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Research Summaries

Entrepreneurs, Star Scientists, and Biotechnology

Lynne G. Zucker and
Michael R. Darby*

We are studying the interaction of scientific and technological progress—particularly when breakthroughs or discontinuities occur—through in-depth case studies and econometric analysis of the science underlying biotechnology, the resulting formation of a new industry, and the transformation of existing industries.¹ Our results indicate that the very best “star” scientists play central roles in both the development of the science and its successful commercialization. The importance of these individuals, especially the more entrepreneurial among them, derives from the tacit character of new breakthrough discoveries. In this way, knowledge, at least when it is new, is embodied in particular individuals; it cannot diffuse rapidly, as might easily-duplicated recipes.

How these star scientists balance their multiple roles as leading scientists and participants—often principals—in the commercialization of their discoveries is shaped by the institutional and legal framework in which they operate. These frameworks differ most sharply at the country level. We therefore have extended our analysis to Japan, which is the second-largest country in terms of both bioscience and commercial application of biotechnology.

**Zucker and Darby are Research Associates with the NBER's Program on Productivity and Technological Change. Darby is also a Research Associate with the NBER's Program on International Finance and Macroeconomics. Both are professors at the University of California, Los Angeles. Their profiles appear later in this issue.*

To assess how often discoveries in basic science—made by the stars—shape commercial technology and business success, we are currently extending our work with our project team to investigate other “high technologies” including semiconductors and interactive media.

Project Team and Relational Database

In 1988, Zucker and Marilyn B. Brewer began a study at the University of California, Los Angeles (UCLA) of elite scientists and the founding of biotech firms, and of the effect of commercial involvement on the productivity of those bioscientists. They defined star scientists for their project as those who by 1990 had recorded more than 40 genetic-sequence discoveries or had authored at least 20 articles reporting such discoveries. GenBank collected discoveries and articles internationally without regard to language or location of publication, so this definition did not favor any particular nationality.²

By the time Darby joined the collaboration in 1992, Zucker and Brewer had hand-collected all the genetic-sequence articles by these 327 star scientists, coded the names of all their co-authors (whether another star or a collaborator), located all of these scientists by affiliation on each article, coded data in all U.S. universities, and collected extensive data on all the firms that had entered biotechnology in the United States.

Since 1992, the relational database has been greatly extended to cover articles up to 1994, has added extensive data on Japanese firms and universities, and has added some initial

data on European firms and universities.³ A parallel database is nearly complete for semiconductors and one has been started for interactive media. The quantitative studies based on this data have all been informed by fieldwork and case studies in which more than 100 scientists, executives, and government and university officials have been interviewed across the United States, Japan, Europe, and Australia.

Star Scientists and Commercialization

Until recently, economists and sociologists studying science and technology have been averse to viewing scientists—particularly top scientists—as pursuing private motives, viewing them instead as disinterested contributors to a shared common pool of knowledge. Our results suggest that star scientists often are better viewed as entrepreneurial individuals who value both financial rewards and the pleasure, recognition, and resources that come from being the first to make a significant new discovery. Collaborations expected to lead to higher valued discoveries, for example, are more likely to be limited to authors from a single organization, and increased use of single-organization collaborations retards the rate of diffusion to new scientists.⁴ One of our interviewees, when asked about delays of publication to enable patenting, responded, “In the university, it's hardly unknown to hold off publishing a breakthrough until you've skimmed off some of the cream.”

The key role of star scientists in commercialization of their discover-

ies is suggested by some of our early results but confirmed more strongly in our most recent analysis. Where and when star scientists are actively publishing scientific articles is a key determinant of where and when firms enter into biotechnology in the United States.⁵ This result seems to support the "geographically localized knowledge spillovers model" in which those nearby—for example, within Route 128 (in Massachusetts) or in Silicon Valley—hear first of breakthrough discoveries as the scientists give the knowledge away in seminars or barroom gossip. However, this model is inconsistent with our interviews, which suggest that the stars are fully cognizant of the value of their discoveries and use it either as the basis for starting their own firms or trading with existing firms.

Our database permits us to see which star scientists have published with scientists from firms—generally agreed by the scientists to be an indicator of both bench-science collaboration and alignment of interests. When we consider the success of California firms in terms of new products in development, there is an apparent value to being located in the same region as universities with star scientists who have many publications. However, this turns out to result entirely from the large positive effects on firm success of those firms that have jointly authored articles with university stars. The large impact of these articles is apparent in other measures of success such as products on the market and employment growth.⁶ We have since replicated these results in work underway for the United States and in Japan, in which we substituted number of patents granted for unavailable data on employment growth.⁷ We illustrate the magnitude and robustness of the effects of these linked star-firm articles in Figure 1. In the United States, linked articles appeared by

1985 for 9 of the 10 most successful (to date) new biotech firms, as measured by market valuation.

An initial working hypothesis of the project—and one still popular in the literature—is that a star scientist who becomes involved in commercialization of his or her discoveries is a loss to the progress of science. We have found instead that the scientists who are more involved in commercialization and patenting are more productive scientifically during their period of involvement. To compare the extreme cases, for example, up until 1990, stars who were ever affiliated with firms and had some patents had an average annual citation rate in genetic-sequence discovery articles 9.17 times that of pure academic stars who neither patented nor ever published with, or as an employee, of a firm.⁸ It could be that only the most successful of the stars have the opportunity to work with existing firms or to obtain financial backing to start their own firms, but by examining their publication history before, during, and after publishing as firm employees, or jointly with firm employees, we find that U.S. scientists publish significantly more articles with significantly higher citation rates during than before or after firm ties. (Japanese stars also publish significantly more while tied to firms, but their increase in citation rate is not statistically significant.) Thus, we conclude that stars who are involved commercially use part of their gains to advance their independent scientific careers: they are partly venture capitalists, rather than wholly tied to the National Institutes of Health or the National Science Foundation.

Because university star links to firms are important in determining both the firms that will be successful and the rate of advancement of the underlying science base, we examine that process in our work with Maximo Torero. We find that the probability that the first article published

with, or as, a firm employee will occur in a given period increases with the academic star's total citations to articles written to date, the percentage of co-authors in other institutions, the number of nearby firms, and, notably, the increase in research productivity of other nearby stars who have already established such commercial ties.⁹ Again, the most productive stars are the most desirable to firms and those stars respond not only to the financial but also to the scientific rewards of commercial involvement.

Effects of Institutions

In collaboration with Shingo Kano of the University of Tokyo; Takuma Takahashi of Nomura Research Institute, Limited; and Kazuo Ueda of the Bank of Japan, we are currently preparing a monograph examining the adoption of biotechnology in Japan, with particular emphasis on how institutional differences have caused that process to differ from what has been observed in the United States. Two key institutional differences are: In Japan, until recently, financial market regulations precluded the venture capital and initial public offering processes that have financed so many U.S. startups, so that virtually all Japanese adoption of the technology has been by pre-existing firms. Japanese national university professors have been precluded from starting firms on the side, but generally they have been able to patent in their own name any discoveries made in their universities. As a result, star-firm collaborations generally occur in Japanese university laboratories, as opposed to U.S. collaborations, in which the work is frequently done in firm laboratories to secure the property rights.

As a result, we see that although stars' publishing still plays the leading role in determining where and when Japanese firms enter, the stars'

impact is significantly less and the impact of pre-existing economic structure is significantly greater than in the United States.¹⁰ As indicated earlier, the effects of university star-firm collaborations on firm success appear to be about as potent in Japan as in the United States, but because Japanese firms send their employees to work in the university laboratories, the stars' economic impact is not nearly so geographically localized as in the United States.¹¹ For a visual summary of highlights of our results, refer again to Figure 1.

The breakthrough technology in the United States has led to a transformation of the pharmaceutical industry, earliest and most importantly through the creation of new firms but also through the transformation of existing firms. Many of the previous incumbent firms have disappeared and others have successfully transformed themselves, even as new entrants have become important players in the drug-discovery part of the business or, in a few cases, full-fledged pharmaceutical firms.¹² Our Japanese collaborators are examining both the transformation of Japanese incumbent pharmaceutical firms and successful and unsuccessful entry by pre-existing firms from other industries.

We have recently found evidence that the European reliance on national research institutes instead of research universities may have disadvantaged European commercial adoption of biotechnology. Figure 2 illustrates that although Europe has a substantial percentage of the world's stars, it has fewer than 10 percent of those who have written articles with or as firm employees. Across countries, the correlation of percentage of stars with firm ties and percentage of stars in research institutes is large, significant, and negative.¹³ Also, the United States and Japan, with the largest percentages of stars tied to firms, have been drawing stars from

the rest of the world, a process that has continued in the 1990s.

Relevance and Future Research

The new growth theory or endogenous growth models generally treat discoveries as a sort of software, "knowledge or information that can be stored in a form which exists outside of the brain," and is therefore nonrivalrous (and possibly nonexcludable) so that public good issues arise.¹⁴ Our evidence for biotechnology indicates instead that the relevant knowledge or information—at least in the breakthrough stage we are investigating—has important elements that are tacit and must be learned by working, directly or indirectly, with discovering scientists. Ultimately, the knowledge diffuses widely and earns only the normal rate of return on the cost of learning it in any reputable graduate program. But between initial discovery and the long run, natural excludability implies extraordinary financial and scientific returns to scientists adept in discovery and ensures that discoveries are normal rivalrous goods. To the extent that our results generalize to other areas of rapid technological progress, revisions in the new growth theories are required.

Policy analysts find our research of interest because by clarifying the potentially important role of star scientists in commercializing their work—and the virtuous circles through which that accelerates scientific advance¹⁵—we are able to identify particular institutions or policies that facilitate or interfere with that process. Examples include across-university variations in rights of professors to serve as principals or consult for companies on the side, research institute rules that effectively insulate scientists from direct commercial involvement, and the role of the Bayh-Dole Act and similar rules in providing

incentives for commercialization.

Our future research agenda attempts to balance opportunities to exploit and extend the unique relational biotechnology database and to apply our methodology to other technologies and science bases. With the collaboration of excellent colleagues and students at UCLA, NBER, and elsewhere, we are continuing the biotech work and simultaneously initiating data collection and research in other high-technology areas.

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² *The definition is biased against those scientists not working in the recombinant-DNA or genetic engineering area. However, as the included areas are the dominant ones in commercial applications of biotechnology, the definition has proven quite useful in practice. The cutoff date is before the perfection of mechanical sequencers that would later inflate the number of sequences a particular scientist could discover.*

³ *At UCLA the project has been run through the Organizational Research Program of the Institute of Social Science Research, with the cooperation of the NBER; the Olin Center for Policy in the Anderson School; and the newly established Center for International Science, Technology, and Cultural Policy in the School of Public Policy and Social Research. Brewer has phased out of the project subsequent to her move to the Ohio State University.*

⁴ *L.G. Zucker, M.R. Darby, M.B. Brewer, and Y. Peng, "Collaboration Structure and Information Dilemmas in Biotechnology: Organizational Boundaries as Trust Production," in Trust in Organizations, R.M. Kramer and T.R. Tyler, eds., Thousand Oaks, CA: Sage, 1996.*

⁵ *L.G. Zucker, M.R. Darby, and M.B. Brewer, "Intellectual Human Capital and*

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14. R.R. Nelson and P.M. Romer, "Science, Economic Growth, and Public Policy," in *Technology, R&D, and the Economy*, B.L.R. Smith and C.E. Barfield, eds. Washington, DC: The Brookings Institution and The American Enterprise Institute, 1996.

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New Products and Price Indexes

Jerry A. Hausman*

What is the value to consumers of new products? The number of new products introduced in any year is astounding. New varieties of consumer goods such as cereal brands are evident, as any shopping trip to a local supermarket or Wal-Mart demonstrates. Potentially even more important are the new products based on technology: more than 55 million cellular telephones are in use in the United States, and more than 20 million people subscribe to the Internet, for example. Does consumer welfare increase significantly with these new goods and services? If so, then the Bureau of Labor Statistics (BLS) is likely miscalculating the consumer price index (CPI), because the CPI does not take into account the value to consumers of new goods and services.

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The economic theory behind the CPI is well developed. The CPI approximates an ideal cost-of-living index (COLI) which, in turn, tells us how much more (or less) income a consumer would need to be as well off in Period 1 as in Period 0 given changes in prices, changes in the quality of goods, and the introduction of new goods (or the disappearance of existing goods). The omission of the effect of the introduction of new goods in the CPI seems quite surprising since most common business strategies fall into one of two categories: either become the low-cost producer of a good just like your competitors' or differentiate your product from theirs. The latter strategy has become the hallmark of much of American (and Japanese) business practices. The sheer number of brands of cars, beer, cereal, soda, ice cream, yogurt, appliances such as refrigerators, and cable television programming all demonstrate the ability of firms to differentiate their products successfully. Furthermore, consumers demonstrate a preference

for these products, because they buy enough of them that businesses make the expected positive profits on the new brands.

In my first paper on this subject,¹ which considers new cereal brands, I find a significant consumer value placed on new goods. This value may cause the CPI to be seriously overstated, since it neglects new products. In the paper, I first explain the theory of cost-of-living indexes. Then, using the classical theories of Hicks² and Rothbarth,³ I demonstrate how new goods could be included. The correct price to use for the good in the pre-introduction period is the "virtual price," which sets demand equal to zero. Estimation of this virtual price requires estimation of a demand function, which in turn provides an expenditure function, and thus allows exact calculation of the CPI.

As an example, I use the introduction of a new type of cereal by General Mills in 1989, Apple Cinnamon Cheerios. The cereal industry has been among the most prodigious