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Author-team diversity and the impact of scientific publications: Evidence from physics research at a national science lab

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ABSTRACT

In the second half of the 20th century, scientific research in physics, chemistry, and engineering began to focus on the use of large government-funded laboratories. This shift toward so-called big science also brought about a concomitant change in scientific work itself, with a sustained trend toward the use of highly specialized scientific teams, elevating the role of team characteristics on scientific outputs. The actual impact of scientific knowledge is commonly measured by how often peer-reviewed publications are, in turn, cited by other researchers. Therefore, how characteristics such as author team seniority, affiliation diversity, and size affect the overall impact of team publications was examined. Citation information and author demographics were reviewed for 123 articles published in *Physical Review Letters* from 2004 to 2006 and written by 476 scientists who used the National High Magnetic Field Laboratory's facilities. Correlation analysis indicated that author teams that were more multi-institutional and had homogeneous seniority tended to have more senior scientists. In addition, the analysis suggests that more mixed seniority author teams were likely to be less institutionally dispersed. Quantile regression was used to examine the relationships between author-team characteristics and publication impact. The analysis indicated that both *weighted average seniority* and *average seniority* had a negative relationship with the number of citations the publication received. Furthermore, the analysis also showed a positive relationship between first-author seniority and the number of citations, and a negative relationship between the number of authors and the number of citations.

1. Introduction

The last 60 years of the 20th century saw a significant shift in the nature of scientific inquiry worldwide. In the United States, the Second World War and the subsequent Cold War generated a significant increase in the scale and scope of government support for both applied and basic scientific research, which was justified by reference to the provision of a larger social need, often in the form of enhanced national security, industrial or knowledge competitive advantages, or other social welfare (e.g., medical advancements). The increase in the scope and scale of scientific endeavors not only brought about an increase in resources, but also an institutionalization of the scientific enterprise, with a concentration of such resources into a relatively small number of large research institutes, centers, and laboratories, usually dedicated to very specific goals, and often centered on the use of specialized instruments or technologies (Beaver, 2001; Hevly, 1992; Katz & Martin, 1997; Price, 1963). As scientific endeavors became larger and more condensed within specialized research institutions, the workforce also became increasingly specialized, and the development of scientific knowledge became dependent on the work and collaborative processes of highly specialized research teams (Hevly, 1992; Katz & Martin, 1997). As more scientific investigations became dependent on the work of teams within large institutional or multi-institutional settings, the relationships between the social characteristics of collaborative teams and their subsequent impact within specific scientific fields became more important (Beaver, 2001; Katz & Martin, 1997; Lee & Bozeman, 2005; Price, 1963; Thorsteinsdóttir, 2000).

Physics research has in many ways become synonymous with the large-scale scientific enterprise, as the necessity for large, often publically funded technology facilities and highly specialized teams became common in the discipline's investigations. For example, an examination of publications in the field of high energy physics indicates that the number of multi-institutional and multi-national author teams steadily increased in the last 25 years of the last century (Lorigo & Pellacini, 2007). While high energy physics research may be on the extreme end of collaborative research teams in terms of the sheer number of participants, the size of many physics research teams across the subfields of the discipline has started to spark discussion and debate regarding how such teams should be organized and how the contributions of team members should be acknowledged (Tarnow, 2002). As scientific collaboration increased as a means of undertaking large-scale research endeavors, it resulted in an increase of multiple-authored publications (Katz & Martin, 1997; Wuchty, Jones, & Uzzi,

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2007). The increase in the incidence of multiple-authorship further highlights the need to examine specific author-team characteristics in relation to the impact of their scientific work outcomes.

2. Problem statement

It has become common to assess the research productivity of individuals, institutions, or nations based on the number of peer-reviewed publications they produce, and/or the number of citations received by those publications (e.g. Adkins & Budd, 2006; Cronin & Overfelt, 1994; Cunningham & Dillon, 1997; Lee, 2003). A valuable body of research (e.g., Shaw & Vaughan, 2008) examines the relationship between individual author characteristics (e.g., academic rank) or the status and type of an institution (e.g., research versus teaching) and productivity. Along those lines, several studies have associated increased collaboration with increased publication productivity on the part of researchers (Beaver, 2001; Katz & Martin, 1997; Lee & Bozeman, 2005). Further studies indicate that collaborations lead to multi-authored publications that are more heavily cited and influential than single-authored publications (Beaver, 2004; Fox, 1991; Katz & Martin, 1997; Lawani, 1986; Lindsey, 1978; Narin, Stevens, & Whitlow, 1991; Rousseau, 1992). Similarly, some researchers have also indicated that collaborative research efforts, which occur through multi-authored publications, have more epistemic authority within some research fields than do single-authored publications efforts (Beaver, 2004; Wray, 2002). While collaboration is thought to have generally positive effects, the incidence and impact of collaboration within research teams, and on the ultimate research outcomes may vary with the cultures of specific research contexts and disciplinary fields (Chompalov, Genuth, & Shrum, 2002; Katz & Martin, 1997; Smith, 1958).

The overall influence of collaboration has been examined concerning its effect on the number of research publications (e.g., articles or books) produced, as well as subsequent impact of the research, but less attention has been focused on the impact of specific author-team characteristics on research publications within specific fields (Beaver, 2004; Haslam et al., 2008). Examining the characteristics of author teams, and the teams' relationships to the properties of peer-reviewed articles commonly associated with their impact within a field of inquiry (e.g., number of citations received), can advance understanding of the structure of scientific publication success and impact. While author-team characteristics are important, evaluating the subsequent influence of these researchers' work is also a crucial component of understanding contemporary scientific inquiry. This research study explores the relationships between measures of author-team composition (author-team seniority, affiliation diversity, and size) and the impact (i.e., citation counts) of articles published in an international physics research journal.

3. Literature review

Membership on an author team has come to represent not only participation in the writing of an article, but also participation in the research effort and results that the article communicates. Therefore, authorship is a key step toward being potentially acknowledged for making a contribution within a field of research. This acknowledgment has typically taken the form of citing the publication in subsequent works, as a means of signifying contribution within the scientific field's broader literature (Birnholtz, 2006; Cronin, 2001). This acknowledgment mechanism, the authorship-to-publication-to-citation relationship, provides a basic means to examine the factors that may impact the scientific work of author teams and, ultimately, the work itself within the broader community network of the scientific field (Price, 1965; Small, 2004). Research that examines publication data, such as author-team characteristics, can provide a valuable means of examining research collaboration. Katz and Martin (1997) indicated that *bibliometric*, or publication-based, research methodologies have certain advantages in comparison to other research techniques for studying collaboration, such as the use of case studies. They noted that the examination of publication data in order to explore collaboration characteristics a) is verifiable, since other researchers should be able to reproduce the results; b) is a relatively inexpensive means of quantifying collaboration characteristics; c) usually involves datasets large enough to produce statistically significant results; and d) is usually not intrusive and nonreactive in regard to the actual processes of the collaborative teams (Katz & Martin, 1997).

While bibliometric studies are a valuable means for examining collaborations, changes in the norms of authorship may impact the extent to which findings from such research can be extrapolated to actual research collaborations. Researchers have identified so-called “gift authorship” or “honorary co-authors” as commonplace within some research communities (Bozeman & Corley, 2004; Hagstrom, 1965; Katz & Martin, 1997; Stokes & Hartley, 1989). Furthermore, in fields such as physics and biology, authorship norms have changed quite dramatically with the increased size of scientific endeavors; an article's authors may be so numerous as to alter more traditional connotations regarding authorship. In several fields, multiple authorship has increased to the point where being an author on a publication signifies some level of participation in the research project, but not necessarily an active role in crafting specific content within the paper or the specific research it communicates (Birnholtz, 2006; Cronin, 2001; Harsanyi, 1993; Katz & Hicks, 1997). Such changing authorship norms and practices require that researchers exercise some caution in extrapolating findings from studies of author teams to actual research collaboration itself (Katz & Martin, 1997).

Despite the need for caution when using publication data as a proxy for examining actual team collaboration, author-team characteristics of peer-reviewed publications do provide a valuable window for examining the underlying characteristics of collaborative research teams. Bibliometric studies have examined how a number of author characteristics may affect scientific outcomes and productivity. For example, individual characteristics such as age, academic rank, funding, gender, marital status, citizenship, job satisfaction, and collaboration strategy influence research productivity of individual research scientists, as measured by straight publication counts (Lee & Bozeman, 2005). Similarly, the effects of demographic and structural characteristics such as gender, ethnicity, seniority, institutional affiliations, and team size have been examined in regard to the productivity of team collaborations (Haslam et al., 2008; Joshi & Roh, 2009; Reagans, Zuckerman, & McEvily, 2004; Zenger & Lawrence, 1989). A full review of the literature of all author-team characteristics or the broader literature that directly examines team demographics is beyond the scope of this study. Therefore, the literature reviewed here is directly related to the primary research questions, and thus centers on the influence of an author team's seniority characteristics, affiliation diversity, and size on the eventual impact of publications within a scientific field.

3.1. Seniority within author teams

Seniority, thought to be correlated with research experience, available resources, and heightened levels of prestige, is often considered to be an important factor in the production of knowledge. The role of seniority within many academic disciplines is thought to translate into higher levels of research productivity and, ultimately, a greater level of impact of the research outcomes themselves. In information science, several authors have examined the role of rank and seniority on scholarly productivity. Bonzi (1992) examined the publication patterns of faculty at a research university and found that productivity early in a career is associated with later career productivity; full professors showed the highest publication productivity. Shaw and Vaughan (2008) found that the cumulative number of peer-reviewed research articles increased with academic rank, as did the number of overall citations of their work in other publications. Not surprisingly, full professors had published far more journal articles than conference papers, compared to assistant professors. Furthermore, examining productivity across the careers of scholars, early-career productivity often correlates with higher later-career productivity (Adkins & Budd, 2006). However, a more nuanced examination of the scholarly creativity and productivity of senior scholars within information science (Cronin & Meho, 2007) indicated that the relationship between creativity and ultimate citation counts may be more complex. High-impact publications happened early in the careers of some scholars, while later in the careers of others. Furthermore, so-called high-impact publications accounted for a high percentage of overall citations for several scholars, while the citations of other scholars were fairly evenly distributed across their publications.

The role of seniority within author teams is often thought to play an important role not only in terms of how individual researchers behave, but also how the teams to which they belong operate. Martín-Sempere, Garzón-García, and Rey-Rocha (2008) carried out an analysis of senior geology researchers in Spanish universities using a mail survey and bibliometric analysis to measure outputs. They found that senior researchers were more often associated with larger research teams with high levels of consolidation and integration, and that larger teams often led to higher levels of productivity. Such consolidated teams had a greater ability to make use of the kinds of research contacts and collaborations that lead to more publications. In addition to such team dynamics, the presence of renowned senior researchers on author teams is thought to impact the likelihood that a manuscript will be published, as the presence of more productive and established researchers on the author team may influence the editorial review process, as well as the number of citations that the publication is likely to receive (Haslam et al., 2008; Merton, 1968; Stewart, 1983). Baldi (1998) examined the likelihood of such an author rank-to-citation relationship by using a network-analytic model to examine articles in astrophysics and, interestingly, found no significant relationship between author rank – calculated as the percentage of full professors in the author team – and the likelihood of the article receiving a citation. Other studies examining the impact of seniority in other research disciplines and employing different measures of seniority itself found different results, however. For example, in studying 10 years of citations for 308 research articles in social-personality psychology published in 1996, Haslam et al. (2008) found that having a more renowned author as the first author correlated with having a higher number of citations. Articles in which the more renowned author's name appeared later in the author list received fewer citations. Furthermore, articles that had more than one renowned author received the most citations on average. These studies show that seniority may be measured in several ways (e.g., percentage of senior authors, order of senior author on publication, etc.) and that the impact of seniority may vary with the method of measurement, and across the research disciplines being examined.

3.2. Author-team affiliation diversity

Scientific collaborations are often multi-institutional efforts that require the scientific human capital, technologies, facilities, and financial resources of many educational, governmental, or industry organizations (Crane, 1972; Price, 1965). While the participation of multiple researchers and institutions is often necessary to undertake scientific inquiry in areas such as astronomy, physics, chemistry, and engineering, such collaborations often bring challenges to the work processes that influence knowledge outputs. Such large-scale scientific enterprises often involve the distribution of a variety of personnel across multiple institutions and a wide geographic area. Therefore, the success of such research endeavors may be influenced by multiple dimensions of proximity (e.g., cognitive, organizational, social, institutional, geographic) between the participants (Boschma, 2005). For example, in some research circumstances, researchers may actually be influenced to collaborate simply because of their geographic proximity (Bozeman & Corley, 2004; Cronin, 2008). Furthermore, a lack of institutional and geographic proximity may bring about difficulties in intra-team communication, coordination, and conflict management, hindering teamwork processes (Hinds & Bailey, 2003). Despite the advances in distributed work technologies, the lack of geographic proximity between researchers is often considered a primary impediment to high levels of team interaction and productivity (Olson & Olson, 2000; Teasely & Wolinsky, 2001). Similarly, Katz (1994) found that geographic proximity influenced international research collaborations between universities in the United Kingdom, Australia, and Canada.

The roles that different dimensions of proximity play in collaborative relationships can also be somewhat complex. Ponds, van Oort, and Frenken (2007) examined the role of geographic proximity and the role of organizational proximity (i.e., similarity in type of collaborating organizations) in research collaborations. Their study found that geographic proximity played a more important role in helping to overcome differences in types of organizations (i.e., academic versus nonacademic) than in situations where the organizations have high levels of institutional proximity. However, other research indicates that geographic proximity may serve as a means to foster coordination and interaction within research collaborations with multiple organizations, even if they are of the same institutional type. Cummings and Kiesler (2005) studied the principal investigators in 62 scientific collaborations. Their findings indicated that research teams with more multi-university affiliations experienced more problems with coordination and had fewer positive research outcomes than teams with fewer multi-university affiliations. In addition, their findings indicated that bringing researchers into closer geographic proximity may mitigate the negative effects of multi-university collaborations. That is, geographic proximity may soften conflicts caused by cultural or task incongruences that may be inherent in multi-institutional participation in research projects.

Such direct studies of research teams may provide some insight into what should occur when examining author teams with members from multiple institutions. Studies examining publication patterns of collaborative teams, however, indicate that the ultimate outcomes of multi-institutional collaborations may be more positive. Porac et al. (2004) examined the publication patterns of two multi-institutional scientific teams and found that while the collaborations resulted in increased publication for the members of both teams, the more interdisciplinary team actually had higher levels of productivity. Katz and Hicks (1997) examined approximately 500,000 U.K.-refereed research and development publications across multiple science and technology disciplines. They found that among author teams with only domestic members, publications with many authors at many institutions had the most impact, when measured by the number of citations received. Moreover, their research also indicated that publications with domestic and foreign collaborators received more citations than publications with only domestic collaborations or single authors.

Other studies have provided similar evidence regarding domestic versus multinational composition of author teams. For example, articles written by teams with more diversity among the nationality of the authors' home institutions often receive more citations when compared with articles with less diversity (Narin & Whitlow, 1990; Narin et al., 1991). Such findings indicate that while heightened levels of affiliation diversity among author teams may represent underlying difficulties associated with communication or coordination, such effects may be mitigated by additional intellectual and technical resources, heighted levels of prestige, and more diverse social networks that influence acceptance and citation of the publications themselves.

3.3. Size of author teams

Multi-authored articles have become the norm in many research fields, so what role does the size of the author team play in the impact of publications within a scientific field? In the work processes and publications of research teams, should the rule of thumb be "the more the merrier?" After all, the size of the research team may serve as an indicator of the potential intellectual, experiential, financial, and technological resources that were available to the team to complete scientific work processes communicated through publication. Some studies have linked larger research collaborations to increased numbers of publications (Katz & Martin, 1997; Price & Beaver, 1966). Such assessments have usually not truly addressed the productivity of the research team, however, since generally they have not considered the effect each additional collaborator has on the team's publication output. Conversely, when examining the number of individual collaborators in relation to the number of publications produced by the overall research team, few studies have found correlations. For example, Cohen (1991) found that if the number of collaborators was measured separately from the number of team publications, then publication productivity was directly proportional to the size of the research team. In other words, research teams of different sizes had the same average output per unit of size. Other researchers have presented similar findings. In a study of Swedish research teams, Stankiewicz (1979) found that the average publication output was directly proportional to team size. Seglen and Aksnes (2000) examined publications per capita within Norwegian microbiology research teams and found no correlation between publication productivity and team size.

While overall productivity of collaborative teams does not seem to correlate with publication productivity, some researchers have asserted that the size of research teams may be related to the actual impact that their publications have within a research field; research by larger teams tends to be more respected and influential (Crane, 1972; Goffman & Warren, 1980; Katz & Martin, 1997). Furthermore, evidence suggests the number of citations received by a publication goes up as the size of the author team increases (Baldi, 1998; Katz & Hicks, 1997; Lawani, 1986). Despite such evidence, other studies suggest different relationships between author and article characteristics and impact. For example, a study by Haslam et al. (2008), using multivariate analysis to examine the impact of author and article characteristics on the citation counts received by articles in three social and personality psychology journals over a 10-year period, found that the size of author teams was not a predictor of impact as measured by citation counts. Such results mirror prior research regarding the size of research teams in a number of science and industry contexts, which found that increasing the size of collaborative teams increases the overall resources available to the team to complete the task, but may also increase difficulty in coordination and the need for administrative and decision-making infrastructure to govern the collaboration (Beaver, 2004).

4. Research questions

Stvilia et al. (2011) examined how the diversity of research teams influences team productivity for physics research in a national laboratory, as measured by the number of peer-reviewed publications. That study indicated that team cohesion was positively related to productivity. In addition, high productivity in teams was associated with high levels of disciplinary diversity and low seniority diversity of team membership. Furthermore, higher proportions of senior team members negatively affected productivity while teams with members in more structural positions within the broader network of researchers performed better than other teams. Quantity, however, is only one facet of productivity. Another important aspect of a research team's performance is the impact of its products within its respective community of knowledge. Traditionally, this impact can be measured as the number of times that the publication is cited by other researchers (Cozzens, 1989; Merton, 1973). This study investigates the effects of author team characteristics on the impact, as measured by the number of citations, of a product of scientific inquiry: a peer-reviewed journal article. The following research questions are examined:

1. What is the relationship between author-team seniority and publication impact?
2. What is the relationship between author-team affiliation diversity and publication impact?
3. What is the relationship between the size of the author team and publication impact?

5. Research methodology

5.1. Research context: the National High Magnetic Field Laboratory

The National High Magnetic Field Laboratory (NHMFL) is home to the largest and most highly-powered magnets in the world. The lab, which is located in Tallahassee, Florida, draws its funding primarily from National Science Foundation grants; additional seed funding and support initially came from the state of Florida. The NHMFL is a collaborative venture between three institutions: Florida State University in Tallahassee; Los Alamos National Laboratory in Los Alamos, New Mexico; and the University of Florida in Gainesville. Scientific teams apply to use its facilities through a user program; a review panel – including the director of the respective magnet program, NHMFL administrative staff, and subject matter experts – evaluate the applications. Selected teams then schedule time to use one of the NHMFL's magnets in order to conduct their experimental studies. In-house NHMFL scientists, research staff, and support staff also coordinate with the teams in order to provide assistance as necessary. Scientific teams do not pay usage fees for work on the magnets themselves; they are, however, responsible for a variety of related costs, such as those for obtaining experimental samples, and traveling to the NHMFL facilities.

The only scientific laboratory of its kind in the United States, the NHMFL annually hosts more than 900 scientists, who use its magnets to run a wide variety of experiments. The lab is multidisciplinary, with scientists working on research from a variety of areas in physics, biology, bioengineering, chemistry, geochemistry, biochemistry, and materials science (National High Magnetic Field Laboratory, 2010a). In addition, scientific teams working at NHMFL facilities vary greatly in terms of their characteristics and composition, particularly in their institutional and disciplinary makeup, and in the seniority of team members. The NHMFL facilities are used to conduct numerous scientific studies each year that lead to a multitude of published findings in conference proceedings, books, posters, and journal articles. The variety of scientific teams at NHMFL makes it a unique environment in which to examine the impact of team characteristics on the production of scientific knowledge.

5.2. Data and analysis

Guided by the literature, including a study of relationships between team composition and productivity at the NHMFL (Stvilia et al., 2011), the effects of author team seniority, diversity, and size on publication impact are investigated.

The data used consisted of the citation information and author demographics of all the articles published in *Physical Review Letters* (PRL) from 2004 to 2006 by scientists who used the NHMFL's facilities in their experiments. The sample included 123 articles authored by 476 scientists and published in PRL. The sample was limited to articles in PRL, which has been described as "the world's foremost physics letters journal, providing rapid publication of short reports of significant fundamental research in all fields of physics" (American Physical Society, 2011), in order to control for any influence of journal prestige or impact on the number of citations. PRL was also chosen because of its high publication rate of NHMFL experiments and high impact factor. Specifically, from 2004 to 2006 NHMFL experiments resulted in 1,418 peer-reviewed publications in 217 distinct journals; of these, about nine percent (123) were published in PRL. This was the second-highest share of publications, following the 13% share of publications published in the *Physical Review B*. PRL's impact factor for 2009, however, is more than twice that of the *Physical Review B*, 7.33 versus 3.47. The impact factors compare similarly for the three years from 2004 to 2006: PRL's impact factors are 7.22, 7.59, and 7.07 for this period, while the impact factors for *Physical Review B* are 3.08, 3.19, and 3.12, respectively (Thompson Reuters, 2011).

The sample was obtained from the lab's publication web page in June 2010 (National High Magnetic Field Laboratory, 2010b). The NHMFL publication page provided only basic bibliographic records for the articles. The publication database of the American Physical Society was used to obtain counts of citations received by each article during the first three years from the article's publication time, as well as information about each author's institutional affiliation (American Physical Society, 2010). For example, if an article was published in 2004, the cutoff year for the article's citation count was 2007. The researchers also collected information about *first-author eminence*, measured by the number of articles published by the first author prior to the year when the article was published. First-author eminence was a local measure based on the number of articles published in American Physical Society journals. The society's publication database was used to find citation counts and other information because its publication outlets such as PRL were primary publication outlets for the NHML research community, which focuses on materials science research. Therefore, the database was seen as an appropriate means to establish both the impact of articles and the eminence of first authors within the research community. The number of citations was a global measure that included both citations from American Physical Society publications and citations supplied by other publishers through CrossRef (Publishers International Linking Association, 2011). Since both the American Physical Society and CrossRef databases have little or no authority control for author identities, the researchers had to use author institutional affiliation, co-author names, institutional and personal Web sites, and curriculum vitae in order to disambiguate authors, and determine final citation and prior publication counts.

In addition, the researchers obtained seniority and institutional affiliation information for each author in the sample from the lab's annual reports. The coding scheme for scientists' seniority levels were developed by lab administrators for their own reporting purposes (National High Magnetic Field Laboratory, 2010c). The rest of the data were collected and disambiguated by using multiple sources on the Web, including scientists' homepages and institutional Web sites. The researchers used the top-level domain name of an author's institution as a code for the scientist's institutional affiliation. For example, if an author was employed by the NHMFL, located at www.magnet.fsu.edu, then the author's institutional affiliation code was set to "fsu.edu." Whenever a scientist's seniority status changed during the time period covered by the articles' sample (i.e., 2004 to 2006), the researchers created multiple demographic profiles for the scientist and connected the article with an appropriate profile for the scientist.

To represent author team seniority, the study considered three group-level metrics: *average seniority*, *weighted average seniority*, and *seniority diversity* (see Table 1). Average seniority is an arithmetic average of seniority codes that gives an equal weight to each individual author in the team. However, the literature suggests that the effects of author characteristics on the number of citations may be diminished by the order of authorship (e.g., Baldi, 1998). The weighted average seniority metric degrades a seniority code contribution to the team seniority with the order of authorship using the harmonic series. That is, the first-author code is weighted by 1, the second-author code is weighted by 1/2, and so forth. The sum of the weighted seniority codes is then normalized by the harmonic number. Seniority diversity was measured as the normalized entropy of the seniority codes for the author-team members using the formula

$$H_{normalized} = \left(-\sum_{i=1}^{N} p_i (\ln p_i) \right) / N$$

where p_i is the probability of the i-th code in the team's set and N is the number of codes in the set.

Furthermore, previous studies found significant relationships between first-author characteristics and publication impact (e.g., Haslam et al., 2008). Hence, in addition to the group-level seniority variables, the relationships of first-author seniority and first-author eminence with the number of citations were also examined (see Table 1).

Affiliation diversity within author teams has also been found to influence the impact of publications (Narin & Whitlow, 1990; Narin et al., 1991). Therefore, the affiliation diversity within the author teams was measured as the normalized entropy of the member institutional affiliation codes. Affiliation diversity was measured using the same normalized entropy formula that was used to measure seniority diversity.

Shapiro–Wilk normality tests showed that none of the variables examined in this study were normally distributed ($p<0.05$). Hence, the study used nonparametric methods – Spearman correlation and quantile regression – to analyze the data. Quantile regression allows for the estimation of various portions (or quantiles) of the dependent-variable distribution; therefore, it can provide a more complete view of the relationships in the model. The median (i.e., 50th percentile) was used. Furthermore, this technique is appropriate when variables are not normally distributed with heterogeneous variances (Cade & Noon, 2003; Koenker & Hallock, 2001).

Spearman correlation analysis found the seniority metrics to be highly correlated (see Table 2). The degree of correlation between average seniority and weighted average seniority was above 0.90. Therefore, two regression models of publication impact were tested, one with average seniority, and another with weighted average seniority. The regression analysis models also included seniority diversity, first-author seniority, first-author eminence, affiliation diversity, and team size as independent variables, and the number of citations as a dependent variable (see Table 3).

Table 1
Metric definitions.

Variable	Definition
Average seniority	Arithmetic average of member seniority codes
Weighted average seniority	$\frac{1}{H(N)}\sum_{i=1}^{N}\frac{s_i}{i}$ where N is the number of authors, s_i is the code of the i-th author, and H(N) is the N-th harmonic number
Seniority diversity	Normalized entropy of member seniority codes: 1 — Undergraduate student 2 — Graduate student 3 — Other 4 — Postdoctoral researcher 5 — Technician, programmer 6 — Senior investigator (not a postdoctoral researcher or student)
First-author seniority	The seniority code of the first author
First-author eminence	The number of articles authored and co-authored in American Physical Society journals by the first author prior to the year when the article was published
Affiliation diversity	Normalized entropy of member affiliation codes
Size	Number of authors

6. Findings

The descriptive analysis of the sample found the number of publications authored or co-authored by individual scientists ranged from

Table 2
Correlation matrix.

	Average seniority	Weighted average seniority	Seniority diversity	First-author seniority	First-author eminence	Affiliation diversity	Size	No. citations
Average seniority	1.00							
Weighted average seniority	*0.90****	1.00						
Seniority diversity	*−0.60****	*−0.51****	1.00					
First-author seniority	*0.58****	*0.85****	*−0.32****	1.00				
First-author eminence	*0.36****	*0.56****	*−0.25**	*0.66****	1.00			
Affiliation diversity	*0.40****	*0.40****	*−0.25***	*0.29***	*0.24***	1.00		
Size	−0.02	−0.03	0.04	−0.02	0.09	0.11	1.00	
No. citations	−0.12	−0.10	0.11	0.00	−0.09	−0.18*	*−0.17*	1.00

* $p<0.05$.
** $p<0.005$.
*** $p<0.0005$.

one to 15, with the median equal to one, and 75% of the scientists having published only one paper. More than 58% of authors were senior investigators. Graduate students and postdoctoral researchers comprised the second and third largest groups, 26% and nine percent. The size of author teams ranged from one to 18, with six as the median, while the number of citations received by the articles ranged from two to 113, with the median being 12. Furthermore, the median of the number of authors and the median of first-author eminence were both six. The median number of citations was 12.

The analysis showed the median regression model with weighted average seniority to be a better fit to the data than the median regression model with average seniority. Both variables were negatively related to the number of citations. However, the regression model with weighted average seniority accounted for a slightly higher amount of variance in the number of citations than the regression model with average seniority. In addition, the coefficient and the level of relationship significance of weighted seniority were higher than those of average seniority. The regression analysis also showed a positive relationship between first-author seniority and the number of citations, and a negative relationship between the number of authors and the number of citations. The rest of the relationships were not statistically significant (see Table 3).

The Spearman correlation analysis found weighted-average seniority and first-author seniority to be negatively correlated with seniority diversity, and positively with affiliation diversity. That is, teams which were more multi-institutional and had homogeneous seniority tended to have more senior scientists. In addition, the analysis showed a negative correlation between affiliation diversity and seniority diversity, suggesting that more mixed seniority teams were likely to be less institutionally dispersed.

Table 3
Quantile regression results.

Variable	Model A Coef (SE)	Model B Coef (SE)
Average seniority	−3.72** (1.07)	N/A
Weighted average seniority	N/A	−6.23*** (1.37)
Seniority diversity	−1.60 (2.88)	−2.46 (2.83)
First-author seniority	1.12* (0.59)	3.15*** (0.82)
First-author eminence	−0.09 (0.06)	−0.08 (0.06)
Affiliation diversity	−3.90 (2.44)	−3.99 (2.42)
Size	−0.63** (0.21)	−0.61** (0.21)
Pseudo R^2	0.04	0.05

Model A = includes average seniority.
Model B = includes weighted average seniority.
* $p<0.05$.
** $p<0.005$.
*** $p<0.0005$.

7. Discussion

The first research question referred to the relationship between author-team seniority and publication impact. The analysis did not reveal any significant relationship between team-seniority diversity and the number of citations. There is a valuable body of literature on the relationship between team-seniority diversity and team productivity, but with little consensus. Studies have found that teams with higher seniority diversity are more productive (e.g., Guimera, Uzzi, Spiro, & Amaral, 2005). Other studies show a negative relationship between seniority diversity and team productivity (e.g., Ancona & Caldwell, 1992; Bunderson & Sutcliffe, 2002). Similarly, a significant negative relationship between team-seniority diversity and the quantity of peer-reviewed articles produced by the team was previously observed (Stvilia et al., 2011). This is the first study that has looked at the relationship between author-team seniority diversity and article impact, as measured by the number of citations. It would be interesting to further explore this relationship with a more representative sample, and in different academic disciplines.

The effects of team-average seniority on publication impact were also explored. The regression analysis showed that an increase in team seniority had a negative effect on the likelihood of the publication receiving citations. At the same time, the relationship between first-author seniority and the number of citations was positive. A significant relationship between first-author eminence (as measured by prior productivity) and the number of citations was not found. Thus, the presence of students and postdoctoral researchers among the authors, and the first author being a senior scientist may both increase the likelihood of a publication being cited. In addition, the use of a weighted-average seniority metric produced a slightly better fit to the data than average seniority. This indicates that the relationship is not linear, and the effect of individual-author seniority on the team's relationship with publication impact may diminish with the order of authorship. Several studies from the literature found that works of full professors were cited more often than the works of assistant and associate professors (e.g., Cronin & Overfelt, 1994; Shaw & Vaughan, 2008). However, those studies examined the author-publication impact relationship without co-author team context.

These results further qualify the findings from the literature, suggesting that a publication authored by a team of low-seniority scientists with a senior scientist as the first author may have a higher likelihood of receiving a citation than a team of all senior scientists. It is important to note that this seniority coding schema differentiated students and postdoctoral researchers into separate categories, while not differentiating among the traditional academic ranks used in the United States—that is, professors at all levels, including assistant professors, were coded as senior investigator (see Table 1). While this scheme is used by the lab for its annual reports and own reporting requirements, its use in this analysis may necessitate some caution when comparing these findings with those from other research efforts, which may use a different measure of seniority.

A possible explanation for the negative relationship between author-team seniority and publication impact can be found in a study of the citation trajectories of information scientists by Cronin and Meho (2007). They found that some scholars produced their most influential woks around the time they received their Ph.D.s. Their finding is also somewhat consistent with Simonton's (1994, 2004) model of creativity, according to which older scientists, after they have produced their high-impact works, are less creative or productive than younger scientists. Since Simonton's model is a function of career age, rather than chronological age; senior scientists produce fewer high-impact publications after their optimum career age is reached. Senior scientists' decline in creativity may be due to their increased administrative responsibilities and/or physical illnesses (Simonton, 1994). In addition, scientists in some disciplines, such as mathematics and physics, exhibit earlier career peaks than others (Simonton, 2004). Physicists' career peaks are most likely to appear in their late 30s. Future studies can examine the relationship between the average age of the author team and the number of citations.

Furthermore, Cronin and Overfelt (1994) found that the relationship between the number of citations normalized by the number of years in field and academic rank was not linear. The normalized citation count showed a downward trend when moving from the assistant professor to associate professor rank, and increased for full professors (Cronin & Overfelt, 1994). This is also similar to work done by Gingras, Lariviere, Macaluso, and Robitaille (2008), which found that productivity increases at a high pace between ages 28 and 40, increases at a slower pace between 41 and 50, and decreases slowly after age 50. In regard to impact, professors experienced a sharp decline in scientific impact from the beginning of their careers until about the age of 50, when impact increases until age 70. Older professors' increasing research impact after age 50 is probably related to their building a team and collaborating with younger professors. This work also suggests that the productivity and impact of researchers are not simply a function of age, but are also influenced by scientific collaboration (Gingras et al., 2008).

The community gathered around the NHMFL is unusual. Although its members can be grouped under a large interdisciplinary umbrella of materials science, they represent different countries, and both industry and academia, each of which has its own particular seniority-ranking model. Furthermore, a quick analysis of the career paths of scientists with academic careers in the sample showed that after receiving a doctorate, most of the scientists had to go through one or more postdoctoral appointments before securing an assistant professor position. This may not be the case in the disciplines and communities examined previously. Conducting a similar temporal analysis of the relationship between citation dynamics and career stages for the NHMFL community could provide an additional, community- and domain-specific insight into the relationship between author-team seniority and publication impact.

The second research question referred to the relationship between author-affiliation diversity and publication impact. The regression analysis did not show a significant relationship between these variables. This aligns with Stvilia et al. (2011), in which a significant relationship between team-affiliation diversity and team productivity as measured by the number of publications was not revealed. One would expect that higher diversity in institutional affiliation would give the team access to greater and more complementary resources. The literature suggests that more author-team diversity may ultimately lead to publications with more impact (Katz & Hicks, 1997; Narin & Whitlow, 1990; Narin et al., 1991). At the same time, the literature also suggests that multi-institutional teams can be less successful than teams with more homogeneous member affiliations, because of increased collaboration costs (Cronin, 2008; Cummings & Kiesler, 2005; Hoegl & Proserpio, 2004; Kraut, Egido, & Galegher, 1988). Future research will use surveys and interviews to further explore scientists' perceptions of the benefits and costs of multi-institutional collaboration.

The last research question referred to the relationship between the number of authors and publication impact. A significant negative relationship between these variables was found. This finding is quite intriguing. Although the literature mostly suggests a positive relationship between these two variables, there is no consensus about the significance and predictive power of this relationship on publication impact (Baldi, 1998; Haslam et al., 2008). As a part of future work, it would be interesting to explore how the number of authors is perceived by citing authors, and whether that number influences their decision to read and cite a paper.

Several limitations stem from the type of data used (i.e., documents). First, *impact* is a multidimensional and contextual concept. The number of citations used as an impact metric is only an inexpensive approximation of article impact, which cannot substitute for a judgment by a panel of subject experts. Second, some data used were taken from the lab's annual reports. In the case of this measure of seniority, the lack of differentiation of the senior researcher category into traditional categories of academic rank may limit the generalizability of the findings. Similarly, it may introduce the need for some caution in comparing the results reported here to those of other studies. Third, the relationship between team-interaction related variables (e.g., member conflicts; level of interaction among members) and publication impact were not examined. The documentary sources used to extract data did not contain that information. Fourth, the reasons, motivations, and norms for citing the papers and assigning authorship were not investigated. The literature shows that some papers can be cited for reasons other than the quality of content or their influence and contribution to the body of knowledge. Some papers are cited because of their flaws, while others are cited preferentially because of existing social relationships between the citing and cited parties (e.g., an advisor-advisee relationship), or the social status of the cited author, such as a journal editor or an eminent author (Baldi, 1998; Haslam & Koval, 2010; Sugimoto, 2010). Similarly, the reasons and norms for giving a publication credit and the order of authorship may vary from one research community to another (Heffner, 1979). Future research may use interviews and surveys to obtain information about co-author relationships and interactions, as well as relationships between cited and citing authors, developing a more nuanced model of publication impact.

Furthermore, the literature shows that a significant portion of publication impact can be predicted by examining its attributes, including the length, the number of references, and the presence or absence of surface features commonly identified with the document's genre (Baldi, 1998; Haslam et al., 2008; Stvilia, Mon, & Yi, 2009). Future work is expected to include an investigation of the relationships between the surface features of articles from the sample and article impact. Likewise, articles from a single physics journal authored by a single community of scientists were examined. While the focus on a single community of scientists does provide a level of control in regard to the potentially confounding effects of cultural norms associated with various scientific communities, it may also limit the overall ability to generalize from the findings.

8. Conclusion

The relationships between publication impact, as measured by the number of citations received, and author team characteristics such as the levels of seniority, institutional affiliation diversity, and the number of authors were investigated. Having a more senior scientist as the first author and lower average seniority levels within the author team increased the likelihood of the publication receiving citations. In addition, an increase in the number of authors had a negative effect on the number of citations. Finally, the relationships of institutional affiliation diversity and seniority diversity with the number of citations were not significant. With multi-authored publications becoming the dominant form of scientific communication (Wuchty et al., 2007), examining the relationships between the properties of peer-reviewed articles and the characteristics of author teams can advance understanding of the structure of scientific publication success and impact. Indirectly, team science is also informed, including the studies of collaboration and collaborative authorship (Baldi, 1998; Cronin, 2004).

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