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Article

Too big to innovate? Exploring organizational size and innovation processes in scientific research

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Abstract

We explore the impact of organizational size in six federally funded research organizations on a range of organizational processes related to the pursuit of innovation. The data utilized consisted of 266 scientists drawn from 64 research projects across five programmatic research areas: alternative energies, biology, chemistry, geophysical sciences, and material sciences. A sixth project category was added to accommodate the highly interdisciplinary character of a handful of projects. Although the data had some limitations, it was found that organizational size had a negative impact on three categories of innovation processes: the amount of time spent in research and professional activities, how research time is spent, and exchanges of technical knowledge. In addition, some potential advantages of larger size, such as: greater research resources, better perceived managerial quality or a visionary strategy, were not found to be significant.

Key words: organizational theory; public research organizations; research and innovation.

1. Introduction

In *Limited By Design*, Crow and Bozeman (1998) posed an important, yet still unanswered, question: how best to design a public research sector for innovation. One important design issue is the most appropriate size of research organizations. Is it better to group a large number of disparate research programs together in a relatively large research organization or is it better to have many smaller specialized research organizations? This is a particularly critical question for public research organizations, like the many federally funded R&D centers (FFRDC) and similar research organizations, arguably some of the most critical components of a national innovation system (Nelson 1993).

In this paper, we ask a very specific question: does organizational size have an impact on a research organization's environment for innovation? While a number of previous studies have examined group, team or project size (Adams et al. 2005; Cohen 1981; Heinze et al. 2009; Seglen and Aksnes 2000), it is important to recognize that modern science is an organizational phenomenon and its pursuit, whether in groups, teams or projects, is strongly determined by the organizational setting (Mote et al. 2011). Further, in contrast to previous studies discussed below which have tended to focus on the impact of size on scientific productivity in academic environments, this paper will look at the impact of size on innovation processes and behaviors in a greatly understudied segment of the R&D infrastructure: public research organizations.[1] Specifically, we will explore this question using data gathered from five FFRDCs and one agency laboratory as part of a study funded by the National Science Foundation through the Science of Science Policy program. Our primary concern in the original study was to identify determinants of scientific innovation, but we began to see patterns across the projects depending on the size of the research organization in which they were embedded. Hence, we undertook this current analysis to better understand these results.

The remainder of this paper is organized as follows: in Section 2 we discuss previous research on organizational size and innovation. In Section 3 we discuss the data used in this analysis, highlighting the difficulty of gathering the data. We present the analysis and key findings in Section 4. In Section 5, we briefly discuss our findings and their implications for science policy.

2. Organizational size and innovation

The issue of organizational size has a long history in organizational studies (Caplow 1957; Kimberly 1976). Studies over the years have explored the impact of organization size on such topics as: innovation (Damanpour 1992), organizational complexity (Hall et al. 1967), job satisfaction (Beer 1964), compensation (Lambert et al. 1991), ethical behavior (Murphy et al. 1992), and managerial style (Vaccaro et al. 2012), to name only a few.

With regard to organizational size and innovation, most studies have tended to focus on the concept of organizational innovation defined as:

> . . . the adoption of an idea or behavior that is new to the organization. (Hage 1999: 599)

Often conflated with the adoption of innovations, but more important for our discussion, is the generation of innovations aimed for use by others outside of the organization, particularly for commercial ends (Cohen and Levinthal 1990). While there is a considerable literature on this topic, much of the research has been conducted on market-based organizations (Lee and Xia 2006) and is marked by varying operationalizations of organizational size and innovation (Camisón-Zornoza et al. 2004). The latter has resulted in a wide inconsistency of empirical results. For example, Damanpour (1992) conducted a meta-analysis of organizational studies and found that larger organizations create more innovation, but this effect is stronger for manufacturing organizations and weaker for service and non-profit organizations. However, Camison-Zornoza et al. (2004) updated and replicated Damanpour's analysis which suggested a positive correlation between organizational size and innovation. Nonetheless, the measures of innovation in the meta-analysis—adoption or creation of new products/services or commercialized technologies—are not completely applicable to research organizations like the FFRDC since they are not typically focused on bringing innovations to market.

Todate, very little research has been done on the impact of organizational size on innovation in public research organizations. An early study by Cohen (1981) looked at publications rates across three organizations, including the National Institute for Medical Research (UK), and the National Cancer Institute (USA). Using the number of scientists as a proxy for organization, the study found, not surprisingly, a direct relation between organizational size and the number of publications. More recently, Bonaccorsi and Daraio (2005) utilized data from the National Research Council (Italy) and INSERM (France) and examined the impact of size (budget and personnel) on productivity (publications). Researchers found no positive relationship between size and productivity, but rather found a significant and negative relationship in several scientific disciplines. In addition, they observed that the most productive institutes tended to be smaller in size.[2]

In contrast, the majority of studies that exist have been conducted in academic contexts. For example, Carayol and Matt (2004) looked at a range of organizational factors, including size, and the impact on scientific productivity at Louis Pasteur University (France). In this study, size was defined as the number of permanent researchers and productivity was defined as publications and patents. The researchers found that size had a significant and negative relationship with productivity. Brandt and Schubert (2013) conducted a survey of the heads of European university-based research units and looked at both group size and organization size. In both cases, they found a curvilinear relationship with size: productivity increased with size up to a certain point, but then experienced diminishing returns to scale. Finally, Horta and Lacy (2011) used survey data of academics at public and private universities in Portugal and found that research unit size was negatively related to productivity, as measured by publications. Interestingly, they also found that size was positively related to information exchange behaviors with international peers.

While academic research organizations are important actors in conducting basic and applied research (Feller 1999), in many cases the organizational context for public research organizations is dramatically different than academic research organizations (Crow and Bozeman 1998). For example, it has been argued that there are distinct differences in funding and organizational leadership (Heinze et al. 2009) and teaching requirements (Olsen and Simmons 1996). Despite the findings on large size in academic research organizations, one can postulate a number of advantages of larger organizational size in public research organizations, particularly those related to economies of scale (Bonaccorsi and Daraio 2005). Certainly larger size is necessary for expensive one-of-a-kind equipment, such as the Z-pulsed Power Facility, the National Synchrotron Light Source and the Relativistic Heavy Ion Collider. And certain missions, such as the exploration of space and weather and climate forecasting, necessitate large numbers of scientists and applied researchers as well as a considerable array of equipment and technologies. Another traditional argument, borrowed from research on organizations, is that larger organizations can be more productive by sharing administrative costs across different units. Perhaps the most interesting argument for larger size involves multiple research areas and the potential for cross-fertilization of ideas for learning and radical innovation (Hage 2011).

But, from this latter advantage stems a potential disadvantage: as the diversity of research programs grows, communication becomes more difficult (Blau 1970). One example is the issue of organizational silos or stovepipes in research organizations (Lyall et al. 2013). Indeed, the thesis of 'open innovation', although focused on business organizations, revolves around communication problems in large firms (Chesbrough 2006). Further, growth in research organizations, such as the addition of new research projects or programs, can also lead to the creation of multiple layers of management, or what is called administrative intensity, which can negatively impact on the quality of the management (Donaldson 2001) and the work environment for scientists (Miller 1967).

Given the paucity of research, however, it is difficult to make a clear determination whether or not organizational size has an impact on the environment for innovation in public research organizations. While the research on academic research organizations is suggestive, it draws on organizations that operate in a very different context.

3. Discussion of the data

The public research organizations we studied were of varying sizes and consisted of five national laboratories administered by the US Department of Energy (DOE) and the Earth System Research Laboratory of the National Oceanographic and Atmospheric Administration. From these research organizations, a purposive sample of 266 scientists was drawn from 64 research projects of varying sizes across five programmatic research areas: alternative energies, biology, chemistry, geophysical sciences, and material sciences. A sixth project category was added to accommodate the highly interdisciplinary character of a handful of projects. Data for the study were collected using a survey instrument developed with previous support from the DOE. This survey, which has been

Table 1. Organizational size and innovation constructs. First column is Pearson correlations with log number of employees. Columns 3–6 test dependence of innovation constructs on organizational size and programmatic area

	Organization size		Two-way ANOVA			
Innovation construct	P	P	F-test log size	P	F-test programmatic area	P
Research/professional time	−0.34	<0.001	35.6	<0.001	1.7	n.s.
Research processes	−0.41	<0.001	52.2	<0.001	0.7	n.s.
Knowledge exchanges	−0.17	0.005	8.5	0.004	4.5	0.001

Table 2. Pearson correlation of organizational size, measured as log number of employees, and allocation of time to work activities

How time spent	Zero-order correlation	Statistical significance
Doing research	−0.341	<0.001
Routine tasks	−0.011	n.s.
Professional activities	−0.182	0.003
Seeking funding	0.322	<0.001
Administrative duties	0.287	<0.001
Organizational duties	0.336	<0.001
Index: funds, administration, organization	0.418	<0.001

field-tested across a wide range of research organizations (Jordan 2005), assesses attributes of the research environment.

The goal for developing the purposive sample was to obtain variation across a number of dimensions, such as size, discipline and goal. The six laboratories were selected to represent a range of size, with size defined as the number of employees: three small labs with fewer than 2,000 employees, two medium labs with 2,000–3,000 employees, and one large lab with over 4,000 employees. Projects within the laboratories were nominated by upper-level managers in their respective research areas to include both large and small projects and projects striving for both incremental and radical innovation. Because each of these national laboratories has had a unique point of origin and a distinctive strategy for growth, the nature of the projects within the same programmatic area differs as well. For example, with biology, one national laboratory focuses on the biology of plants, another on neural networks and a third on biosystems.

It is interesting to note that data collection at the larger laboratories was much more time-consuming and difficult, although gaining permission and access to the laboratories in the first place was already difficult (and perhaps an important reason why very little research has been conducted on public research organizations). Obtaining permission and access was an iterative process, involving the DOE, the Office of Management and Budget and human subjects review boards at the respective laboratories, which consumed almost two years. In addition, and as expected, there was also reluctance to participate in some of the laboratories.

Of our original goal of obtaining responses from 75 projects, we were only able to obtain responses from 64 projects. However, the 266 scientists who completed the survey reported not only about the specific project for which they were selected, but all the projects in which they were engaged. The average scientist in our sample is involved in over five projects and therefore, their responses also give insights into a large swathe of projects despite the loss of 11 of those selected. All of the scientists working on the selected projects were invited to participate in the study, and we experienced at least a 50% response rate for each project (see section on Supplementary data for additional information).

Our choice of dependent variables also necessitates some discussion. Our original goal was to measure innovation within the project not as a function of productivity, traditionally defined as publications and patents, but as the amount of innovation achieved within the aims of the project (Mote et al. 2007). However, the difficulties described above forced us to rethink our dependent variable. Similarly to Horta and Lacy (2011), we looked at the impact of size on individual behaviors and organizational processes. Specifically, our solution drew on a number of survey items to develop three constructs that we argue capture innovation processes at the individual and organizational level, that is, the time and routines involved in the development of innovations: first, the amount of time spent on research and professional activity; second, the organizational environment for five specific innovation processes; and third, the organizational environment for four kinds of knowledge exchanges and learning. In this manner, we hoped to measure the organizational context for pursuing research innovation, which has been identified as important for creativity and innovation (Amabile 1987; Amabile et al. 1996; Heinze et al. 2009). A fuller discussion of these constructs is provided in the section on Supplementary data.

4. Exploring organizational size in the six labs

The relationship between the size of the research organization and each of the constructs is reported in Table 1. The first construct capturing the use of time was measured with a list of six activities: research (literature review, research planning and review, theorizing, experimenting and writing papers), routine tasks (checking equipment, and keeping logs on the data collected), professional activities (reviewing papers, attending conferences, presenting research), seeking funds and interacting with sponsors, administration (paperwork, personnel issues and communication not related to research) and organizational activities (national security issues, safety issues). In Table 2, Pearson correlations provide further support that the larger the organization in which the project was embedded, less time was spent on research and professional activities and more time was allocated to seeking funds, administration and organizational activities. While these time allocations did vary by programmatic research area, they were not found to be significant in a two-way ANOVA by programmatic area.

The second construct for measuring innovation processes examined the organizational parameters for the conduct of research, independent of how much time is allocated to actual research. For this

Table 3. Organizational size and project context

Project context	Organization size ρ	P	Two-way ANOVA F-test log size	P	F-test programmatic area	P
Research resources	−0.06	n.s.	1.1	n.s.	1.5	n.s.
Management quality	−0.35	<0.001	36.0	<0.001	1.4	n.s.
Organizational strategy	−0.33	<0.001	31.8	<0.001	0.2	n.s.

First column is Pearson correlations with log number of employees. Columns 3–6 test dependence of innovation constructs on organizational size and programmatic area.

construct, the survey gathered responses on five important processes that have been found to be positively associated with the pursuit of innovation: authority to make research decisions, excitement in doing research, time to think creatively, freedom to explore new ideas, and the ability to take large risks. These five processes were identified in an earlier DOE-funded study (Jordan 2005) and have strong support in the sociological and management literatures (Argote and Miron-Spektor 2011). The data reported in Table 1 provides support for the assertion that the environment of larger research organizations might hinder innovation. The larger the size of the laboratory, the less excitement, time to think creatively and ability to take risks ($r = -0.41$, $p < 0.001$). The finding that larger organization size seems to discourage creativity and risk taking is supported by the absence of significant differences by programmatic area in a two-way ANOVA.

Finally, the third construct addresses the amount of exchanges of technical information that occur among researchers. When scientists engage in these exchanges, the type of learning occurs that is a precursor to innovation, that is, collaborative understanding and the sharing of tacit information. Scientific exchanges of technical information were measured in four ways: researchers offering critical thinking to others, technical exchange within the same programmatic research area, technical exchange across different programmatic research areas, and technical exchange within the larger organization. This speaks to the innovation dilemma identified earlier. On the one hand, the presence of multiple programmatic areas should encourage positive technical exchanges since diversity is associated with innovation; but on the other hand, larger size and higher levels of administrative intensity might discourage technical exchanges. The latter appears to be the case. Larger size is negatively associated with this third innovation construct ($r = -0.17$, $p < 0.005$), although the association is weaker than with the two previous constructs of innovation. One explanation for this weaker relationship is found in the two-way ANOVA, where there are significant variations by programmatic area. Size retains its level of statistical significance, although it appears to be less critical than programmatic area.

Although the impact of organizational size on three constructs measuring innovation processes was negative, it still might be the case that larger research organizations offer other advantages, as discussed above. For example, we might expect projects within larger research organizations to have more research resources, be able to attract or retain higher quality management, or put forth a more visionary, cross-disciplinary strategy (Dodgson et al. 2002; Etzkowitz and Leydesdorff 2000; Nelson 1971).

Table 4. Pearson correlation of organization size and an index of research resources

Research resources	Zero-order correlation	Statistical significance
Funds to explore new ideas	−0.160	0.009
Stability of funding	−0.201	0.001
Equipment for research	−0.008	n.s.
Lab environment	0.017	n.s
Quality of technical staff	0.083	n.s.
Staff mix	0.003	n.s.

In Table 3, we report the results of our exploration of the impact of organizational size on these areas of project context. Research resources for projects were measured with six items: two measures of financial resources (funds to explore new ideas and stability of funding), two measures of human capital (quality of technical staff, and staff mix), and finally two measures of physical resources (equipment and physical environment). There is a no linear relationship between size and an index of these six items. Apparently larger organizational size has no advantage in attracting research resources to projects. Table 4 provides Pearson correlations with the individual items and although there is no linear relationship between size and research resources, there is with financial resources. Size has a zero-order correlation of −0.16 ($p = 0.0009$) and −0.20 ($p = 0.0001$) with resources for exploring new ideas and the stability of funding, respectively. The stability of funding is a critical resource for taking risks because some research suggests that the instability of funding influences scientists to propose more incremental advances (Judge et al. 1997).

We measured the quality of middle management (defined as above immediate supervisor and below executive management) as an index of five attributes: integrity, adding technical value, total value added, appropriateness of performance indicators, and planning. On these measures, scientists in larger research organizations perceive their managers being of lower quality ($r = -0.35$, $p < 0.001$) as reported in Table 3. One potential explanation for the negative impact is that in a larger organization, those managers deal with greater levels of administrative intensity, which might impact the perception of their quality as a manager. Although we met with many outstanding managers during our study, another explanation could be that managers are often recruited from the scientific ranks based on research success, rather than managerial ability (Sapienza 2005). Again, in a two-way ANOVA, organization size retains its negative impact and programmatic area does not have a significant association.

Finally, we explore the notion of a research organization's vision and strategy as these relate to respondents' projects using an index of eight items: vision; strategy for implementing the vision; identification of new areas for research; investment in new areas for research; investment in basic research; depth of competencies; mixed portfolio of basic, applied and developmental research; and allocation of funds across programmatic areas. As reported in Table 4, organization size is negatively related to researchers' positive perception of organizational vision and strategy as measured by these eight items ($r = -0.33$, $p < 0.001$). The two-way ANOVA analysis indicates that again, the programmatic area does not have a significant association.

5. Conclusions

To summarize and conclude, this analysis was motivated by a straightforward question: does the organizational size of a public research organization have an impact on the environment for innovation? Specifically, we found that larger size had a negative impact on our three measures of innovation processes: the amount of time spent on research and in professional activities, the five research processes associated with innovation, and the amount of exchanges of technical information. In addition, it is important to note that larger size also decreased the perception of the quality of middle management and organizational vision and strategy.

These findings raise a number of issues about the management of large research organizations and the stimulation of innovation. First, a consistent finding in the organizational size literature, regardless of the type of organization, is that as organizational size increases, so also does organizational complexity and formalization (Josefy et al. 2015). It is understandable that increases in layers of management, divisional and departmental structures, as well as rules and reporting requirements, might lead to reductions in time for research and technical exchanges as researchers increasingly spend more time addressing organizational complexity. Second, increases in organizational complexity have traditionally been addressed with greater amounts of coordination and control. While this approach is useful for maintaining efficiency, it can harm those processes that are conducive for innovation, such as collaboration, autonomy, and risk taking. Efforts like that of the National Nanotechnology Initiative to establish multidisciplinary centers are a step in the right direction, but they must be supported by managerial and organizational policies that facilitate increased collaboration across layers of organizational complexity (Galbraith 2010). Finally, just as larger teams necessitate different leadership styles and behaviors (Jordan et al. 2011), the findings suggest that there might be a leadership mismatch in the larger organizations. Interestingly, Vaccaro et al (2012) suggest that differences in leadership style in large and small organizations might play a key role in managerial innovation, that is, the adoption of new processes, practices and structures. In their study, they found a transactional leadership style more conducive in small organizations and a transformational leadership style more appropriate for large organizations, in part, to compensate for increased complexity.

We recognize that there are some limitations to our data. First, the data for this analysis comes from a purposive sample of projects drawn from selected research areas. While research areas were selected to provide comparison across research organizations, we acknowledge that this is a non-representative sample of the organizations and our conclusions are limited in their generalizability. Further, while the survey utilized is comprehensive, it gathers the perceptions of researchers about the research environment in which their projects reside and may be subject to respondent bias. Also, although we were unable to incorporate a dependent variable for scientific innovation, we have a number of measures that capture the organizational environment for the pursuit of innovation. Finally, the study only focuses on size defined as the number of employees, which does not address other important factors of organizational complexity, such as structural complexity (Damanpour 1996) and the characteristics of research portfolios and objectives (Jordan et al. 2008).

Despite these limitations, the results of our analysis suggest that larger size has a number of detrimental effects on innovation processes, as well as not offering the expected benefits of additional research resources for projects. However, it would be wrong to immediately conclude from these findings that bigger is badder. While there has been a considerable literature on organizational size and innovation, the overwhelming majority of studies have focused on market-based organizations and the accumulated findings have been indeterminate. This paper highlights a distinct gap in the literature on organizational size and innovation, and organizational studies in general (Cummings and Kiesler 2014), on public sector research organization. It is clear that broader studies with more representative samples are needed for a more complete analysis.

As Hallonsten and Heinze (2012) discuss, the US national laboratory system and, by extension the public research sector, is a path-dependent system that has experienced relatively little institutional change over the decades. Given the results of our analysis, although limited, we suggest, as have others (Crow and Bozeman 1998; Teitelbaum 2008), that there is a critical need for more research, particularly of public research organizations, to inform a discussion and rethinking of the structure of the public research sector and the design, and management, of research organizations.

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Notes

1. We adopt the OECD's definition of a public research organization (as distinct from an academic research organization) as a:

   > . . . heterogeneous group of research performing centres and institutes with varying degrees of publicness. (OECD 2011)

2. To the authors' knowledge, these are the only two published studies on organizational size and innovation in public research organizations.

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