Team structure and scientific impact of “big science” research

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Purpose of the research

This abstract summarizes the results of a research project aimed at understanding how the organizational and cognitive features of research carried out in a Large Scale Research Facility (LSRF) affect their scientific outcomes. We examine the case of the Neutron Science Department of Oak Ridge National Laboratories (ORLN/NSD).

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) and are designed with the aim of fostering collaborative research. 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).

In this paper, we ask whether *i.*) variations in scientific are associated with team members coming from different types of knowledge institutions (universities, government research laboratories, firms); *ii.*) specific types of team structures are associated with higher or lower performance; *iii.*) knowledge integration at the different levels of individuals and teams lead to different performance; *iv.*) team diversity has a different impact on performance in basic and applied projects.

In particular, we focus our attention on the effects of the presence of Secondments, i.e. scientists who have permanent or temporary dual appointments or affiliations with both a LSRF and with another knowledge institution, typically a university.

The paper addresses one of the “basic” problems of organization design, i.e. specialization, as well as the issue of team composition, that is a major stream in organizational literature. Therefore, the paper contributes to the “organization” topic of the conference, as it develops the aforementioned themes with regard to organizational design in science.

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). 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 and enhance the opportunities for access to complementary knowledge; LSRFs have great visibility, scientists who get access to these research settings also accrue higher reputations (Ponomariov & Boardman, 2010).

As collaborative research is the dominant model of knowledge production in LSRFs, we deem relevant to understand what features of collaborating teams are conducive to higher scientific performance.

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. 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.

The three institutional settings in which scientific research 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).

Social network theories suggest that generation of novel ideas benefits from brokerage between otherwise disconnected social groups (Fleming, Mingo, & Chen, 2007; Phelps, Heidl, & Wadhwa, 2012): 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 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 (Burt, 2004; McFadyen & Cannella, 2004; Perry-Smith, 2006). These theoretical expectations are supported by empirical research on emerging scientific fields (Heinze & Bauer, 2007; Heinze, Shapira, Rogers, & Senker, 2009). Based on these considerations, we expect that contribution to collaborative research by Secondments, who belong to different institutional settings, is associated with higher scientific impact compared to contributions from any other institutional position (*Hypothesis 1*).

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. Teams involving individuals with generalist knowledge tend to perform better than those composed of specialists as the former 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, multi-institutional teams require coordination as each institutional setting presents specific priorities, incentives, norms of practice and cultures (Cummings & Kiesler, 2005, 2007; Ponds, van Oort, & Frenken, 2007). Whether individual vs. team-based diversity is more productive depends primarily on the architecture of the problem at hand (Simon, 1996); the problem architecture of connecting instrument experience with domain knowledge has low decomposability and high requirements for iterations (Joerges & Shinn, 2001). We therefore expect that research produced by teams in which Secondments are present obtain higher scientific impact than research produced by teams in which institutional diversity is achieved by interaction of residents with scientists affiliated with other institutions (*Hypothesis 2*).

Finally, we consider the interdependencies between institutional and cognitive dimensions. Building on (Boschma, 2005), (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. This implies that increases in team diversity along one dimension require reduced diversity along other dimensions. The codified and abstract content of scientific knowledge presents lower costs of coordination along the cognitive dimension, thus allowing more opportunities for collaboration; instead, the tacit component of applied know-how requires context-specific negotiation of meaning (Asheim, Boschma, & Cooke, 2011). Furthermore, in tightly coordinated fields, such as Physics, effective collaboration is enabled by agreement upon the research agenda and methods that reduces the necessity of negotiating goals and outcomes (Whitley, 2000). We then expect that Multi-institutional collaborations are more effective when addressing fundamental research, or issues in the field of Physics (*Hypothesis 3*).

Methods

Our empirical case of a LSRF is ORLN/NSD, one a prominent big science laboratory in the USA, which operates two world-class neutron scattering facilities. We take the journal articles produced at the facility as our units of analysis. 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 measure of scientific impact and dependent variable is the number of *Citations* received by each paper until 2011. Our first explanatory variable considers the *Institution Types* to which coauthors belong to, distinguishing among the following: Resident, Secondment, University, Research Centre, Business, Multiple (i.e. combinations of University, Research Centre, Business, but not Resident); we the consider the *Team Structure*, comparing teams in which Secondments are present to those in which all authors belong to the same Institution Type, and to multi-institutional teams. We further articulate this variable to capture the presence of NSD and Multiple affiliated. The cognitive dimension is captured by the *Discipline* (distinguishing between Physics and other fields) and *Orientation* towards basic or applied issues. We control for the *Size* of the team, the average *Citation level* of publications in a given combination of ISI Subject Categories and the *Year of publication*.

Main results

We first observe the institutional composition of teams: we find scientists affiliated with either Resident or Universities or Research Centers in almost two-thirds of the papers; presence of Secondments or Multiple affiliated is less frequent, appearing in about one-quarter of the papers. The majority of papers is multi-institutional, typically involving Residents (39%) and Secondments (25%), while 17% do not include NSD personnel; mono-institutional papers account for 19% of the total. The cognitive profile of research at NSD is characterized by prevalence of contributions specialized in Physics (53%) with a basic orientation (58%).

The descriptive statistics indicate that the mean and median citation level of papers in which Secondments are present is higher than that of paper with any other team structure. The Negative Binomial regression analyses confirm this finding. In particular, they reveal that Secondments outperform all other institution types, and that university affiliation moderately detracts from performance (Hypothesis 1). We also find that teams spanning multiple institutional types have the lowest performance: this is the case whether or not teams include resident scientists from ORLN/NSD or with Multiple affiliation. It should be emphasized that Multiple affiliated occupy a broker position, similarly to Secondments, but, differently from them, they do not have extensive direct experience of the instrumentation of a specific LSRF. This finding shows that knowledge integration at the level of individual scientists outperforms team level integration and stresses that importance of instrument experience at the facility (Hypothesis 2). Finally, we find that team diversity is associated with stronger performance in basic research than in applied research (Hypothesis 3).

We believe that these results offer novel implications for the design of LSRF research, emphasizing particularly the benefits of strong, durable linkages between LSRFs and academia.

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