Department of Economics "S. Cognetti de Martiis"

Via Po, 53 – 10124 Torino (Italy)
Tel. (+39) 011 6704917 - Fax (+39) 011 6703895
URL: http//www.de.unito.it

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THE ORGANIZATION, ECONOMICS AND POLICY OF SCIENTIFIC RESEARCH. WHAT WE DO KNOW AND WHAT WE DON'T KNOW

Cristiano Antonelli, Chiara Franzoni, Aldo Geuna

Dipartimento di Economia "S. Cognetti de Martiis"

LEI & BRICK - Laboratorio di economia dell'innovazione "Franco Momigliano"
Bureau of Research in Innovation, Complexity and Knowledge, Collegio Carlo Alberto

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The Organization, Economics and Policy of Scientific Research. What we do know and what we don't know

Cristiano Antonelli*†, Chiara Franzoni§†, Aldo Geuna¥†+

* Dipartimento di Economia "S. Cognetti de Martiis", Università di Torino, Via Po 53, Torino, Italy 10124, Tel. +39-011-6704403, Email: cristiano.antonelli@unito.it

§ DISPEA Dipartimento di Sistemi di Produzione e Economia d'Azienda, Politecnico di Torino, C.so Duca degli Abruzzi 24/b, Torino, Italy 10129, Tel. +39-011-5647205, Email: chiara.franzoni@polito.it.

¥ Dipartimento di Economia "S. Cognetti de Martiis", Università di Torino, Via Po 53, Torino, Italy 10124, Tel. +39-011-6703891, Email: aldo.geuna@unito.it

† BRICK Bureau of Economic Research on Innovation, Complexity and Knowledge, Collegio Carlo Alberto, Via Real Collegio 30, Moncalieri, Torino, Italy 10024.

+ Grenoble Ecole de Management, 12, Rue Pierre Sémard, BP 127, 38003 Grenoble Cedex 01, France.

ABSTRACT.

The knowledge and instruments developed in recent years have paved the way to a substantial contribution from economics to support political and social decision making in matters of scientific progress, such as efficient funding, institutional settings, and allocation. We review the progress made in recent years and predict future directions.

Keywords: economics of science; science and research policy; literature review

1. Introduction

Scientific and technological advances have for long been recognized as being among the main drivers of national social and economic development and one of the primary ways to achieve improved wellbeing for citizens. Among the missions of economics is the production of new insights, better explanatory models, and new instruments for understanding of the scientific enterprise, in order better to serve social and economic progress.

A community of scholars from various subfields of economics has been established, motivated by the common interests of improving understanding and the well functioning of the forces and means behind the organization of science, and informing policy making in matters of funding, allocation, and efficient use of resources. Compared to the early contributions to the Economics of Science, academic work in these field has burgeoned to produce an established area of interest, with solid background references, scope, and implications.

In this paper we describe some recent progress and the major challenges for the future as a background to and introduction for the four papers that comprise this *Special Section.*

2. THE EMERGENCE OF A GROWING FIELD

Until the 1990s, contributions to the Economics of Science focused on two broad areas of investigation: i) the effects of life cycles and career mechanisms on the productivity of scientists (Levin and Stephan, 1991; Stephan and Levin, 1992); and ii) the effect of the reward mechanisms in science on the strength of competition in research (Dasgupta and David, 1987; Dasgupta and Maskin, 1987), with a special focus on the intellectual property rights regime (Dasgupta and David, 1994; Nelson, 2004). Two excellent surveys by Paula Stephan (1996) and Arthur Diamond Jr (1996), define the state of the art in this literature.

A large number of contributions stemming from several streams of economics has built on these seminal works, aimed at improving our understanding of science. These contributions have broadened the community of scholars interested in this field and also the themes of interest, the approaches, methodologies, and notions exploited. In the sections below we describe this growing body of work and the process of recombination and convergence that has occurred in the last few years. An exhaustive study is beyond the scope of this brief essay; however, we highlight in the following what we believe are the recent most relevant contributions stressing their methodological origins from various subfields of economics.

2.1 Science and the Labour Market

A fairly important body of work has emerged based on the tradition of labour economics, focusing on the science and engineering workforce, and the academic job market, which accounts for the lion's share of this workforce. The use of survey data, such as those of the US Scientists and Engineers Statistical Data System (SESTAT),[1] combined with bibliometric indicators, has enabled several quantitative individual-level analyses. For example, studies on the relationship between the taste-for-science and wages (Stuart, 2006), the effect on tenure and promotion in scientific careers of such factors as gender, family, ethnicity (Ginther and Kahn, 2006), and social networking or exchanges with the industrial world (Stuart and Ding, 2006). Other important works related to assessing the contribution of foreign-born scientists (Stephan and Levin, 2001), and the effect of international mobility of scientists on the national scientific base (Len, 2008; Hunter et al., 2009).

However, most of these studies relate to the US workforce; other national workforces are relatively unexplored, often due to lack of data. The paper by Lissoni and colleagues (2010) in this *Special*

[1] See NSF, http://www.nsf.gov/statistics/sestat/

Section is an exception. Lissoni et al. present one of the first studies on the European academic job market, based on individual-level measures of performance. The work models the probability of promotion among a large sample of academic physicists in France and Italy, and shows the responsiveness of career mechanisms to past productivity, research impact, gender and cohort. This work is important because it provides evidence on systems of recruiting and promotion based on a civil-service model of university employment, typical of many European countries. Complementary to this is the article by Kelchtermans and Veugelers (2010), also in this *Special Section,* which tackles the problem of how 'system factors', such as promotion policies and research funding, can impact on scientific production. On the basis of a panel of individual researchers from the biomedical and exact sciences at the Katholieke Universiteit Leuven in Belgium, they apply a quantile regression approach to count data and assess whether productivity drivers have different effects at different points in the distribution. They find that distribution incentive factors (such as promotion and access to research resources) have more impact at the bottom of the distribution, i.e. for the less brilliant scientists. They find also a small and near insignificant effect of teaching, and a small significant substitution effect for patenting (more important in chemistry). These results clearly warn of the need to move away from approaches based on average estimations (hence the title 'The Average Scientist Does Not Exist'). Research policies should be fine tuned to the various levels of the distribution, and should provide more incentives at the bottom end of the distribution as the returns from funding are higher for the lower quintiles.

2.2 Industrial Economics and Science

Industrial economics tools have been applied with some success in the quest for effective organization of scientific undertakings. This line of investigation has raised several important issues related to the existence of economics of scale and scope in fostering scientists' productivity (Carayol, 2007; Carayol and Matt, 2004a,b). In this context, much attention has been paid to the effects of size and specialization on the selection, identification, and exploitation of new research stars (Zucker, and Darby, 1996; Schiffauerova and Beaudry, 2010). Bonaccorsi and Daraio (2007) compare the effects on scientific fertilization of having them concentrated in a few centres of excellence, against having them disseminated. Goldfarb, et al. (2009), in their study, question the advantages and limitations of specialization in research activities, as opposed to the traditional joint production of research and teaching.

2.3 Science and Regional Economics

Contributions that use typical notions of regional economics have explored the effects of external economies, both in the generation of science (research) and in the exploitation of scientific knowledge from business firms. In research, the fundamental role of external knowledge is generally confirmed. The evidence suggests that spatial proximity is an important enabling factor since it facilitates market transactions that would not take place without repeated interactions, and exchanges of tacit knowledge and trust. Several empirical investigations suggest that regional proximity among scientific institutions increases scientific production (Antonelli et al., 2010). Clustering also occurs among scientific institutions and business firms that perform research activities in the same regional space, (Audretsch and Feldman, 1996). Other contributions cast doubt on the role of proximity within clusters, or stress the effects of proximity in terms of a more effective transaction in the new markets for knowledge (Audretsch and Stephan, 1996).

In terms of the exploitation of technological knowledge, investigations into the extent to which knowledge externalities matter, shed light on some new aspects of the role of spatial proximity, such as the effect on entrepreneurial activities in a local system (Zucker, Darby, and Brewer, 1998). Zucker, Darby, and Armstrong (1998), using detailed data on Californian biotechnology, stress the positive role of proximity to particular star scientists rather than generic knowledge. Their results suggest that the positive impact of the research conducted within universities on co-localized firms stems from the transactions between these star academics and firms, rather than from pervasive knowledge spillovers. The interactions between firms and academics are also beneficial to these latter: stars collaborating with, or employed by firms, or holding patented inventions have significantly higher citation rates than unconnected academic stars.

2.4 Property Rights on the Outcomes of Research

The issue of appropriability of the products and byproducts of scientific research has been the subject of intense speculation since the early 1990s. Among the earliest contributions to this debate were the articles by law professors Rebecca Eisenberg and Michael Heller (Eisenberg, 1992: Heller and Eisenberg, 1998), which were published in *Science*. The historical antecedent to both these papers was the flurry of patent applications for genes and genetically modified organisms that were filed in those years, by a new breed of entrepreneurial biotech labs, based in universities and private firms. Patenting by the National Institutes of Health and US universities increased as a result of the Bayh-Dole Act of 1980, and the increased number of patentable items (e.g. genetically modified organisms, including mammals). Heller and Eisenberg (1998) maintain that, on the one side, private property on scientific results is meant to sustain private investments in technology development, and on the other, that protecting a research tool, a gene, or some other basic achievements that serve as an input for further research, is likely to raise the downstream costs of the investigations. At the same time, too much property rights protection increases the cost of negotiations among the parties holding the rights on complementary pieces of knowledge, a situation known as the ‘anticommons effect’. The socially optimal solution involves a separation of the roles of public and private research, and their related rights to claims of exclusivity (Aghion et al., 2008). The scholarly works stemmed from this debate analyse the potential effects of the anticommons at three different levels: i) the outputs of individual researchers; ii) the rules governing the functioning of the scientific community; and iii) the institutional mission of universities and their governance. Several empirical assessments show that technology transfer through patenting, does not hamper research productivity (Azoulay et al., 2007; Calderini et al., 2007). Some studies also find that these activities are often the antecedents to more prolific research (Breschi et al., 2007). However, definitive proof of the long-run effects is still lacking[2] and little is known about the effects on teaching. Furthermore, doubts have been cast on the pace of knowledge diffusion when science is encumbered by overly strong property rights protection (Murray and Stern, 2007), and especially on the efficiency of the institutionalization of transfer mechanisms (Crespi et al., 2010).

2.5 Science and Higher Education

The Economics of Higher Education provides a useful framework to study universities’ decisions about budgets, funding and recruiting, which account for the largest share of their total research expenditures. Several scholars focus on the peculiar production functions of universities, and how the quality of users –students and peers- contributes to determining the quality of education and research (Rotschild and White, 1995). For example, the brightest students improve the learning of all other students, because they act as inputs with superior marginal productivity. This is justification for the practice of price discrimination (scholarships) based on talent. When the resource endowments of universities is very uneven, e.g. because of donations (Winston, 1999), the brightest students are disproportionately attracted by the more wealthy institutions and these universities cumulate further advantages, compared to others. A similar mechanism is at work in the case of faculty members, who also generate positive externalities for the research achievements of their peers and students. The contribution by Sylos-Labini and Zinovyeva (2010) in this *Special Section* accounts for this mechanism empirically, showing that the proportion of students that choose a research career is affected by the quality of the faculty involved in their undergraduate studies. The best research faculties are comparatively better at grooming young talents for scientific

[2] For a comprehensive review, see Siegel and Wright (2007); for a critical review see Geuna and Muscio (2009).

careers and should perhaps be subject to specific policy attention. This evidence also supports the coupling between education and high quality research, rather than favouring specialization of tasks.

A number of studies analyse university research performance. Johnes (1992) and Massy (1996) show that, apart from profit maximizing universities, it is often difficult to identify a clear set of institutional objectives. Also, the government-university relationship is often characterized by principal-agent conflicts; universities may be productive in ways that are different from those valued by government. Johnes (1992), among others, considers the incidence of student drop-out, degree pass rates, and quantity and quality of the research produced by academic staff, as the universities' contribution to social welfare.

2.6 Technologicl change and Science

It is only recently that notions typical of the economics of technological change have been used to analyse the development of science. So far, little work has been done on investigating the effects of the introduction of new technologies on the performance of research. Agrawal and Goldfarb (2008) study the consequences of the adoption of information and communication technologies in the US academic system. They suggest that the adoption of BITNET increased research collaboration between US universities, although unevenly. Middle-tier universities seem to have been the primary beneficiaries: collaboration with top-tier institutions increased, while the reverse is not true. Co-localized pairs experienced the largest effects in magnitude. Winkler, Levin and Stephan (2010) study the effects on research productivity of the adoption of BITNET, the domain name system, JSTOR or journal storage, and other electronic library resources. Their results support the hypothesis that information technology improves the careers of faculty, especially at low-tier (compared to higher-tier) institutions.

2.7 Mechanism Design of Research Organizations

The idea behind mechanism design is that institutions are analysed as mechanisms that produce desirable outcomes, under the assumption that *agents have private information and are self-interested*. Its application to the analysis of the organization of the research system as distinct from individual research institutions, is a fast-growing area of investigation. The organization of the research system has undergone significant changes since the end of the 20th century. The separation between research activities conducted in academic and public institutions and firms' research activities has been dwindling. In-house corporate R&D has been progressively substituted by market transactions and outsourced to knowledge suppliers, including high-tech entrepreneurial ventures and universities. Knowledge is traded either in the form of intellectual property rights or through research contracts. This emerging organization of research enables a more efficient exploitation of the intrinsic economies of scope between research and teaching that characterize academic institutions. For example, unlike corporations, universities can make a good use of older, less research active scientists in teaching activities (Antonelli, 2008). University-industry relationships are the subject of a large body of work that enquires into the determinants and effects of this relationship for both parties, and the efficiency of the institutions and contracts involved in these transactions. Several extensive reviews are available.[3]

Another strand of this research explores the allocation and efficient use of resources at the level of institutions (universities, research centres), departments, and single research units or individuals. Adams and Griliches (1998), using data on 40 American universities during 1981-1989, examine the impact of research and development expenditure on research output. They show that the cost per paper is very similar for the top ten and less highly ranked universities, while the cost per citation is 30% less for the top ten universities. Private universities expend more per paper and less per citation than do state-owned universities. Aghion et al. (2010) provide statistical correlations showing the productivity of universities (measured by patents) and their levels of autonomy, and the extent to which they compete for funding. The paper by Adams and Clemmons (2010) in this *Special Section* develops the analysis of research productivity in US universities focusing on intra and inter-university knowledge-flows and interdisciplinary knowledge-flows. The authors find evidence that external flows (from other universities) have increased compared to internal (from the same university) flows. On average, interdisciplinary flows have increased less than intradisciplinary ones, although in engineering and mathematics internal flows show much greater increases. Finally, Adams and Clemmons explore the impact of knowledge flows on research output and find an important and significant effect. The contribution of external knowledge-flows and same field knowledge-flows is more important for scientific discovery than other knowledge flows.

2.8 Science and Economic Growth

While there is a general consensus that scientific knowledge is at the origins of economic growth and much work has been done on assessing the effects of new technological knowledge, very little empirical investigation has been directed to assessing the actual effects of new knowledge on growth since Jaffe's (1989) path-breaking contribution. Jaffe provides only indirect evidence of the positive effects of science on growth, but his empirical study confirms that academic research affects the efficiency and levels of research activity in firms. He finds a significant effect of university research on corporate patents, particularly in the areas of drugs, medical technology,

[3] See, e.g. Perkmann and Walsh, 2007.

electronics, optics, and nuclear technology. He also shows that university research has an indirect effect on local innovation by fostering research in firms located nearby. A more direct exploration of the effects of academic research on economic growth is provided by Adams (1990), who uses measures of science rather than technology to study the effect of new scientific knowledge on economic growth, and develops new indicators of accumulated academic science. His empirical evidence suggests that new scientific knowledge has a major effect on total factor productivity. The impact of this strong causal relationship has a lag of roughly 20 years from the emergence of a new field of research in the academic community to increased economic productivity. Mansfield (1991) adopts a completely different approach. Focusing on a sample of 76 US firms from seven industries, he estimates the benefits of recent (published within 15 years of the relevant innovation) academic research on company innovation. He finds that 11% of new products and 9% of new processes would have been delayed quite significantly without academic research. He also estimates that, in the absence of academic research, companies would have lost out on sales of new products and processes by respectively 2.1% and 1.6%. In a follow up study (Mansfield, 1998) he finds even higher returns from academic research.

Adams and Clemmons (2008) assessed the effects of production of scientific papers on industries and scientific fields, and implement a representation of the structure of basic research flows in a modern, science-intensive economy. They show that flows of basic research are large within petrochemicals, drugs, software and communications: chemistry, physics, and engineering knowledge spreads throughout all industries, while biology and medicine knowledge is concentrated in petrochemicals and drugs respectively. They find that the effects of the advances in computer science are restricted to software and communications. In general, basic research flows are concentrated in scientific fields rather than industries. Their findings indicate that there is strong elasticity between changes in production of scientific papers and changes in industrial output.

3. CONCLUSIONS: EMERGING ISSUES AND WORK AHEAD

Following this brief survey of some of the main achievements since the end of the 1990s, we stress the complementarity and the variety of approaches that have been recombined and applied and we conclude this essay by highlighting some promising directions for research in the future. We point to possible developments in terms of perspectives of enquiry, new topics, and new methodological tools.

In the last decades economics of science has grown into a full-fledged area of investigation thanks to a process of recombinant growth drawing from a wide range of tools and methodologies taken by the typical research traditions of a broad array of fields of economic investigation. The relevance of the processes of growth by recombination that characterize creative undertakings is confirmed once more. In terms of perspectives of enquiry, in the early contributions to the economics of science the individual researcher tends to be the subject of analysis, with the organization of science at the institutional level, in both the private and public domains, receiving less attention. The interplay between the individual researcher (with her set of motivations and rewards) and the institution (department, school, or central administration) to which she belongs has even received less attention. A classical principal-agent framework would offer a simple starting point for deeper investigation of these interactions.

In terms of the directions of enquiry, we can point to at least three. First, the contribution of science to innovation and to economic growth, is poorly understood. A few important studies have been published, but much more research is needed to answer some fundamental questions. Second, in looking at proximity and spatial effects, few investigations focus on assessing the possible existence of negative externalities. For example, it is not clear whether effects would differ for concentrations of homogeneous research activities compared to clusters of different ones. These could be assessed in terms of Jacobs (scope) and MAR (scale) externalities in science. Also, the effects of technical externalities and the consequences of agglomeration and personal interactions on knowledge sharing processes have been investigated quite thoroughly, but little work has been done on the effects of spatial proximity in terms of pecuniary externalities. Third, much recent work in these areas does not address the central issue of determining the efficient amount of resources that the system should invest in the generation and dissemination of knowledge, or analyse the problems involved in identifying to which fields resources should be directed. Clearly, these tasks are not straightforward, given the uncertainty associated with research, but some progress should be possible. For example, it would seem extremely important to provide an analytical framework that encompasses the need for interactions between academia and the business community - both before and after the generation of knowledge. Existing analyses considered the dissemination of knowledge already generated, but overlook the crucial problem of identifying where resources should be invested and the levels of investment required in different areas. The basic methodology of mechanism design would provide a basis for such investigation. It is clear, that in a homogeneous Hayekian system the alignment of incentives among profit-seeking agents is (expected to be) able to address these issues. If universities are funded by the state, and have no incentives for successful identification of new profitable knowledge fields, how do they decide about the direction of their research activities? How are new fields of activity chosen if profits cannot be predicted? The emergence of knowledge outsourcing might be part of a spontaneous order (implemented by design?) that enables better dissemination of knowledge once generated, and also better allocation of resources for the generation of new knowledge.

One starting point might be modelling different science and research trajectories. Existing work has identified two processes that explain the development of research trajectories. First, deliberately chosen pathways, based on the technical and cognitive capacities of the investigators and their expectations in terms of returns. Second, organization of research as a problem solving activity, with the problem to be solved coming from industry, government (space mission, defence projects), or scientific enterprise (e.g. big science projects, scientific tools). Although the returns from research may be unpredictable, and levels of risk impossible to calculate, a proportion of these types of research is fairly predictable in terms of probability of success.

Finally, with regard to the tools of analysis, there is a need to move beyond the consolidated set of bibliometric techniques developed in the 1960s, based on productivity (counts of articles), and impact (citation counts). These measures, although useful, do not take account of other features relevant to scientific productivity and constrain the scope of enquiry. Several indicators have been proposed within bibliometric studies, but their use in economic enquiry is limited and needs further development and testing by statistical economists. For example, backward citations analysis could be used to construct measures of scope and interdisciplinarity, and content analysis could be applied to map subfield coverage, evolution, etc.

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