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The bureaucratization of science

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ABSTRACT

While science is traditionally treated as a distinct domain of work organization, increasingly science is organized around larger and larger work groups that resemble small firms, with knowledge as the product. The growth of organized science raises the question of whether we also see a bureaucratic structuring of scientific work groups as predicted by organization theory, with implications for the academic credit system and scientific labor markets. Building on organization theory, we examine the relation between project group size, technical environment, and bureaucratic structuring of scientific work. Using survey data on scientific projects, we find size predicts bureaucratic structuring, with declining marginal effects. We also find that interdisciplinarity and task interdependence have distinct effects on bureaucratic structuring. Finally, the relationship between size and some dimensions of bureaucratic structuring is contingent on levels of work group interdependence in the field. We conclude with a discussion of the implications for policy debates about authorship and scientific careers.

1. Introduction

"Secretaries post off papers from the laboratory at an average rate of one every ten days. However, far from being reports of what has been produced in the factory, members take these papers to be the product of their unusual factory." (Latour and Woolgar, 1979:47).

Science is increasingly becoming a team activity (Wuchty et al., 2007). While this trend began decades ago (Price, 1963; Swatez, 1966), the sizes of contemporary research teams in many fields are beginning to approach that of medium-sized firms (Biagioli, 2003; Birnholtz, 2006; Milojević, 2014; Pavlidis et al., 2014; Salonius, 2008). Rather than a focus on an individual's lab bench, scientific work increasingly takes place in a setting that more closely resembles a small "factory" or "quasi-firm", run by a "small businessperson" lab director (Etzkowitz, 1983; Hackett, 1990; Latour and Woolgar, 1979; Shrum et al., 2007). This growth in the size of scientific work teams raises the question of the impact of size on the organization of scientific work (Carayol and Matt, 2004; Chompalov et al., 2001; Swatez, 1966). We extend prior work on the organization of science by examining the internal organization of scientific projects, in particular how the structuring of research projects varies by size and environmental context, building on the classic sociology of organization structures (Blau, 1970; Child, 1973; Meyer, 1972; Pugh et al., 1968).

We argue larger research teams are associated with more bureaucratic structuring of the team: greater division of labor, standardization, hierarchy and decentralization. Furthermore, project scope and team interdependence also affect bureaucratic structuring. Finally, the size–structure relation is contingent on the level of interdependence in the research team.

In addition to developing the sociology and economics of science, this work also tests the utility of organization theory for explaining the structures of self-organizing groups of professionals, and by examining the effects of size at modest group sizes (with the bulk of the projects having on the order of 5–10 people), to see how sensitive these size–structure relationships are across even a modest size range.

Two key insights drive this discussion. First, a scientific project is not a point mass, but consists of a group of members organized along a variety of dimension (Barley and Bechky, 1994; Carayol and Matt, 2004; Chompalov et al., 2001). And, this internal structure may be critical to performance (Andrews, 1976; Carayol and Matt, 2004; Cummings et al., 2013; Fox and Mohapatra, 2007; Hollingsworth, 2009). Secondly, science is not science. Fields differ significantly in their structure and dependencies (Collins, 1975; Fuchs, 1992; Hargens, 1975; Whitley, 1984). Therefore, we examine the internal structure of scientific projects, and the environmental contexts in which these structures operate.

In the following sections, we discuss the changing nature of scientific work, use organization theory to generate hypotheses about

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the structural implications of these changes, test these hypotheses using recently collected data from a broad sample of research projects across scientific fields, and then conclude with a discussion of the implications of these findings for the sociology and economics of science: in particular, training, careers, and the reward structure in science.

2. The growth of organized science

While science being conducting in organizations (such as universities, government labs, and industry labs) is not a new phenomenon (Blau, 1994; Pelz and Andrews, 1976), we are observing a fundamental change in the organization of individual research projects. While traditionally science is seen as an individual endeavor (Hagstrom, 1964; Shrum et al., 2007), increasingly scientific projects are group activities, and the groups are growing larger (Adams et al., 2005; Wuchty et al., 2007). While high-energy experimental physics is the extreme example, it is not rare to find research labs with dozens of members and research papers with 10 or more authors. For example, Wuchty et al. (2007) show the rise in the number of authors per paper over the last 40 years, with mean group size in science and engineering nearly doubling over this period. Similarly, Adams et al. (2005) find an increase in co-authored papers, in the number of authors per paper, in papers spanning institutions, and in international collaborations.

3. Size, interdisciplinarity, technology, and the bureaucratization of scientific work

This work on the relation between size and structure begins with Weber's classic analysis of the characteristics of bureaucratic organization (in contrast to paternalistic or collegial organization), which emphasizes the importance of division of labor, formalization and standardization, hierarchy and decentralization, as well as specialized competence and internal careers, among other aspects of the ideal-type bureaucracy (Weber, 1978). Weber (1978) notes that bureaucratization is associated with increasing size and scope of the organization.

3.1. Bureaucracy as a multidimensional concept

Bureaucracy is a multidimensional construct. While each of these dimensions is correlated, they are formally distinct, and a particular organization can be high on one dimension while low on another (Hall, 1962; Pugh et al., 1968). These dimensions include (with the labels varying across studies): Division of Labor/Specialization/Complexity; Standardization/Formalization; Hierarchy/Vertical span; Supervisory intensity/Span of control/Configuration; and Decentralization (Hage and Aiken, 1967; Hall, 1963; Pugh et al., 1968). By division of labor, this literature on bureaucratization means the extent to which the tasks in the organization are divided into stable bundles. By standardization, they mean the extent to which the process for executing those tasks is specified. Hierarchy means the extent to which there are multiple levels of appeal and supervision (i.e., formally ranked lines of reporting). And, finally, centralization/decentralization means the extent to which those lower in the hierarchy can make independent decisions (discretion), even if those decisions may have to be formally approved by those higher in the organization and the extent to which they participate in the decision-making overall (participation). Thus, "bureaucratization" is the extent to which a particular structure is high on each of these dimensions.

3.2. Size

This program of systematizing empirical studies of organization structures produced a series of studies that found size a key driver of structure (Blau, 1970; Child, 1973; Meyer, 1972). These studies have important implications for the work of science as research group size increases. As scientific activity increasingly becomes organized into multi-member projects, the sociology and economics of science also need to take into account the more organized nature of scientific work.

Prior studies of research units (labs, departments, universities) mostly focus on the relationship between size of research units and their performance. For example, there is some evidence that research productivity increases with unit size (Cummings et al., 2013; Johnston, 1994; Stankiewicz, 1979; Wallmark et al., 1973) while evidence by Cohen (1980, 1981) and Seglen and Aksnes (2000) shows that productivity (i.e., publication rate per capita) is independent of unit size. Similarly, Blau (1994) finds a large positive correlation between size of the academic institution and publication productivity per faculty, but that effect becomes not significant after controlling for research focus, reputation, and other university characteristics. Qurashi (1984, 1993) compares the relative publication rate per person across successive size ranges and finds a non-monotonic relation. There is also contrary evidence showing a negative relationship between size and productivity (Bonaccorsi and Daraio, 2005; Carayol and Matt, 2004; Mairesse and Turner, 2005). Horta and Lacy (2011) find a positive relationship between research unit size and international publications, but a negative relationship between size and national publications, and no relation between size and overall productivity.

While the main focus of this prior research is the direct relation between size and productivity, these studies point to the need to examine the team-level structures that are associated with increased size and that might predict outcomes, such as productivity or creativity (Carayol and Matt, 2004). This prior work argues that as size increases, a research group might face coordination difficulties, and hence, we should find the research groups having more decentralization of decision making and greater division of labor, becoming more bureaucratically structured (Bonaccorsi and Daraio, 2005; Cohen, 1980; Johnston, 1994; Kretschmer, 1985; Wallmark et al., 1973). Although this change in scientific teams may generate analogies between manufacturing and science as production of knowledge, knowledge, not products, is still the main goal of science (Bonaccorsi and Daraio, 2005; Wallmark et al., 1973), and so it is an open question whether scientific work groups will also become more bureaucratically structured as size increases.

Our goal is to examine the extent to which scientific work becomes increasingly bureaucratically structured as size increases. Here we are concerned with the bureaucratization of the scientific research tasks themselves. There may be additional bureaucratic procedures related to interacting with university administration (Blau, 1994) or funding agency reporting requirements, for example, that are outside the scope of our analysis (e.g., procedures related to hiring decisions, institutional review boards [IRBs], export control compliance documentation, procurement procedures, progress reporting requirements, etc.).[1] In other words, we are focusing on the "production" aspects of science (Dewar and Hage, 1978).

As size increases, there are potential productivity gains from division of labor (Becker and Murphy, 1992; Blau, 1970; Smith,

[1] For example, Blau (1994) notes that faculty productivity (publications per capita) is positively associated with decentralization of faculty appointment decision-making (with department faculty influence having a positive effect and dean influence having a negative effect).