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Minerva unbound: Knowledge stocks, knowledge flows and new knowledge production☆

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Abstract

Regional growth of new knowledge in nanotechnology, as measured by counts of articles and patents in the open-access digital library NanoBank, is shown to be positively affected both by the size of existing regional stocks of recorded knowledge in all scientific fields, and the extent to which tacit knowledge in all fields flows between institutions of different organizational types. The level of federal funding has a large, robust impact on both publication and patenting. The data provide support for the cumulative advantage model of knowledge production, and for ongoing efforts to institutionalize channels through which cross-organizational collaboration may be achieved.

Keywords: Bibliometrics; Boundary Spanning; Collaboration; Nanotechnology; Organization type

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1. Introduction

What factors influence the rates at which new knowledge is produced in technological fields? The particular study reported in this paper is part of a more general research program driven by this question, whereby we seek to understand the processes that determine the productivity of authors and inventors in new technology, as measured by counts of articles and patents (see, e.g., Zucker et al., 1998a,b; Zucker et al., 2002). In the study reported here, our counts of documents are obtained by statistical analysis of the contents of NanoBank, an open-access digital library of articles and patents in the field of nanotechnology (Zucker and Darby, 2006). Our approach is guided by a theoretical conception of the production of scientific knowledge as an activity that is deeply embedded in a complex network of social structures and practices, and that the forms taken by these structures and practices are crucial determinants of the forms taken by knowledge production in later periods in the same place. While it is conventional to refer to science as cumulative, we argue and demonstrate that there is a significant cumulative effect even when the knowledge produced is discontinuous and revolutionary in some respects.

We present the results of tests of two related hypotheses. The first of these is that the frequency of publication, during a given period and in a given geographical region, of articles and patents *relating to nanotechnology* is correlated with the size of the existing "knowledge stock" of all other (non-nanotechnology) articles and patents *in all fields of science* previously published in that region. The second hypothesis is that the frequency of publication, during a given period and in a given geographical region, of articles and patents relating to nanotechnology is correlated with the extent to which articles and patents in the existing knowledge stock of the region are *co-authored* by affiliates of institutions of different organizational types.

The results of our tests allow us to draw two sets of conclusions. In the first place, we are able to differentiate the respective merits of two competing kinds of claims about the ways in which existing knowledge stocks affect the evolution of new fields of knowledge such as nanotechnology. In the second place, we are able both to evaluate, on the basis of their impact on productivity, ongoing efforts to institutionalize channels through which cross-institutional collaboration (or "knowledge flow") may be achieved, and to demonstrate the utility of a method by which the impact of stocks of tacit knowledge (as opposed to that of stocks of recorded knowledge) may be estimated.

In the course of our investigations of the links between knowledge stocks, knowledge flows, and knowledge production, we are also able to assess the impact (on productivity of knowledge in nanotechnology) of the cumulative stock of funding dollars awarded by the National Science Foundation (NSF) to nanotechnology projects initiated by institutions in a given region.

The paper is structured as follows. Firstly, we contextualize our hypotheses by considering the impact, on the production of new knowledge, of general knowledge stocks (Section 2), and of barriers to the flow of knowledge across institutional boundaries (Section 3). We then provide a justification of our focus on geographically localized knowledge flow (Section 4), before describing our methods of measuring knowledge (Section 5), of identifying "nano-relevant" documents (Section 6), and of categorizing those documents by organizational type and geographical region (Section 7). In Section 8, we describe our methods of data analysis; in Section 9, we present the results of the tests of our first hypothesis, about the impact of knowledge stocks; and in Section 10, we present the results of the tests of our second hypothesis, about the impact of knowledge flows. Finally, we draw our conclusions (Section 11).

2. General knowledge stocks: their impact on the production of new knowledge

Researchers in the economics of scientific knowledge have long been concerned to assess the impact of knowledge production on economic growth (see, e.g., Stephan, 1996; Foray, 2004). How closely do measurements of the rates at which new knowledge is produced correlate with measurements of the rates at which the economy grows as a whole? A number of production functions have been proposed that model the relationship between output quantities of goods and services and input quantities of knowledge. Considerable attention has also been paid to the task of identifying the conditions under which rates of knowledge production (and thus economic productivity in general) can increase most rapidly. Correspondingly, production functions have been developed that may be used to predict the rate at which new knowledge will be produced in the future (see, e.g., Adams, 1990).

Comprehensive functions of this latter kind typically quantify inputs of three principal types: time, physical resources, and human (i.e., intellectual) resources. In practice, the intellectual capital accessible to an institution includes both (i) knowledge that is recorded or codified in documents, and (ii) the tacit knowledge or know-how that is stored only in the minds of the institution's scientists and researchers. Research in economics