This section addresses two questions:

- Do levels of expressive and concrete collaboration differ for individuals in the humanities, sciences and social sciences?
- Does the degree of overlap between these differ for individuals in the humanities, sciences and social sciences?

Concrete collaboration

The sample size is quite small and of course is limited to a number of people working in a single research-intensive university in Australia. Further, these people agreed to participate in the study, so they are likely to be amongst the most productive of individuals at the university. Their productivity is comparatively quite high, as we shall see in the analysis to follow, and so these figures cannot be extrapolated to academics in general. Of the academics interviewed in 2008 and 2010, there are 63 individuals for whom information was available about their publications in the period of interest (2009 to 2013).

The sample is shown in Table 1, which presents the split across gender, levels and disciplines. Overall, more academics in this study were from the Sciences and Social Sciences, more of them were male, and more were at the most junior (lecturer) and senior (professor) levels. In addition, there is a high level of female Science academics in this sample. Further, the Social Science sample was confined to academics located in the Faculty of Arts, which does not include the two large

TABLE 1: SAMPLE DESCRIPTION

		INTERVIEWEES FROM THE LEWIS (2013) STUDY				INTERVIEWEES WITH PUBLICATIONS DATA			
	Discipline	**Humanities**	**Science**	**Social Science**	**Total**	**Humanities**	**Science**	**Social Science**	**Total**
Gender	Female	11	13	12	35	6	13	5	24
	Male	13	16	23	50	11	11	17	39
Level of seniority	Lecturer	8	5	15	27	5	5	11	21
	Senior Lecturer	2	4	4	10	2	4	2	8
	Associate Professor	4	2	4	10	1	2	4	7
	Professor	6	8	6	19	6	6	3	15
	Other	5	9	6	19	3	7	2	12
	Total	**24**	**27**	**34**	**85**	**17**	**24**	**22**	**63**

disciplines of economics and psychology. These two fields are likely to have collaboration practices that are more like the Sciences, with more co-authors and more interdisciplinary collaboration. Hence, their omission is likely to have had the effect of making Social Science look less like Science than it generally would.

As would be expected, there are differences between the three disciplines in regard to publications data. The appendix shows these descriptive data for 2009–2013 in detail, using the individuals as the unit of analysis. Overall, in the five year period the sample of academics studied have published more than 15 publications, or three per year. Science academics have more publications than those in Humanities and Social Sciences, but the differences are not statistically significant. It is worth noting that in this database, a book counts the same as a journal article and a book chapter (each of these counts as one publication).

Due to skewness of the number of publications, the median values point to more pronounced differences between disciplines, although they are still not significant. This finding needs to be interpreted in the light of the percentile rank of each academic. We extracted each individual's percentile rank based on the number of publications in the five year period in the academic area in which (s)he works. As can be seen from the appendix, the academics included in the study are above average in productivity in their field. This is especially true for the humanities, where 50 per cent of the sample was in the top 15 per cent.

Significant differences in co-authorship patterns were found between disciplines, as the percentage of single-authored papers is 76 and 62 for Humanities and Social Science academics (respectively), while in Science they had no sole-authored publications. When only the multi-authored papers are analysed, the mean number of co-authors on a paper, not including the ego (focal individual), is below two in Humanities and Social Science, and it is four in Science. This difference is also statistically significant. These findings suggests (not surprisingly, given that many of these will be based in laboratories with daily interaction amongst team members) that Scientists at The University of Melbourne both collaborate more often, and also collaborate with more other people, than do Humanities and Social Science academics.

Differences between the disciplines in regard to the number of different co-authors were also statistically significant (see Table 2). While scientists in Humanities and Social Science disciplines had around nine different co-authors in the five year period on average, that number in Science disciplines was substantially higher – a mean of 62 different co-authors. As can be seen from the difference in the mean and median value, and from the skewness values, the distribution of co-authors is positively skewed, showing the presence of individuals with extremely high numbers of co-authors.

TABLE 2: CONCRETE COLLABORATION (CO-AUTHORSHIP)

NO OF DIFFERENT CO-AUTHORS

Discipline	Mean	Median	Min	Max	SD	Skew.	N
Humanities	8.82	4	1	38	10.93	1.84	17
Science	62.08	52	10	189	48.76	1.35	25
Social Science	8.68	7	1	27	7.22	1.04	22
Total	29.58	13	1	189	40.52	2.31	64

One-way ANOVA: p=0.00; Independent Samples Median Test: p=0.00)

TABLE 3: EXPRESSIVE COLLABORATION (DISCUSSION NETWORKS)

NUMBER OF DISCUSSION PARTNERS

Discipline	Mean	Median	Min	Max	SD	Skew	N
Humanities	7.35	7	3	10	2.55	-0.19	17
Science	8.25	10	3	10	2.25	-0.89	24
Social Science	8.18	9	3	11	2.38	-0.89	22
Total	7.98	9	3	11	2.37	-0.65	63

(One-way ANOVA: p=0.444, Independent Samples Median Test: p=0.692).

Expressive collaboration

For the discussion networks (the measure of expressive collaboration used here), there was no significant difference between disciplines in regard to the number of collaborators (Table 3), although in Science the number of discussion partners was the highest, and in Humanities, the lowest, following the same pattern as for the number of co-authors This is not surprising, given that interviewees were asked to name up to ten of their most important discussion partners, thereby reducing the variability of the responses with many people listing ten names. Given that over 50 per cent of scientists from Science disciplines reported 10 discussion partners, it is possible that the number of reported partners was underestimated due to this limitation in Science disciplines. It also indicates that discussion as a form of collaboration is quite common even in the Humanities. Finally, this is a simple count of the number of discussion partners, and not an assessment of the frequency or intensity of discussion.

DISCUSSION AND CO-AUTHORSHIP OVERLAP

Because academics who were interviewed reported full names of their discussion partners, we were able to look for those partners in their co-authored publications in the 2009–2013 time period, and see the degree of overlap between concrete and expressive networks. This is presented in Figure 1 for the three discipline areas. The overlap is highest for Science at around five people, lowest for the Humanities (less than two), while in Social Science it was slightly more than two. The differences are statistically significant,[2] suggesting that the number of co-authors who are also discussion partners varies considerably across discipline areas.

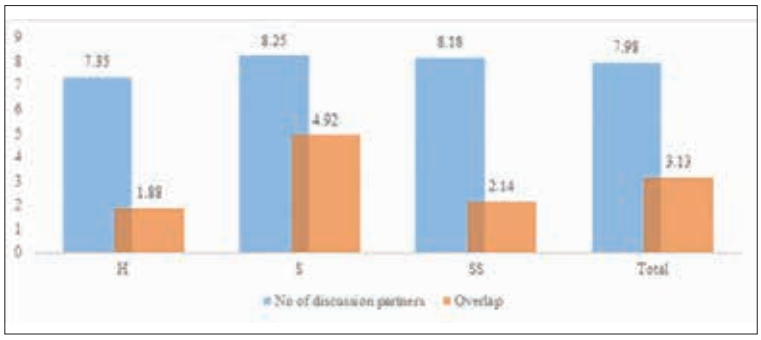

FIGURE 1: Overlap between discussion and co-authorship network

However, as shown in Table 2, the number of co-authors was substantially higher for the Science field, making the possibility of overlap between concrete and expressive network more likely for Science. Hence, we did a second analysis that allows for comparison across the disciplines, based on the maximal possible value of the overlap. This confirmed that in Science there is not only a tendency to have a greater number of co-authors, discussion partners and a greater overlap between the two, but that this finding is not changed even when we take into account the maximal possible number of the overlap.

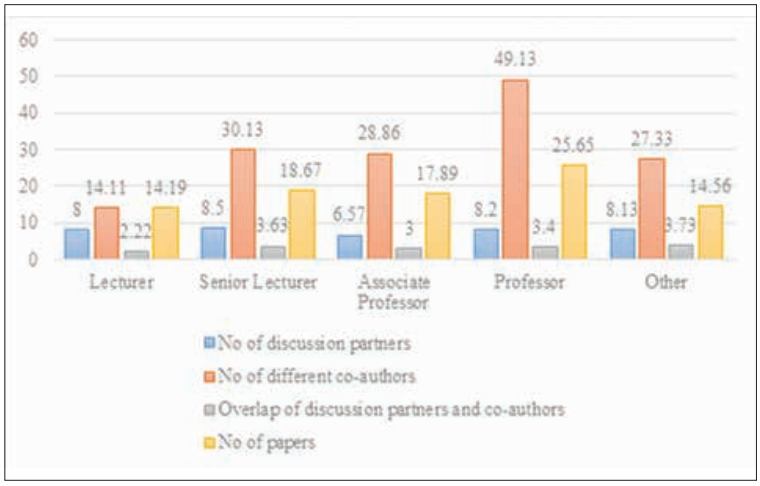

FIGURE 2: Concrete and expressive networks by academic level

The number of different co-authors, discussion partners, and the overlap between these for the whole sample by academic level and gender are shown in Figures 2 and 3. Senior lecturers and professors tend to have the highest number of discussion partners and different co-authors (Figure 2). It is expected that senior academics had managed to build wider networks than early academics, and Figure 2 confirms this, with a clear upwards trend in line with seniority.

Figure 3 shows that women had a higher (but not statistically significant) number of co-authors then men. This is consistent with the results of some previous studies (Bozeman & Gaughan 2011), although the sample here is influenced by the relatively large number of female Science academics (who have more co-authors than those in the other two disciplines). There do not seem to be gender differences in the number of discussion partners, the overlap between concrete and expressive networks, or in the number of papers produced (although this is actually the number of publications, including books which makes a difference in comparing across disciplines).

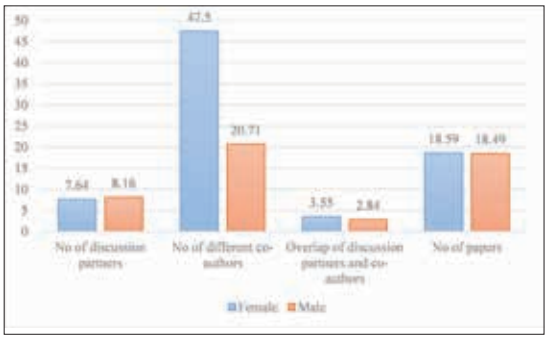

FIGURE 3: Concrete and expressive networks by gender

Correlations between the measures of collaboration and productivity used in this study are presented in Table 4. There are strong correlations between the number of publications, percentile in the field, number of different co-authors and overlap of the two types of collaboration. The number of discussion partners is not correlated with productivity or number of different co-authors, only with the degree of overlap between discussion and co-authorship. The overlap to maximal possible overlap ratio is not correlated with anything, except for the overlap of discussion partners and co-authors. This ratio is not as directly influenced by/dependent upon the number of co-authors and publications, and the lack of correlation with the other variables could indicate that it captures another aspect of collaboration and productivity not covered by bibliometric measures.

2 *One-way ANOVA: $p=0.00$; Independent Samples Median Test: $p=0.00$*

TABLE 4: CORRELATION MATRIX OF PUBLICATIONS AND COLLABORATION #					
VARIABLE	2	3	4	5	6
1. No of publications	.885**	.455**	0.038	.436**	0.04
2. Percentile for No of publications		.385**	0.139	.388**	-0.053
3. No of different co-authors			0.219	.821**	0.128
4. No of discussion partners				.314*	0.221
5. Overlap of discussion partners and co-authors					.532**
6. The overlap to maximal possible overlap ratio					

 # Spearman's rho correlation
*** Correlation is significant at the 0.01 level (2-tailed).*
** Correlation is significant at the 0.05 level (2-tailed).*

Further analysis indicates that the correlation between the numbers of co-authors and discussion partners is different when examined by discipline area. There is a positive association between the number of different co-authors and the number of discussion partners in Social Science and Humanities, but not in Science.

STRUCTURES OF COLLABORATION

A final comparison of collaboration across the three discipline types is shown in the following series of network maps. In each case, the focal individual is shown as a square at the centre of the map. Each of the circles are individuals that they have co-authored publications with in the period 2009-2013. The circles that are shown as white are also located at The University of Melbourne, while the grey circles are people located somewhere else. Heavier lines linking the individuals indicate multiple publications.

Based on what has been presented in the preceding discussion, it would be expected that Humanities academics will have fewer co-authored publications, fewer co-authors in total, and fewer co-authors per publication, while Scientists would have the most of each of these, and Social Scientists will be somewhere in between these two. This is clearly seen in the maps that follow, which give a sense of how these groups of co-authors are clustered around an individual academic.

A typical map for a Humanities scholar is shown in Figure 4. The individual has co-authored with just two other people over this five year period – one internal and one external to the university. Most of this person's publications are sole-authored (this is an historian).

FIGURE 4: Humanities co-authorship map

The next map is for a Social Scientist (Figure 5). This shows a pattern of co-authorship in both reasonably large groups (on the left hand side) as well as several publications with two authors, with a number of different people on the right hand side, who are both internal and external. It is also apparent that this person (located in culture and communication studies) has a (top right) group of co-authors internal to The University of Melbourne.

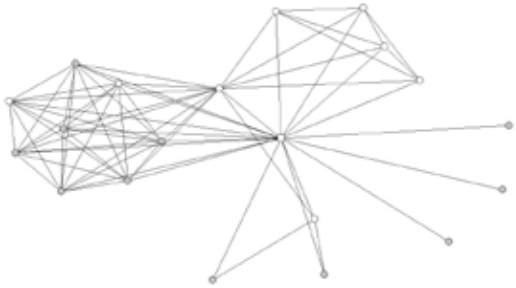

FIGURE 5: Social Scientist co-authorship map

Figure 6 is the map for a botanist, and shows many co-authors, both internal and external to the university, and a few distinct clusters of people working on different publications. Some publications have just three authors while others (in the middle-lower right) have many more. In contrast to the Social Scientist shown in Figure 5, it is easy to see the larger number of co-authors per publication.

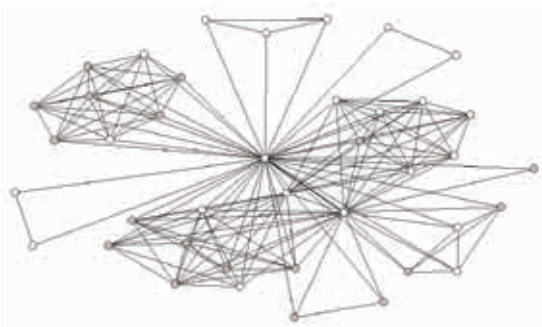

FIGURE 6: Science co-authorship map (botany)

The final map is also from Science, but demonstrates someone who crosses into the medical field and publishes with more people and larger groups, and teams that are a mixture of internal and external colleagues. In this map (Figure 7) it is also clear that there is a cluster of people close to the centre that this individual has multiple publications with as indicated by the heavy lines, and that these are all internal except for one person on the lower right.

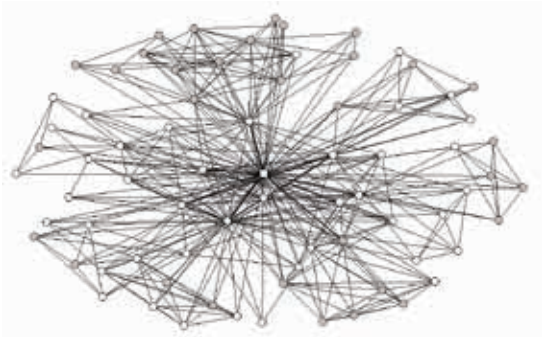

FIGURE 6: Scientist co-authorship map (anatomy and neuroscience)

COLLABORATION AND RESEARCH QUALITY

This section examines the relationship between collaboration and research quality - the latter being a variable that is difficult to measure, and is often assumed to be related to quantitative indicators such as impact factors and citations (Lewis 2014). In doing so, we draw on interviews with 18 of the academics from amongst those interviewed in the earlier study. They were asked for their own views on this topic.

In our analyses of the interview data we first elicited the salient understandings of research quality among the interviewed academics, on the basis of them identifying and discussing three of their own publications from the last ten years that they deemed to be of a particular high quality. We then analysed their views concerning the contribution various forms of collaborative activity have made to them producing high-quality research.

Analysis of the entire body of interviews revealed three major themes under which the predominant understandings of research quality can be grouped. We label these themes epistemic, reputational, and contributory:

- Epistemic – knowledge-based attributions of quality
- Reputational – attributions of quality that focus on academic measures of esteem
- Contributory – attributions that identify research quality with the actual impact a piece of research has had beyond the academy.

The majority of respondents (14) identified research quality with more than one of these themes. Most academics (16) invoked varieties of the epistemic theme (with originality or novelty of ideas or approach being most frequently mentioned here (11)). Varieties of the reputational theme (e.g., prestigious publisher or journal or high citation counts) were offered by 8 academics coming from all discipline areas. Answers that fitted with the contributory theme (e.g., influencing public debates and policy, developing treatments for pests and diseases) were presented by 9 academics, again coming from all discipline areas.

Several specific forms of collaborative activity were singled out as having made a significant contribution to the production of high quality research. These can be grouped under the following three major themes: Personal relationships and support, intellectual exchange, and complementary skills and expertise (methodological or theoretical).

The last theme was alluded to by nine of the interviewed academics, including all Scientists (six). Academics from the Humanities and Social Sciences most frequently identified various forms of intellectual exchange as having played an important role in the production of high-quality research (eight out of 12, with eight total mentions across all three discipline areas). The importance of personal relations and support, also including specific (inter)personal attributes such as trust, enthusiasm and respect, was stressed by 5 academics coming from all discipline areas. Several academics emphasized the important role that face-to-face interactions continued to play in building and sustaining research collaborations, including large-scale international ones.

The majority of academics (14) tended to consider international collaboration as essential for the production of high-quality research. Most outspoken in this regard were the Humanities academics, who all stressed the importance of international discussion networks and the associated intellectual exchanges for their own research. This finding resonates with that from the earlier Lewis (2013) study, which found that Humanities academics had many more external discussion partners than their colleagues in other discipline areas. The production of high-quality research was typically linked to formal forms of collaborative activity (that is, to specific research grants) for 11 academics, including, not surprisingly, all interviewed Scientists (six), but only one academic from the Humanities.

For the majority of academics, collaborative activity (formal or informal) usually resulted in co-authored publications (13), usually journal articles. This again included all the Scientists interviewed, as one would expect. In the Humanities and Social Sciences disciplines, where there is still some emphasis on the research monograph, this output continues to be published primarily by a single author. But the production of this output was nevertheless frequently framed by our participants in terms of a more collaborative effort. Here collaboration was repeatedly seen to include both the informal intellectual exchanges with academics peers as well as the engagement with the body of knowledge already published.

FINDINGS AND IMPLICATIONS FOR RESEARCH POLICY

Two kinds of collaboration – *concrete*, through co-authorship, and *expressive*, through discussion networks – were examined in this paper. We investigated the differences in collaborative activity across three broad discipline areas – the Sciences, Social Sciences and Humanities – and analysed the overlap between these two forms of collaboration, finding substantial differences between them. Based on this (limited) sample, we found that concrete collaboration was (not surprisingly) positively associated with producing a greater number of publications. Of more interest is the finding that expressive collaboration was not associated with producing a higher number of publications – leading to speculation that this form of collaboration might have a larger impact on the *quality* rather than the *quantity* of publications (see Lewis 2013; 2014).

We also presented some specific examples of network structures, showing the marked differences for individuals in different discipline areas and fields. Finally, we described what academics see as the collaborative practices that typically support high quality research in their own discipline, inferring in the process salient differences in perceptions of the collaboration-quality link between discipline areas. Although the data used in this study is a relatively small sample of academics from a single, research-intensive institution based in one country, and it is weighted towards women in Science disciplines, the analyses provide some food for thought.

The findings include that:

- Science academics have more co-authored publications, more co-authors in total, and more co-authors per paper than their colleagues in Social Sciences, who in turn have more than those in the Humanities
- There are no disciplinary differences in regard to the number of discussion partners (although this is constrained by the method of collecting these data)
- The overlap between discussion and co-authorship networks is highest for Science and lowest for the Humanities, with Social Science sitting in between
- Senior academics have more co-authors than their junior colleagues, as do the women in this sample
- The number of publications is positively correlated with the number of different co-authors
- Humanities scholars have simple co-authorship networks with few partners, Social Scientists have more co-authors and groups of co-authors, and Scientists have the most elaborate networks with many sub-groups and many people in each of these
- International discussion networks are particularly important for Humanities scholars
- Academics need intellectual exchange to improve their ideas, be published in high reputation outlets, and reach wider audiences to make an impact, and each of these is seen to be associated with the production of quality research.

Important disciplinary differences emerged, not surprisingly. But it is a reminder that research policy needs to keep these differences firmly in mind. Most policy to date has focused on the need to support concrete collaboration, which is believed to enhance research productivity. This belief overlooks the shaky foundations of this claim, which has some basis for Science disciplines, but very little for other discipline areas. It also pays little attention to the link between collaboration and high quality research, rather than simply quantity. Finally, it appears to disregard all indications that research is also a social and relational activity. Expressive collaboration happens organically, arising from disciplinary norms built around the sharing of ideas, and mutual interest in intellectual problems. Expressive collaboration, which is much less visible and much less easy to count, is also crucial, and for all disciplines.

Our analysis suggests that focusing research policy on concrete collaboration alone will be most helpful to Science academics, since the overlap between their discussion and co-authorship networks is high. This allows them to reap the benefits of collaboration incentives, as they currently stand, as it fits with how they also exchange ideas through discussion. For Humanities and Social Science scholars, this overlap is lower. The effects of privileging concrete collaboration will be more severe for those disciplines that rely heavily on expressive collaboration. Further, without support for discussion and exchange, particularly on an international scale, it is likely that research quality in the Humanities and Social Sciences will suffer the most.

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Appendix: Publications data descriptive statistics

DISCIPLINE	HUMANITIES							SCIENCE							SOCIAL SCIENCE							
	M	Mdn	SD	Skew	Min	Max	N	M	Mdn	SD	Skew	Min	Max	N	M	Mdn	SD	Skew	Min	Max	N	p [3]
Publications No 2009-2013 *	18.29	15.00	13.07	1.32	1	51	21	19.6	18.0	13.9	1.1	3	54	25	16.27	10.00	13.64	1.69	2	60	26	0.684/ 0.419
Percentile for No of publications [1]	73.41	86.03	26.48	-1.14	11.18	98.82	17	69.8	77.7	25.2	-0.8	21.53	98.31	21	63.41	66.67	28.49	-0.43	13.68	100	21	0.505/ 0.315
Fraction of single-authored publications	0.76	0.77	0.19	-0.41	0.4	1	21	0.0	0.0	0.1	3.4	0	0.4	25	0.62	0.67	0.29	-0.68	0	1	26	0.000
Avg No of authors per multi-authored publication [2]	1.53	1.13	0.81	1.77	1	3.67	17	4.0	3.7	1.5	0.7	1.22	8.04	25	1.62	1.50	0.76	2.28	1	4	22	0.000

No – number; M – mean; Mdn – median; SD – standard devation; Skew. – skewness; Min. – minimum value; Max. – maximum value

** Source: Melbourne Research Windows*

1 - In comparison with others in same discipline; Source: Melbourne Research Windows

2 - Not including ego

3 - ANOVA/Median Test

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