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Team structure and scientific impact of ?big science? research

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Abstract

This paper summarizes preliminary results from a project studying how the organizational and cognitive features of research carried out in a Large Scale Research Facility (LSRF) affect scientific impact. The study is based on exhaustive bibliometric mapping of the scientific publications of the Neutron Science Department of Oak Ridge National Laboratories in 2006-2009. Given the collaborative nature of research carried out at LSRFs, it is important to understand how its organization affects scientific impact. Diversity of teams along the institutional and cognitive dimensions affects both opportunities for combination of knowledge and coordination costs. The way specific collaborative configurations strike this trade-offs between these opportunities and costs have notable effects on research performance.
The findings of the paper show that i.) scientists combining affiliations to both the facility and to an external university of research laboratory (secondments) out-perform all other types of institutional affiliations. ii.) Teams spanning multiple institutional types have the lowest performance. This is the case whether or not teams include resident scientists from Oak Ridge National Laboratories. iii.) Knowledge integration at the level of individual scientists clearly outperforms team level integration. iv.) Team diversity is associated with stronger performance in basic research than in applied research. Implications for the organisation of research collaboration of LSRFs and for their skill structures are discussed.

Jelcodes:O31,O32

Team structure and scientific impact of "big science" research

Introduction

This paper presents preliminary results from a study on the way organizational and cognitive features of research carried out at a Large Scale Research Facility (LSRF) affect their scientific impact. LSRFs are organizations that operate complex research infrastructures to pursue "big science" projects whose outcomes have high relevance for science policy goals. Many countries are prioritizing the development of LSRFs in order to achieve is part of the science policy strategy of many countries, given their relevance to generate high quality science with implications for economic development (Jacob & Hallonsten, 2012). As a consequence, investment in LSRFs has been sustained even during the current global economic downturn and is expected to increase in the next years (Institut Laue-Langevin, 2013). In the American context, the government launched a network of LSRFs during War World II to perform military research; in the following decades, these organizations have proven their ability to adapt their mission to evolving policy goals, thus maintaining autonomy and adequate level of funding (Elzinga, 2012; Hallonsten & Heinze, 2012; Westfall, 2012).

We investigate LSRFs because they organize research activities according to principles – such as orientation to a public mission and active management of collaborations – that are different from academic and industrial research (Wagner, 2006). In particular, collaborations are driven by their nature of indivisible resources that drives scientists to team up in order to effectively make use of the infrastructure (Katz & Martin, 1997). However, scientists operating in these facilities seem to establish collaborations according to criteria that are similar to those characterizing academic research in general (Lauto & Valentin, 2013). Despite their importance for science policy (Jacob & Hallonsten, 2012), empirical evidence on LSRFs is scant and only very recently quantitative indicators of performance have been developed (Hallonsten, 2013).

The aim of this paper is to understand LSRFs as arenas of knowledge integration (Singh, 2008). The above particular features of LSRF imply that they both attract and are dependent upon specialized areas of expertise and knowledge which have not developed standard interfaces in the global research community. To a large extent, these diverse pools of knowledge must be integrated as part of the research carried at the facility. Research collaboration is one important expression of knowledge integration, but it is also expressed in at the level of single scientists who individually build the capabilities to link up different domains of knowledge which are otherwise difficult to connect. So-called "secondments" are positions in which individual scientist have dual appointments or affiliations with both the facility and with another knowledge institution, typically a university. They play a particular role in the skill structure found at LSRFs. The very existence of this job category bears witness to the challenge faced by facilities in integrating different areas of complex knowledge. Secondments offer the opportunity to observe knowledge integration at the level of individual scientists as distinct from the level of collaborative teams.

Based on a original data covering the publications produced at Neutron Science Department of Oak Ridge National Laboratories (ORLN/NSD) in 2006-2009, we find that presence of scientists who have a dual affiliation – to a LSRF and to other research organizations – contributes to the scientific performance of a research team by virtue of their boundary spanning function. We are currently expanding our empirical analysis to publications produced until 2011, and the final version of this paper will be based on this extended dataset.

Using this 2006-2009 dataset, we study the performance of LSRF research in terms of its citation impact on the global scientific community. Applying multivariate regressions we isolate effects on the impact of research attributable to various sources of scientific expertise and to the different forms of its integration. Our main questions and findings are as follows:

- Are variations in performance is associated with team members coming from different types of knowledge institutions (universities, government research laboratories, etc.)? We find that the dual institutional affiliation represented by secondments out-performs all other types of institution. University affiliation moderately detracts from performance.
- Are there specific types of team configurations associated with higher or lower performance? Our findings show that teams spanning multiple institutional types have the lowest performance. This is the case whether or not teams include resident scientists from Oak Ridge.
- Does knowledge integration at the different levels of individuals and teams lead to different performance? The results show that knowledge integration at the level of individual scientists clearly outperforms team level integration.

- Are there differences between basic and applied research in the way team diversity affects the performance of research? We find that team diversity is associated with stronger performance in basic research than in applied research.

The present finds add to, and are consistent with, a companion paper based on the same data set, identifying the principles of how scientists organize collaborations in LSRF research (Lauto & Valentin, 2013). To our knowledge the two papers are first in undertaking an exhaustive bibliometric study of a major LSRF for a duration of several years. The present paper offers novel insights into key determinants of the scientific significance of research in LSRF, with important implications for their knowledge production and for the way they build requisite scientific skills.

Theoretical framework

LSRFs present a series of organizational features that correspond to the major rationales for research collaboration identified in the literature (Heinze & Kuhlmann, 2008; Katz & Martin, 1997; Melin, 2000). The foremost reason why research carried out at LSRFs is collaborative lies in the presence of complex, expensive, specialized instrumentation that cannot be replicated at smaller scale: scientists can make effective use of such research technologies only by using them collectively. Furthermore, facilities are endowed with dedicated technical staff and permanent scientists who are specialized in experiments related to the facility: the literature recognizes access to complementary knowledge and expertise as a powerful driver of collaboration. Exploiting these cognitive resources permit collaborating scientists a more effective division of intellectual labor by pooling skills and knowledge, and learning new skills or techniques. Finally, as LSRFs have great visibility, so scientists who get access to these research settings also accrue higher reputations.

Since collaborative research is the dominant model of knowledge production in LSRFs, it is important to understand what features of collaborating teams are conducive to higher scientific performance. Although contributing to the academic debate is only one of the goals of LSRFs, we believe that it ranks high among the priorities of individual scientists working and accessing these facilities, in particular those working in academic settings.

It is well established that creative activities, including production of scientific knowledge (Heinze, 2013), benefit from the combination of complementary knowledge bases and approaches to problem solving (Dahlin, Weingart, & Hinds, 2005; Nooteboom, Van Haverbeke, Duysters, Gilsing, & van den Oord, 2007). Such diversity improves framing of research issues, generation of insights, identification of patterns in data as well as access to external sources of knowledge. Scientists contribute to this diversity not only based on their distinct disciplines. The perspective of scientific and technical human capital (Bozeman & Corley, 2004; Bozeman, Dietz, & Gaughan, 2001) suggests that scientists build unique endowments of scientific, technical and social knowledge, social networks, skills and resources through formal education, professional activity, and social relations. Therefore patterns of scientific human capital differ not only across disciplinary specialties but also across the *institutional settings* in which scientific research is carried out, since they influence scientists' approach to problem selection and problem solving.

The three institutional settings in which scientific research is carried out – academic organizations, government laboratories, and firms – present distinctive goals, values, incentive structures, formal rules and cultural norms and specialization in specific research technologies (Dasgupta & David, 1994; Etzkowitz & Leydesdorff, 2000; Whitley, 2000). Academic research aims at advancing and diffusing scientific knowledge and rests on the rules of "open science", rewarding scientists based on the impact of their contributions to the scientific literature; by contrast, governments and other non-profit organizations engage in research that has implication for policy or societal policy goals, while companies prioritize exploitation of research in the innovation process. These institutional differences concern not only the priorities that scientists pursue, but also influence scientists' cognitive styles. Hence different institutional affiliations of team members are an important source of diversity in research collaboration.

Social network theorists debate whether generation and diffusion of novel ideas benefit more from a cohesive structure, in which most actors are connected to each other, or from the operation of brokerage. In the latter case otherwise disconnected clusters in the network are connected by a single (or few) overlapping positions. They are in the position to combine and broker those flows of information which would otherwise have circulated only within disparate sub-networks (Burt, 1992). Brokerage positions have been shown to be conducive to idea generation while it hinders diffusion of ideas (Fleming, Mingo, & Chen, 2007; Phelps, Heidl, & Wadhwa, 2012). As we are interested in the process of production of scientific knowledge – rather than in the diffusion of discoveries in the scientific community – we emphasize the brokerage perspective. According to this stream of the literature, individuals who are connected to distinct social groups – i.e. are positioned close to the structural holes of a social network – have an advantage in terms of idea generation and creativity. As members of a social group tend to have homogeneous cognitive and social features, those who are connected with different groups are exposed to a wider scope of ideas and can access to multiple knowledge sources; furthermore they have the opportunity to become acquainted with their different working practices and way of thinking and behaving. The "broker" position offers the opportunity to produce fresh ideas by aggregating and giving new meaning to previously unrelated information, that other members in a social network can hardly access because they are embedded in redundant relationships (Burt, 1992, 2004; Perry-Smith, 2006). As a matter of fact, both the size of a scientists' collaboration network and the strength of individual partnership relations present decreasing returns on knowledge production (McFadyen & Cannella, 2004).

Empirical studies emphasize that scientists who are brokers between complementary cognitive domains *or* who have multidisciplinarity as their *individual* orientation obtain stronger scientific performance, including generation of breakthroughs (Heinze & Bauer, 2007; Heinze, Shapira, Rogers, & Senker, 2009). However, (Jansen, Görtz, & Heidler, 2009) show that the impact of brokerage and closure depends on the degree of development of a field, with emerging fields, such as nanoscience, benefitting from the former and established fields, such as astrophysics, from the latter.

As we pointed out, the scientific research is carried out in three institutional settings: academic organizations, government laboratories, and firms. We argue that scientists who are affiliated with multiple institutional settings occupy broker positions, as they connect distinct institutional settings. In the case of research carried out at a LSRF, we submit that the benefit of multiple affiliations are maximum for secondments. In fact, secondments not only enjoy the advantages of brokerage but also benefit from familiarity with the instrumentation installed at the facility. A number of studies on research involving advanced and dynamic instrumentation show the particular role of scientists with specialized and deep insights into its application. The brokerage position between instrument knowledge and other domains represented by secondments therefore offers possibilities for facility related research with higher impact compared to that obtained with any other institutional profile (Joerges & Shinn, 2001). Hypothesis-1: *Contribution to collaborative research by secondments is associated with higher scientific impact compared to contributions from any other institutional position.*

Diversity in a team may be achieved either by involving scientists from different scientific communities and institutional settings (Bercovitz & Feldman, 2011), or by involving scientists who individually span different cognitive and institutional domains. In other words, the options concern exploitation of diversity either at team- or at individual-level.

Research has found that groups involving individuals with a generalist knowledge tend to perform better than those composed of specialists. Generalist members are more effective in circulating information and present higher flexibility in adapting to different cognitive frameworks (Rulke & Galaskiewicz, 2000). Furthermore, team members who work across different institutional settings arguably have internalized the contradictions between their missions, incentives and working practices.

By contrast, pursuit of project goals in a team that involves a variety of scientists with different institutional affiliations requires coordination among its team members. As each institutional setting present specific priorities, incentives, norms of practice and cultures, scientists participating in collaborative projects have to negotiate goals, align interpretations and to coordinate working practices. Furthermore, institutional settings are generally characterized by specific working routines that require an active management of interfaces among different social groups. Finally, diverse teams may experience misunderstandings due to existence of prejudices and stereotypes associated with specific institutional settings and difficulties in communication (Bercovitz & Feldman, 2011; Cummings & Kiesler, 2005, 2007; Heinze & Kuhlmann, 2008; Hoekman, Frenken, & Oort, 2009; Ponds, van Oort, & Frenken, 2007). In short, integrating knowledge at team level gives rise to a number of challenges which may offset the advantages they have above individual generalists in terms of knowledge diversity. Whether individual vs. team-based diversity is more productive depends primarily on the architecture of the problem at hand (Simon, 1996). Based on detailed case studies of instrument-intensive research (Joerges & Shinn, 2001) the problem architecture of connecting instrument experience with domain knowledge has low decomposability and high requirements for iterations. These features suggest that knowledge integration at individual level will outperform team-level integration. Hypothesis-2: *Integration of instrument-expertise with domain knowledge at the level of individual scientists brings stronger scientific impact than integration pursued at team-level.*

Finally, we consider the interdependencies between institutional and cognitive dimensions. Building on (Boschma, 2005) theory on proximity effects in innovation, (Lauto & Valentin, 2013) argue that the costs of coordinating scientists belonging to different institutional, cognitive, social, geographical and organizational settings constrains research collaboration in LSRFs. Building on this argument (Lauto & Valentin, 2013) demonstrate an upper boundary for the total diversion across all dimensions which can be accommodated into collaborative research. Increases in team diversity along one dimension require reduced diversity along other dimensions. With regard to the cognitive dimension, it is useful to contrast scientific knowledge to applied know-how: the former is characterized by low ambiguity of meaning by virtue of its strong codified and abstract content; applied knowledge instead entails a relevant tacit component that requires context-specific negotiation of meaning (Asheim, Boschma, & Cooke, 2011). As a consequence, projects addressing fundamental issues allow greater space for institutional variety, as they present lower costs of coordination along the cognitive dimension. Furthermore, it is important to stress that entire scientific fields differ in terms of intellectual coordination (Whitley, 2000): in projects developed in scientific fields characterized by tightness of theoretical and methodological coordination, such as Physics, effective collaboration is enabled by agreement upon the research agenda and research methods that reduces the necessity of negotiating goal of experiments and meaning of results. The high degree of intellectual coordination implies that scientists share the same priorities and methodologies independently from the organization or the national research system they belong to. It is not surprising that work carried out at big-science labs in Physics is characterized by a higher intensity of collaboration than the average of field (Newman, 2004).

Based on these arguments submit Hypothesis 3: *Multi-institutional collaborations are more effective when addressing fundamental research or issues in the field of Physics.*

Methods

Our empirical case of a LSRF is ORLN/NSD, one of the most prominent big science laboratories in the USA which is part of the network of 17 laboratories of the Department of Energy (science.energy.gov/laboratories). The laboratory conducts basic and applied research in the areas of neutron science, biological systems, energy, advanced materials, supercomputing and national security. NSD accounts for about 600 of 4500 staff of ORLN (www.ornl.gov/about-ornl; neutrons.ornl.gov/about/). The laboratory operates two world-class neutron scattering facilities: a Spallation Neutron Source and a High Flux Isotope Reactor. These facilities were renovated respectively in 2006 and 2007.

We take the journal articles produced at the facility between 2006 and 2009 as our units of analysis. We are currently working to expand the dataset to publications until 2011. We can precisely identify these publications because, since 2006, ORLN/NSD lists on its website all the publications produced by its staff or by external scientists who used its laboratories.

We retrieved full bibliometric records of these publications from Web of Science. We obtained a final sample of 409 articles that we analyze with quantitative methods.

Our dependent variable is scientific impact, measured as the number of *Citations* received by each paper from publication until April 2011. Deliberately we do not refer to this measure as "scientific quality" due to the ambiguity of that terminology. Often high scientific quality refers to that relatively small number of discoveries which are radical "game changers" in the development of science. Attempts to explain the differentiating mechanisms of the emergence of exactly this limited number of discoveries would require methodologies different from those applied in this paper. Instead our methodology relates to the notion that science advances and cumulates on the basis of a multitude of contributions (Campbell 1974; 1986). Citation impact picks up the significance of a specific body of research in that cumulative development, reflecting particularly its utility to subsequent research. Without offering radical breakthroughs, single papers of various altitudes are the stepping-stones required to reach the much fewer game-changing discoveries, as evidenced by more detailed accounts of their emergence (Hollingworth 2006). Hence "impact" is the preferred term of this paper and by the "performance" of scientific work we refer to its results in this respect.

The first set of explanatory variables considers the presence or absence of *Institution Types* in the coauthors team; to this purpose we employ six dummies corresponding to the following institution types: Resident, Secondment, University, Research Centers, Business, Multiple. Each variable takes value 1 if a given institution type is present in the coauthors team and 0 otherwise. Residents are those affiliates to any of the departments of ORLN; we adopt this broad definition of the focal organization to the entire laboratory because publications in our dataset do not generally report more fine-grained information on the departmental affiliation of scientists. However, we believe that this approximation does not deteriorate the validity of our findings, as the institutional setting of NSD can be reasonably considered as analogous to that of the other departments of ORLN. "Secondment" comprises those scientists who, in a given paper, indicate affiliation to ORLN and other institutions. This indicates that their work was financed by different institutions or was actually carried out in different organizations, e.g. within a mobility scheme or during a visiting period. The category Research Centers considers affiliates with independent and government-funded organizations, including U.S. Federal Laboratories like ORLN. We single out ORNL as a separate category since this is the the focus of our analysis. "Multiple" characterizes the authors who are affiliated with a variety of institutions, but not to ORNL/NSD.

The variable *Team Structure* includes several categorizations of team configurations. *Mono-institutional* teams have all their members belonging to the same institution type, while *Multi-institutional* teams have members from different institutional types. Within the latter group we distinguish between those in which *Secondment* are present (either in combination with other institution types or alone), and those that are *Multi-institutional* but do not include Secondments. We introduce two further distinctions with regard to this category: a first version of the variable between multi-institutional teams in which ORLN-affiliates are present or absent; a second version, considers presence or absence of multiple-affiliated scientists.

A third explanatory variable concerns the *Discipline* distinguishing between articles contributing only to Physics and its subfields, from those contributing both to Physics and other fields or exclusively to other fields. The cognitive profile is also captured by *Orientation* towards basic or applied issues; we ascribe a basic orientation to a paper if it is published in a journal categorized as "basic scientific research" in the four-fold classification developed by CHI Research for non-biomedical fields (Narin, Pinski, & Gee, 1976); by contrast, applied journals are those classified at the levels "applied technology", "engineering science-technological science" "applied research-targeted basic research".

We apply three controls: *Size* of the team, which is measured as the number of coauthors. The *Citation level* of the field to which a paper contributes is calculated as the average citations received in the period of analysis by all the publications in the combination of ISI Subject Categories to which it is referred to. Finally, we consider the *Year of publication* to take into account that papers published early in our period of observation has a longer citation window compared to papers published late in the period.

After carrying out a descriptive statistical analysis, we single out the factors associated with papers with higher scientific impact by means of a series of Negative Binomial Regression models. We chose this specific model because Citations is a count variable with an over-dispersed distribution. We can exclude that the result of the regressions are biased by muticollinearity as the VIF is below the threshold of 10.

Results

We first examine the institutional composition of the papers (Table 1): we find scientists affiliated with either Resident or Universities or Research Centers in almost two-thirds of the papers; presence of scientists with Secondments or Multiple affiliation is less frequent, appearing in about one-quarter of the papers; only a marginal portion of publications under consideration are the result of a collaboration with industry. The majority of papers is multi-institutional, typically involving Residents (39%) and Secondments (25%). A considerable share of papers (17%) is the result of collaborations that do not involve NSD personnel, i.e. involves teams that are attracted by the facilities of ORLN/NSD, rather than by individual connections; mono-institutional papers account for 19% of the total.

Table 1 – Organizational profile of ORLN/NSD papers. Frequency of Institution Types and distribution of papers by Team composition.

Variable	Frequency	Percent
Institution type		
ORLN Resident	261	63.81
Secondment	103	25.18
University	267	65.28
Research Centre	270	66.01
Business	16	3.91
Multiple	103	25.18
Team structure		
Mono-institutional	76	18.58
Presence of Secondment	103	25.18
Multi institutional with ORNL	161	39.36
Multi institutional without ORNL	69	16.87
Multi institutional with Multiple	71	17.36
Multi institutional without Multiple	159	38.88

Turning to the cognitive dimension (Table 2) we find that research at NSD is characterized by prevalence of contributions specialized in Physics (53%) with a basic orientation (58%).

Table 2 – Cognitive profile of ORLN/NSD papers. Distribution of papers by Orientation and Discipline.

Variable	Frequency	Percentage
Basic Orientation	241	58.92
Physics specialized	215	52.57

We next consider the institutional and cognitive dimension together and we examine how the Orientation and Disciplinary specialization varies across Team structures (Table 3). The Table suggests some regularity regarding the nature of research carried out by teams with different profile: mono-institutional teams tend to address applied issues in fields different from Physics or combining Physics with other fields. By contrast, multi-institutional teams involving ORLN/NSD scientists are more oriented towards basic studies in Physics. Research that does not involve ORLN/NSD scientists presents a more varied cognitive profile.

We now turn to the relationship between institutional and cognitive features of research and its scientific impact. Citations present a left-skewed distribution: the mean is 8.064 with a standard deviation of 31.285; the median is 2 and values range between 0 and 554. Table 4 presents the mean and median number of citations obtained by articles in each institutional and cognitive combination.

Table 3. Distribution of papers by Cognitive and Team structure.

	Orientation		Discipline		Total
Team structure	Basic	Applied	Physics spec.	Other	
Mono-institutional	23	53	24	52	76
	30.26	69.74	31.58	68.42	100.00
Presence of Secondments	79	24	65	38	103
	76.70	23.30	63.11	36.89	100.00
Multi institutional with ORNL	103	58	94	67	161
	63.98	36.02	58.39	41.61	100.00
Multi institutional without ORNL	36	33	32	37	69
	52.17	47.83	46.38	53.62	100.00
Total	241	168	215	194	409
	58.92	41.08	52.57	47.43	100.00

Table 4. Mean and median (in parentheses) citation received by papers by Team structure, Orientation and Disciplinary specialization.

	Orientation		Discipline		Total
Team structure	Basic	Applied	Physics spec.	Other	
Mono-institutional	2.478 (0)	3.283 (1)	3.115 (1)	2.875 (0)	3.039 (1)
Presence of Secondment	18.861 (5)	11.542 (2)	24.526 (3)	12.846 (6)	17.155 (4)
Multi institutional with ORNL	7.990 (3)	2.034 (1)	4.612 (1)	6.723 (2)	5.845 (2)
Multi institutional without ORNL	7.222 (4)	3.000 (2)	3.432 (2)	7.250 (4.5)	5.203 (3)
Total	10.913 (3)	3.976 (1)	8.223 (3)	7.887 (1)	8.063 (2)

Table 4 indicates that articles produced by teams including Secondments obtain more citations than papers with any other team structure; by contrast, those that result from a mono-institutional collaboration present the lowest mean and median value. Papers that are basic-oriented and specialized in Physics have higher impact than those investigating applied issues and those contributing issues in fields different from Physics. The data suggest the presence of few highly cited papers targeting to fields different from Physics.

In order to validate these results by considering possible spurious effects between variables, we perform a regression analysis. We run two sets of models, one taking Institution Types and the other taking the Team Structure as the main explanatory variable; in both cases, we consider also *Discipline* and we control for *Size*, *Orientation*, *Citation level* and *Publication Year*.

The first set of models, presented in Table 5, considers first the controls (Model 1) and then introduces *Discipline* (Table 2) and then *Institution Type* (Table 3). We observe that *Discipline* takes out the positive effect of basic orientation emerged from Model 1, while controls for *Size* and *Citation level* maintain their positive and significant sign in all the models. Examining the Institution Types in Model 3, we find that the category of secondments is associated with an increase of the citations received by a paper. The odds-ratio (e^{β}) corresponding to the coefficient indicates that presence of a secondment in a coauthoring team doubles the chances for a paper to receive an additional citation. A negative impact, significant at 10% level, is found instead for presence of University scientists. All the other institutional types are not correlated with performance. Given the prominence of Secondments among institution types, we deepen our examination by contrasting papers in which these scientists are present to other institutional profiles. Model 4 shows that papers with at least one Secondment in their team are more likely to have higher citation rate than any other team configuration – either mono or multi institutional. The results broadly support *Hypothesis-1*.

We deepen our investigation by considering the origins of institutional diversity; specifically, we distinguish between diversity generated through a multi-institutional team configuration and the diversity associated with the dual affiliation of secondments. Multi-institutional teams including ORLN/NSD residents (row 9) represent at team level a type of knowledge configuration very similar to that found at the individual level of secondments (row 14). The knowledge integration obtained at team level has a significantly lower performance than that obtained by secondments. We also learn that for multi-institutional teams it makes no significant difference for their performance whether or not they include an ORLN/NSD resident (rows 9 and 10).

Table 5. Results of Negative Binomial Regression of Citations. Coefficients and Robust Standard Errors (in parentheses). Cases=409.

	Model 1	Model 2	Model 3	Model 4	Model 5
1. Institution Type					
2. Resident			-0.151 (0.159)		
3. Secondment			0.767*** (0.167)		
4. University			-0.269* (0.160)		
5. Research Centre			-0.140 (0.170)		
6. Business			-0.066 (0.367)		
7. Multiple			0.213 (0.178)		
8. Team Structure					
9. Multi institutional with Residents				-0.813*** (0.180)	
10. Multi institutional without Residents				-0.770*** (0.223)	
11. Multi institutional with Multiple					-0.679*** (0.213)
12. Multi institutional without Multiple					-0.880*** (0.187)
13. Mono institutional				-0.447* (0.242)	-0.488** (0.246)
14. Presence of Secondments				baseline	baseline
15. Physics Specialized		0.245 (0.204)	0.211 (0.194)	0.209 (0.193)	0.211 (0.194)
16. Basic oriented	0.436*** (0.163)	0.275 (0.210)	0.229 (0.204)	0.283 (0.206)	0.251 (0.208)
17. Size	0.162*** (0.022)	0.158*** (0.022)	0.140*** (0.024)	0.147*** (0.022)	0.141*** (0.023)
18. Field citation	0.120*** (0.030)	0.135*** (0.032)	0.101*** (0.031)	0.113*** (0.031)	0.111*** (0.031)
19. Year					
20. 2007	0.016 (0.251)	0.070 (0.254)	-0.115 (0.254)	-0.079 (0.250)	-0.074 (0.249)
21. 2008	0.353 (0.235)	0.417* (0.241)	0.259 (0.234)	0.300 (0.234)	0.307 (0.233)
22. 2009	-0.081 (0.270)	0.001 (0.278)	-0.331 (0.284)	-0.242 (0.275)	-0.240 (0.274)
23. Constant	-0.342 (0.292)	-0.475 (0.310)	0.082 (0.365)	0.328 (0.363)	0.406 (0.373)
24. Ln-alpha	0.615 (0.083)	0.612 (0.083)	0.528 (0.085)	0.539 (0.084)	0.535 (0.084)
25. Alpha	1.850 (0.153)	1.843 (0.152)	1.696 (0.143)	1.714 (0.144)	1.708 (0.144)

As these results point out the benefits of diversity at individual rather than at team level, we examine whether increased performance is associated with teams including single members with multiple affiliations. These are scientists affiliated to different institutional settings – Universities, Research Centers or Firms – but not to ORLN/NSD. Similarly to Secondments they occupy a broker position, but differently from them they do not have extensive direct experience at instrument level. Model 5 reveals that teams both with and without Multiple affiliated are penalized compared to Secondments. Institutional diversity at individual level associated with the Multiple profile does not compensate for lack of expertise on research instrumentation; as a matter of fact, Wald tests (not presented here) do not find a significant difference between performance of Multi institutional teams with and without residents, nor between Multi-institutional and Mono-institutional configurations. This result indicates the importance of the presence of scientists who not only are able to work across institutional domains, but also have instrument experience at the facility. Overall, *Hypothesis-2* finds support.

Finally, we examine whether team composition is associated with different performance levels depending on the cognitive profile of a paper. To this purpose, in Table 5 we interact Team Structure with Orientation and Discipline respectively in Models 6 and 7. For teams including Secondments the models show no statistical difference between basic vs. applied orientation (rows 30 vs. 34) nor between their disciplinary specializations in physics vs. other fields (rows 39 vs. 44). These findings reiterate that teams including Secondments simply have higher performance regardless of the field of investigation or orientation of specific publications (the Models allow a direct comparison in the case of investigation in Applied studies and Other Fields; for investigations specialized in Physics we calculated coefficients and tested their significance with Wald tests).

We further explore the differences between orientations and disciplines in various other team configurations by means of calculations on coefficients and Wald tests. We find only one statistically significant difference: Multi-institutional teams involving Residents perform better when addressing basic (row 31) as compared to applied (row 27) research (coefficient 0.647, significance 5%).

These results provide partial support to *Hypothesis 3*, expecting that fundamental research and tight disciplinary coordination reduce cognitive misalignments, so that multi-institutional collaborations are effective.

Table 6. Results of Negative Binomial Regression of Citations; models with interactions. Coefficients and Robust Standard Errors (in parentheses). Cases=409.

	Model 6	Model 7
26. Team structure X Orientation		
27. Multi institutional with ORLN X Applied	-1.147*** (0.349)	
28. Multi institutional without ORLN X Applied	-0.790** (0.384)	
29. Mono institutional X Applied	-0.394 (0.355)	
30. Secondment X Applied	baseline	
31. Multi institutional with ORLN X Basic	-0.501 (0.343)	
32. Multi institutional without ORLN X Basic	-0.619 (0.388)	
33. Mono institutional X Basic	-0.688 (0.451)	
34. Secondment X Basic	0.183 (0.357)	
35. Team Structure X Discipline		
36. Multi institutional with ORLN X Other fields		-0.867*** (0.297)
37. Multi institutional without ORLN X Other fields		-0.839** (0.345)
38. Mono institutional X Other fields		-0.300 (0.325)
39. Secondments X Other fields		baseline
40. Multi institutional with ORLN X Physics Specialized		-0.538* (0.312)
41. Multi institutional without ORLN X Physics Specialized		-0.448 (0.363)
42. Mono institutional X Physics Specialized		-0.575 (0.395)
43. Secondment X Physics Specialized		0.246 (0.328)
44. Basic Oriented		0.268 (0.206)
45. Physics Specialized	0.184 (0.193)	
46. Size	0.145*** (0.023)	0.143*** (0.023)
47. Field Citation	0.109*** 0.030	0.116*** (0.031)
48. Year		
49. 2007	-0.129 (0.252)	-0.069 (0.251)
50. 2008	0.296 (0.235)	0.344 (0.236)
51. 2009	-0.213 (0.276)	-0.213 (0.276)
52. Constant	0.458 (0.416)	0.306 (0.421)
53. Ln-alpha	0.524 (0.085)	0.532 (0.084)
54. Alpha	1.689 (0.143)	1.703 (0.144)

Concluding remarks

As its point of departure, this paper has built on evidence to the effect that integration of diverse sources of knowledge is a key requirement for research at LSRFs. We have examined outcomes from obtaining this integration in a variety of forms, contrasting team-level with individual level integration, comparing a number of different configurations of collaboration, and analyzing how outcomes of collaborations are mediated by various cognitive profiles of research (disciplines and basicness). Our main theoretical notion has been that research collaboration embodies both opportunities and coordination costs. Specific collaborative configurations, or the difference between team-level vs. individual integration, are organizational solutions representing tradeoffs between these two concerns.

The overarching conclusion emerging from our findings is that the performance of LSRF research significantly depends on the choice of organizational solution to the challenge of knowledge integration.

The most effective organizational form seems to be knowledge integration at the level of individual scientists. This comes out in the contributions of Secondments which obtain impact notably above that of institution-specialized teams or any other cross multi-institutional configurations. Still, within these other configurations, mono-institutional teams significantly outperform their cross-institutional counterparts.

In the companion paper mentioned above (Lauto & Valentin, 2013) we studied patterns in the way scientists self-organize into different team configurations for the same 409 ORLN/NSD affiliated papers we study here. We found that LSRF scientists indeed do self-organize so as to minimize the different types of coordination costs we have referred to above. Organizational patterns indicate a pervasive underlying tendency to economize on coordination costs associated with intra team distances between team members in terms of institution, nationality, scientific discipline, and research orientation (basic vs. applied), reflected in the tendency on part of teams to trade-off these dimensions of distance against each other. Teams accommodating more internal distance on one dimension will reduce distance on other dimensions. The present paper takes the explanation and implications of those previous findings further. Teams are indeed penalized in terms of lower research performance when their coordination cost increases as a result of high level of internal distances. We also found evidence of cross-dimensional tradeoffs in the fact that teams may accommodate higher internal institutional distance, when then their research has a basic orientation as compared to the larger cognitive heterogeneity of applied research.

To our knowledge no previous research on LSRFS has documented these differences across its various organizational and cognitive forms. These results have implications for a number of issues in the organization of LSRF research. The strongest implication arguably refers to the role of secondments. In the understanding of this paper secondments represent an investment in the integration of domain-specific knowledge with a deeper specialization into LSRF instrumentation.

The strong performance associated with this investment bears witness not only to the general importance of knowledge integration as a challenge to LSRF research. It also suggests that this investment is a particularly effective solution to this challenge. Positions as secondment at a specific LSRF comes about often though a complex interplay between the facility, research councils or other funding bodies, universities or research laboratories and research groups within them. Given the challenge of this coordination, it is not difficult to understand why secondments make up only 7% of the authors contributing to publications considered in this study. Without venturing into guesswork regarding their optimal share of LSRF research the present findings suggest a notable increase in the payoff of LSFR research with increase in number of secondments.

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