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Colloquium Paper

This paper serves as an introduction to the following papers, which were presented at a colloquium entitled "Science, Technology, and the Economy," organized by Ariel Pakes and Kenneth L. Sokoloff, held October 20–22, 1995, at the National Academy of Sciences in Irvine, CA.

Science, technology, and economic growth

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Systematic study of technology change by economists and other social scientists began largely during the 1950s, emerging out of a concern with improving our quantitative knowledge of the sources of economic growth. The early work was directed at identifying the importance of different factors in generating growth and relied on highly aggregated data. However, the finding that increases in the stocks of conventional factors of production (capital and labor) accounted for only a modest share of economic growth stimulated more detailed research on the processes underlying technological progress, and led to major advances in conceptualization, data collection, and measurement. It also focused attention on theoretical research, which was clarifying why market mechanisms were not as well suited to allocate resources for the production and transmission of knowledge as they were for more traditional goods and services. The intellectual impetus that these studies provided contributed to an increased appreciation by policymakers of the economic significance of science and technology, and a more intensive investigation of its role in phenomena as diverse as: the slowdown of productivity advance in the West, the extreme variation in rates of growth across the world, and the increased costs of health care.

In organizing the National Academy of Sciences colloquium on "Science, Technology, and the Economy," we sought to showcase the broad range of research programs now being conducted in the general area of the economics of technology, as well as to bring together a group of scholars who would benefit from dialogues with others whose subjects of specialization were somewhat different from their own. While the majority of participants were economists, there was also representation from a number of other disciplines, including political science, medicine, history, law, sociology, physics, and operations research. The papers presented at this colloquium have been shortened and revised for publication here.

Expenditure on research and development (R&D) is typically considered to be the best single measure of the commitment of resources to inventive activity on the improvement of technology. Accordingly, the colloquium began with a background paper by Adam Jaffe (1), which provided an overview of trends and patterns in R&D activity since the early 1950s, as well as some international comparisons. He discussed how federal spending on R&D is roughly the same today in real terms as it was in the late 1960s, but that expenditures by industry have nearly tripled over that period—raising its share of all funding for R&D from roughly 40% to 60%. Basic research has fared relatively well and increased its share of the total funds for R&D, with universities being the primary beneficiary of the marked shift of federal spending in this direction. From an international perspective, what stands out is that the historic pattern of United States leadership in R&D expenditures as a share of gross domestic product has been eroding in recent years; and that the United States devotes a much higher proportions of its R&D expenditures to defense and to life sciences than do counterparts like Germany, Japan, France, and the United Kingdom.

Following Jaffe's overview were two talks on projects aimed at improving on our measures of the quantity and value of contributions to knowledge. The first, by James Adams and Zvi Griliches (2), examined how the relationship between academic research expenditures and scientific publications, unweighted or weighted by citations, has varied across disciplines and over time. As they noted, if the returns to academic science are to be estimated, we need good measures of the principal outputs—new ideas and new scientists. Although economists have worked extensively on methods to value the latter, much less effort has been devoted to developing useable measures of the former. The Adams–Griliches paper also provides a more general discussion of the quality of the measures of output that can be derived from data on paper and citation counts.

Adam Jaffe and Manuel Trajtenberg (3) reported on their development of a methodology for the use of patent citations to investigate the diffusion of technological information over geographic space and time. In illustrating the opportunities for linking inventions and inventors that the computerization of patent citation data provide, they found: substantial localization in citations, lower rates of citation for federal patents than for corporate, a higher fertility or value of university patents, and citation patterns across technological fields that conform to prior beliefs about the pace of innovation and the significance of gestation lags.

National laboratories have come under increasing scrutiny in recent years. Although they perform a much smaller share of United States R&D than they did a generation ago and have been the target of several "restructuring" programs, these laboratories continue to claim nearly one-third of the federal R&D budget. In their paper, Linda Cohen and Roger Noll (4) reviewed the historic evolution of the national laboratories, and explored whether there is an economic and political basis for sustaining them at their current size. They are deeply pessimistic about the future of the laboratories in this era of declining support for defense-related R&D, portraying them as lacking potential for cooperative enterprises with industry, as well as political support.

Scholars and policymakers often ask about the significance and effects of trade in intellectual capital. Naomi Lamoreaux and Kenneth Sokoloff (5) offered some historical perspective on this issue, presenting research on the evolution of trade in patented technologies over the late nineteenth and early twentieth centuries. Employing samples of both patents and assignments (contracts transferring rights to patents), they found evidence that a class of individuals specialized in inventive activity emerged long before the rise of industrial research laboratories. This rise of specialized inventors was

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Abbreviation: R&D, research and development.

related to the increasing opportunities for extracting the returns to discoveries by selling or licensing off the rights, as opposed to having to exploit them directly. They also found that intermediaries and markets, supportive of such trade in technological information by reducing transaction costs, appear to have evolved first in geographic areas with a record of high rates of patenting, and that the existence of these and like institutions may in turn have contributed to the persistence over time of geographic pockets of high rates of inventive activity through self-reinforcing processes.

The paper by Keith Pavitt (6) was perhaps more explicitly focused on the design of technology policy than any other presented at the colloquium. Making reference both to the weak association across nations between investment in R&D and economic performance, and to the paucity of evidence for a direct technological benefit to the information provided by basic research, he argued that the major value of such activity is not in the provision of codified information, but in the enhancement of capacity to solve technological problems. This capacity involves tacit research skills, techniques and instrumentation, and membership in national and international research networks. In his view, the exaggerated emphasis on the significance of codified information has encouraged misunderstanding about the importance of the international "free-rider" problem and a lack of appreciation for institutional and labor policies that would promote the demand for skills and institutional arrangements to solve complex technological problems.

One afternoon of the colloquium was devoted to papers on economic issues in medical technology. Many economists have long been concerned that the structures of incentives in the systems of health care coverage used in the United States have encouraged the development of medical technologies whose value on the margin is small, especially relative to their cost. The paper by Mark McClellan (7) presented new evidence on the marginal effects of intensive medical practices on outcomes and expenditures over time, using data on the treatment of acute myocardial infarction in the elderly from 1984 through 1991 from a number of hospitals. In general, McClellan found little evidence that the marginal returns to technological change in heart attack treatment (catheterization is the focus here) have declined substantially; indeed, on the surface, the data suggest better outcomes and zero net expenditure effects. Because a substantial fraction of the long-term improvement in mortality at catheterization hospitals is evident within 1 day of acute myocardial infarction, however, McClellan suggests that procedures other than catheterization, but whose adoption at hospitals was related to that of catheterization, may have accounted for some of the better outcomes.

Lynn Zucker and Michael Darby (8) followed with a discussion of their studies of the processes by which scientific knowledge comes to be commercially exploited, and of the importance of academic researchers to the development of the biotechnology industry. Employing a massive new data set matching detailed information about the performance of firms with the research productivity of scientists (as measured by publications and citations), they found a very strong association between the success of firms and the extent of direct collaboration between firm scientists and highly productive academic scientists. The evidence is consistent with the view that "star" bioscientists were highly protective of their techniques, ideas, and discoveries in the early years of the revolution in genetic sequencing, and of the significance of bench-level working ties for the transmission on technological information in this field. Zucker and Darby also suggest that the research productivity of the academic scientists may have been raised by their relationships with the firms because of both the opportunities for commercialization and the additional resources made available for research.

The paper by Alan Garber and Paul Romer (9) begins by reviewing the arguments that lead economists and policy makers to worry that market allocation mechanisms, if left alone, may not allocate an optimal amount of funds to research activity. They then consider the likely costs and benefits of various ways of changing the institutional structures that determine the returns to research, including strengthening property rights for innovative output and tax subsidy schemes. The discussion, which is weighted to medical research, points out alternative ways of implementing these schemes and considers how their relative efficacies are likely to differ with the research environment.

Iain Cockburn and Rebecca Henderson (10) followed with an empirical investigation of the interaction between publicly and privately funded research in pharmaceuticals. Using a confidential data set that they gathered, they begin by showing that for their sample of 15 important new drugs there was a long and variable lag between the date of the key enabling scientific discovery and the market introduction of the resultant new chemical entity (between 11 and 67 years). In at least 11 of the 14 cases the basic discoveries were done by public institutions, but in 12 of those same cases the major compound was synthesized at a private firm, suggesting a "downstream" relationship between the two types of research institutions. They stress, however, that private sector research scientists often publish their results and frequently co-author with scientists from public sector institutions, suggesting that there are important two-way flows of information. There is also some tentative evidence that the research departments of firms that have stronger ties to the public research institutes are more productive.

Steve Berry, Sam Kortum, and Ariel Pakes (11) analyze the impact of the lowering of emission standards and the increase in gas prices on the characteristics and the costs of producing automobiles in the 1970s. Using their construct of a "hedonic" cost function, a function that relates the costs of producing automobiles to its characteristics, they find that the catalytic converter technology that was introduced after the lowering of emissions standards in 1975, did not increase the costs of producing an auto (though it may have hurt unmeasured performance characteristics). However, the more sophisticated three-way and closed-loop catalysts and the fuel injection technologies, introduced following the further lowering of emissions standards in 1980, increased costs significantly. They also show that the miles per gallon rating of the new car fleet increased significantly over this period, with the increases occurring primarily as a result of the introduction of new car models. Though the new models tended to be smaller than the old, there was also an increase in the miles per gallon in given horsepower weight classes. This, together with striking increases in patenting in patent classes that deal with combustion engines following the 1973 and 1979 gas price hikes, suggests a significant technological response, which allowed us to produce more fuel efficient cars at little extra cost.

Since the founding of Sematech in 1987, there has been much interest in whether this consortium of United States semiconductor producers has been effective in achieving the goal of promoting the advances of United States semiconductor manufacturing technology. The original argument for the consortium, which has received substantial support from the federal government, was based on the ideas that it would raise the return to, and thus boost, spending on investment in process R&D by increasing the extent to which new knowledge would be internalized by the firms making the investments, and increase the social efficiency of the R&D conducted by enabling firms to pool their R&D resources, share results, and reduce duplication. Douglas Irwin and Peter Klenow (12) have been studying whether these expectations were fulfilled, and here review their findings that: there are steep learning curves in production of both memory chips and microprocessors;

there exist efficiency gains from joint ventures; and that Sematech seems to have induced member firms to lower their expenditures on R&D. This evidence is consistent with the notion that Sematech facilitates more sharing and less duplication of research, and helps to explain why member firms have indicated that they would fully fund the consortium in the absence of the government financing. It is difficult to reconcile this, however, with the view that Sematech induces firms to do more semiconductor research.

In his presentation, Richard Zeckhauser (13) suggested that economists and analysts of technology policy often overestimate the degree to which technological information is truly a public good, and that this misunderstanding has led them to devote inadequate attention to the challenges of contracting for such information. Economists have long noted the problems in contracting, or agency, that arise from the costs of verifying states of the world, or from the fact that potential outcomes are so numerous that it is not possible to prespecify contingent payments. All of these problems are relevant in contracting for technological information, and constitute impediments to the effectiveness of invention and technological diffusion. Zeckhauser discusses how government, in its role as enforcer and definer of property rights in intellectual capital as well as in its tax, trade, and antitrust policies, has a major impact on the magnitude of contracting difficulties and the way in which they are resolved. United States policies toward intellectual capital were developed for an era of predominantly physical products, and it is perhaps time for them to be reexamined and refashioned to meet current technological realities.

As long as authorities have acted to stimulate invention by granting property rights to intellectual capital they have been plagued by the questions of when exploitation of such property rights comes to constitute abuse of monopoly power or an antitrust violation, and what should their policies be about such cases. The final paper presented at the colloquium offered an economic analysis of a contemporary policy problem emanating from this general issue—whether or not to require holders of intellectual property to offer licenses. As Richard Gilbert and Carl Shapiro (14) make clear, the effects of compulsory licensing on economic efficiency are ambiguous—for any kind of capital. They show that an obligation to offer licenses does not necessarily increase economic welfare even in the short run. Moreover, as is well recognized, obligations to deal can have profound adverse consequences for investment and for the creation of intellectual property in the long run. Equal access (compulsory licensing in the case of intellectual property) is an efficient remedy only if the benefits of equal access outweigh the regulatory costs and the long run disincentives for investment and innovation. This is a high threshold, particularly in the case of intellectual property.

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