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Essays on the Production and Commercialization of New Scientific Knowledge

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Abstract

Scientific research frequently generates tremendous economic value. Yet, this value tends to be elusive and public and private organizations often struggle to obtain returns from their investment in science. This dissertation examines persistent challenges to the production and commercialization of new scientific knowledge.

The first essay describes simultaneous discoveries and their potential as a new research tool for social scientists. The second essay uses this tool to examine the role of firms and universities in the translation of scientific knowledge into new technologies. The third essay explores tradeoffs associated with collaboration in the production of new scientific knowledge.

Summary

1. BACKGROUND

This dissertation investigates the relationship between organizations and science. On the one hand, public and private organizations invest heavily in pushing the scientific frontier with the hope that economic gains will follow (e.g., Cohen and Levinthal 1990; Henderson, Jaffe, and Trajtenberg 1998; Aghion et al. 2010). Some scientific discoveries can indeed open the door to the creation of new technologies, new firms, or even new industries (Rosenberg and Nelson 1994; Fleming and Sorenson 2004). On the other hand, economic returns from investments in scientific research are often disappointing. The process of scientific discovery involves tremendous uncertainty and the appropriate organization of knowledge work is often unclear. In addition, it sometimes takes years before a new piece of scientific knowledge is used to produce a novel technology (Rosenberg 1994; Mokyr 2002). High failure rates make investment in science-based innovation tremendously costly. People, companies, and nations intending to use science as a source of competitive advantage need to understand these tensions.

To address these critical issues, this dissertation explores the process of production and commercialization of new scientific knowledge. In three distinct essays, it investigates the phenomenon of simultaneous discoveries, the process by which organizations use scientific knowledge to produce new technologies, and the organization of scientific work. It therefore examines the production and commercialization of scientific knowledge from a variety of perspectives, at the level of individuals, organizations, and knowledge itself. This research proposes simultaneous discoveries—"knowledge twins"—as a new research tool for social scientists. It also provides insights about the role that organizations play in amplifying or obstructing the technological impact of new scientific discoveries. Finally, it expands our understanding of the tradeoffs associated with collaboration in scientific research. The ambition of this dissertation is to help scholars, managers, and policymakers generate economic value from scientific research.

Micro-economic empirical analysis of the production of scientific knowledge and of its development into new technologies has traditionally relied on large bibliometric and patent datasets (e.g., Henderson, Jaffe, and Trajtenberg 1998; Fleming and Sorenson 2004; Wuchty, Jones, and Uzzi 2007). These datasets have been extremely helpful in uncovering

general patterns and trends in scientific discovery and in invention. One limit of such datasets, however, is that the process preceding discovery, invention, or failure, is unobserved. As a result, the drivers of productive efficiency in discovery and in invention remain unclear. In order to get around this difficulty, this dissertation uses various approaches that complement those bibliometric and patent datasets. For instance, the first essay proposes a new research tool—simultaneous discoveries operationalized as "paper twins"—and uses insights from computer science and sociology to generate a large dataset of such events. The second essay studies these knowledge twins in order to analyze science-based invention or the absence thereof as a function of the environment of discovery. Finally, the third essay examines publications but at the level of a scientist's year of work.

2. OVERVIEW OF THE DISSERTATION ESSAYS

Scientific knowledge is often seen as a source of competitive advantage for individuals, firms, and nations. Yet, the creation of economic value from scientific research is challenging, raising important questions about the appropriate process of production and commercialization of new knowledge. Contributing to this line of inquiry, this dissertation is composed of three essays investigating respectively (1) the phenomenon of simultaneous discoveries and its potential as a research tool, (2) the use or non-use of new scientific knowledge to produce new technologies, and (3) the organization of scientific work.

2.1 Simultaneous Discoveries as a Research Tool: Method and Promise

Half a century after Merton's description of simultaneous discoveries "as a strategic research site" (Merton 1963), they are hardly ever used by social scientists. This essay attempts to unleash the potential of simultaneous discoveries as a research tool. First, they provide a lens into the determinants of creativity in general and scientific advancement in particular (e.g., Merton 1961). Indeed, their frequency constitutes striking evidence that creative ideas, although novel, might not necessarily be unique. Second, simultaneous discoveries provide important insights about the process of social construction of science (Kuhn 1969). These events are often associated with racing and conflict about credit allocation and are therefore revealing of many features of the institutions that contour scientists' behavior. Third, simultaneous discoveries are instances in which the same

knowledge emerges around the same time in two different environments. As such, they can be used to conduct "twin studies" of new knowledge and identify the impact of the environment on the utilization (or non-utilization) of that knowledge.

This essay also proposes the first systematic and automated method to build a dataset of simultaneous discoveries. The method goes beyond the old debates about the scientific similarity of two (twin) discoveries. It is based on the insight that teams of scientists that make the same discovery around the same time will share the credit for that discovery—and that credit-sharing will be visible in the citation patterns of scientific papers (Cozzens 1989). This method is further implemented into an algorithm that generates a dataset of 578 recent simultaneous discoveries made by 1,246 teams of scientists working in a variety of settings around the world.

2.2 Is Knowledge Trapped Inside the Ivory Tower? Technology Spawning and the Genesis of New Science-Based Inventions

The third essay of the dissertation investigates some of the conditions under which organizations translate —or fail to translate— scientific discoveries into new technologies. Historical examples reveal that, while this development can be very rapid in certain circumstances, scientific knowledge can sometimes remain unexploited for years (Rosenberg 1994; Mokyr 2002). For instance, the first person who purified EPO, Eugene Goldwasser, could not find anyone who would invest in turning his scientific discovery into a new technology. The first firm that did work on this project, five years later, was a start-up named Amgen; and it created a new technology (recombinant EPO) that became one of the most successful drugs ever produced by the biotechnology industry. Discerning the circumstances under which scientific discoveries are developed into new technologies is very difficult because the technological potential of the scientific knowledge is always unobserved. This essay addresses this challenge by using simultaneous discoveries to conduct the first "twin study" of new scientific knowledge.

Specifically, the paper examines the relative impact of universities and firms as discovery environments on science-based invention (e.g., Henderson, Jaffe, and Trajtenberg 1998; Aghion et al. 2010). Analysis of follow-on inventions, based on 39 simultaneous discoveries between academia and industry involving 90 teams, reveals that the team from

industry produces more than 3 times more inventions based on its discovery than the co-discoverers from academia. Moreover, third-party inventors are 10-20% more likely to cite the industry publication in their patent than its academic twin. Taken together, these results indicate that new scientific knowledge is more likely to be utilized to produce new technologies if it emerges in firms than if it emerges in the "Ivory Tower."

2.3 Exploring Tradeoffs in the Organization of Scientific Work: Collaboration and Scientific Reward

This essay, coauthored with Fiona Murray and Joshua Gans, explores the use of collaboration in scientific research. Prior studies on the topic have been optimistic about this organization of creative work, showing for instance that more collaborative scientific papers (and patents) tend to be of higher quality than those that have fewer authors (e.g., Wuchty, Jones, and Uzzi 2007; Singh and Fleming 2010). This type of evidence does not consider, however, that collaboration is a choice, and that its benefits in terms of output quality might be offset by coordination costs and challenges with regard to credit allocation. This paper explores these tradeoffs in two ways. First, we develop a formal model to structure our understanding of the factors shaping scientists' collaborative choices. Second, we test our model's assumptions empirically by examining the actual choices made by 661 faculty-scientists from one institution – the Massachusetts Institute of Technology – over a thirty-year period from 1976 to 2006.

We find that collaboration is associated with important tradeoffs, including higher-quality publications, lower individual productivity and disproportionate credit attribution—i.e. that credit for a given collaborative paper is shared across coauthors in a way that sums to more than 1. Interestingly, these results suggest that the "net value" of collaboration in creative work might be superior for the credit-seeking worker than it is for the output-focused manager or policy-maker. The type of collaborator has also important consequences. For instance, the benefits of collaboration are particularly high and its costs are particularly low when the collaboration brings together individuals having different skills and perspectives—as in the case of cross-departmental collaborations.

3. FUTURE DIRECTIONS AND CONCLUSIONS

This dissertation opens the door to a variety of potential studies of the production and commercialization of new scientific knowledge. Below, I describe four such studies that are currently underway but are not formally part of this dissertation.

One study examines the influence of the geographic location of the discovery team on science-based invention. The project, titled "Geographic Localization of Knowledge Spillovers: Evidence from Knowledge Twins," investigates current debates about the extent to which knowledge spillovers are localized. Using citations of 275 twin papers in the patent literature, it is possible to identify the extent to which inventors are more likely to draw on scientific knowledge that emerges within closer geographic proximity—while keeping the discovery constant. Early results indicate that knowledge spillovers are localized not only at the country level, but also very strongly at the metropolitan-area level.

Another project investigates the division of innovative labor across different types of organizations. This study is titled "In the Shadow of Uncertainty: Entrepreneurial Strategy and the Selection of New Projects," and it explores how entrepreneurs exploit uncertainty (Knight 1921) to compete against incumbents in pharmaceutical R&D. Using instances in which the same discovery is made simultaneously in an entrepreneurial venture and at a large firm, the preliminary results indicate that entrepreneurs tend to disengage from projects involving too little uncertainty for fear of competition with companies that have much greater resources. On the other hand, larger firms tend to reject ideas with high uncertainty, providing space for young firms to grow, "sheltered from competition" by this very uncertainty.

The managerial implications of the division of innovative labor are explored in a working paper titled "Idea-Centered Innovation Management: A Novel Approach to R&D for the Biopharmaceutical Industry." Most current approaches to innovation management do not consider that R&D ideas have different uncertainty profiles, therefore calling for different organizational structure. This paper proposes a new approach to innovation management that takes this uncertainty into account. The relevance of the new approach is illustrated in the context of the alliance between Sanofi and the Center for Biomedical Innovation at MIT.

Regarding the production of new scientific knowledge, one project, titled "Is Collaborative Diversity Creative or Costly? Group Composition, Inspiration, and Time

Wasted" (with Fiona Murray), proposes an analysis of the specific impact of different types of collaborative diversity on creative performance. Our preliminary results indicate that the costs and benefits of collaboration are driven by distinct mechanisms. For a given scientist, the addition of a new collaborator is associated with lower productivity but does not have any significant correlation with output quality. On the other hand, collaborating across disciplines is associated with higher-quality work but is not significantly linked with lower productivity. These findings highlight the complexity of the relationship between collaboration and creativity and provide a more nuanced view of the tradeoffs associated with collaboration in scientific research.

In conclusion, the overarching ambition of this research is to improve our understanding of how individuals, firms and nations can use scientific research as a source of competitive advantage. This agenda will continue to require innovative approaches, using various empirical strategies and drawing insights from a number of disciplines. My hope is that this dissertation and continuing research will provide new insights about the drivers of scientific discovery, science-based innovation, organizational performance, and economic growth.

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