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The Contribution of Science and Technology to Production

James Adams*

Economists have long recognized that knowledge is a factor of production, and even the most important factor, given its role in labor quality and the design of capital goods. Still, it is one thing to assert a general proposition and quite another to provide confirmation of it in detail. My research is part of a larger initiative at NBER that seeks to provide this information. In essence, the work is a search for tangible evidence of flows of knowledge, specifically scientific and technical knowledge, followed by an examination of their effects on firms and other institutions. Of course private incentives, internal organization, public policy, and legal structure all affect the use of science and technology by firms, universities, and federal laboratories. Thus, broader aspects of modern economies and of modern economics govern the role of knowledge in production. These provide many opportunities for research.

The basic idea of the research is to begin by specifying a vector of stocks of past knowledge flows in the production function. The production function may specify outputs of final or intermediate goods or it may specify increments of new knowledge, such

as industrial inventions or discoveries in basic science. From this root idea there flow a number of subsidiary ideas. One is the reshaping of goods production and the redirection of Research and Development (R and D) that result from the accumulation of knowledge. A second is the distinction between knowledge that is internal to an organization, and outside knowledge, or knowledge spillovers. A third theme is the importance of limitations on flows of outside knowledge or knowledge spillovers that are imposed by absorptive capacity, human and institutional constraints, and the intrinsic relevance of the information. A fourth theme is the comparable importance of basic and often academic science for production, besides that of industrial R and D. Finally, the research recognizes the role that contract design and public policy play in deliberate knowledge transfer between firms and outside R and D performers. These in turn influence the limits of the firm in R and D. In pursuing each of these themes, the design, collection, and assembly of new and high quality economic data forms a critical part of the work.

Characterizing the Contribution of Knowledge

Using data on plants owned by chemical firms that span manufacturing, I have found that firm R and D in the same product area as the plant is

biased towards skilled labor, so that the skill bias of firm R and D is localized in technology space.¹ In addition, firm and industry R and D shift investment in plant capital towards equipment capital. This link should not be overlooked because equipment turns out to be skill-biased. Thus the skill bias of R and D takes place through two distinct channels, a direct one that operates through the small part of R and D that is targeted on the plant, and an indirect and potentially much larger one that operates through the accumulation of equipment capital.

The accumulation of outside knowledge, or knowledge spillovers, could alter the rate and direction of industrial R and D. Using survey data from industrial R and D laboratories as well as historical case studies, I find that outside knowledge shifts R and D effort towards learning about external research and away from internal research.² Similarly, in cross-equation tests I find that university R and D increases learning expenditures targeted on academia, and industrial R and D increases learning expenditures devoted to industry, but not conversely. These results are observationally consistent with the view that outside opportunities alter the composition of industrial R and D, presumably in more profitable directions, and are consistent with the historical case studies.

In all of this research, where the

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data allow a comparison I find statistically significant effects of university science as well as industrial R and D on industrial R and D and industrial patents.³ Thus basic science as well as applied research and development are important to industrial research.

Another set of findings concerns limits on the influence of outside knowledge on R and D performing firms. In work with Adam Jaffe, I find that the effect of firm R and D on plant productivity is amortized by geographic and technological distance. We also find that the number of plants in a firm and industry dilute the impact on productivity of firm R and D and of industry R and D spillovers.⁴ These results suggest restrictions that may apply to economy-wide returns from spillovers. In other work, I find that knowledge spillovers from universities are more localized than spillovers from other firms.⁵ This finding is curious because published findings should not be localized. The puzzle is explained by the industry-university cooperative movement, which encourages firms to work with local universities. The universities are subject to incentives that allow firms to make use of their capabilities and to gain access to the wider world of scientific research. The same is not true of access to proprietary knowledge in other firms.

Channels of Knowledge Flow

In work with J. Roger Clemmons and Paula Stephan that uses data on scientific publications, a counterpart to industrial patents, I also find that technological distance and other factors limit knowledge flows among universities.⁶ In this case we explore a citation channel of knowledge flow that is conditional on reading and afterwards contributing to the science literature. The size of the channel is summed up by the citation probability. This equals actual

citations divided by potential citations within cells that are classified by citing and cited fields and years. We estimate citation functions using the citation probability as the dependent variable, where field and year effects are the independent variables.⁷ Assuming that citations represent scientific influence of papers cited, this probability is equivalent to a utilization rate of cited literature by an average citing paper. Thus, our finding that the citation probability is 10 to 100 times greater within fields than between fields can be read to imply that field boundaries amount to technological barriers, in part because of decreased relevance. The fact that cross-field citation parameters resulting from the estimation are statistically significant in less than one fourth of the possible cases only serves to reinforce this conclusion. In the same paper we find within fields that citation probabilities are greater from lesser universities to top universities than conversely, and we find that citations to peer institutions increase with rank. These results suggest that scientific influence increases with quality of university departments, which levels the capabilities of diverse institutions, but that reinforcing effects of quality among peer institutions may instead sustain differences in the capabilities of institutions.

In assessing the significance of the citation channel it is important to consider alternative channels of knowledge flow. This is despite the fact that in the literature of industrial R and D, one key channel of knowledge flow is found to be the scientific literature. The citation channel can be thought of as disembodied and informal, in that it does not require meetings or formal knowledge-sharing agreements, but it is not all-inclusive.⁸ In recent research with J. Roger Clemmons, Grant Black, and Paula Stephan, which uses the same data on publications as the citation study, I have explored an alternative

channel of collaboration in science.⁹ As an alternative to citation, collaboration is undoubtedly more costly and more time-intensive but it offers the chance to acquire tacit knowledge that would not be available otherwise.

The paper describes trends and cross-sectional patterns in scientific teams measured by authors per paper, and in institutional collaboration, measured by the location of team members in separate institutions. The data are steeply trended. Team size increases by 50 percent over the sample period. However, counts of institutions per paper increase by 60 percent. Counts of foreign institutions, while comparatively rare, increase by five-fold. We conclude that team workers in science are becoming more geographically and even internationally dispersed. This trend accelerates around the start of the 1990s, suggesting a decline in costs of collaboration. Our hypothesis is that the deployment of NSFNET and its connection to networks in Europe and Asia in the late 1980s are responsible for this change. The hypothesis is not unreasonable, given research and journal publication lags.

In addition the paper explores reasons for teams and institutional collaborations. We find that more highly ranked departments, departments whose scientists have earned prestigious awards, departments with larger stocks of federal R and D, and departments in private universities are more likely to form large teams and to engage in institutional collaboration. In the case of firms and foreign institutions especially, we find that placement of graduate students significantly increases collaboration. Finally, the evidence suggests that scientific output and influence increase with team size and institutional collaboration. Since these factors imply an increase in the division of labor, the results suggest that scientific productivity increases with the scientific division of labor.¹⁰

Limits of the Firm in R and D

Consistent with the literature of Property Rights Economics, contractual design and public policy clearly influence the extent to which firms turn to outside partners for complementary R and D assets and the extent to which they benefit from knowledge transfer.¹¹ In papers that use the data on R and D laboratories alluded to in earlier sections of this article, I have explored this aspect of the practice of industrial R and D.

In work with Eric Chiang and Jeffrey Jensen, I find that Cooperative Research and Development Agreements (CRADAs) comprise the main channel by which federal laboratories increase patents as well as firm R and D.¹² The CRADA effect survives controls for simultaneous equation bias, it survives inclusion of alternative effects of federal laboratories on firms, and it is consistent across patents and R and D expenditure in industrial laboratories. While subject to justifiable skepticism about the usefulness of incentives in this setting, the results suggest that CRADAs may be beneficial precisely because of the mutual effort that they require of firms and government laboratories. In another paper with Chiang and Katara Starkey, I have found that Industry-University Cooperative Research Centers (IUCRCs) also contribute to research productivity of industrial laboratories.¹³ Their effect entails the participation of university researchers in consulting, collaboration and placement with firms. Both CRADAs and IUCRCs are incentive-based policy initiatives put in place around 1980 whose aim was to promote knowledge transfer from the public sector to private industry. The evidence contained in the two papers suggests that they may have had an effect. Finally, in a third paper with Mircea Marcu I explore the behavior of R and

D sourcing in industrial laboratories.¹⁴ In this paper we find that sourcing appears to be driven by sentiments towards Research Joint Ventures (RJVs), the option to purchase and acquire, and research with federal laboratories. When we turn to the effects of sourcing, the evidence suggests that the primary motive is that of cost-saving. This contrasts with RJVs, which contribute to new products, and with internal research, which contributes to both patents and new products. All of this suggests that deliberately shared R and D comes in different varieties designed to meet different objectives of firms.

Ongoing Research

Along with coworkers, I continue to study the role of science and technology in production. At present we are engaged in a study of the factors that determine the speed of diffusion of scientific research across sectors and fields of science, including a comparison of the speed of diffusion of science with that of patented technology. We are also engaged in studies of the determinants of industrial scientific discovery, of the relationships between firm patents and stock market value, and scientific research both inside and outside the firm. I continue to pursue longstanding interests in research contributions of the university system.¹⁵ This system is not only a current hotbed of ideas, but the health of the system going forward may prove critical to the United States and other economies. In conclusion, I am confident that the study of the contributions of science and technology to the economy will provide grist for the economists' mill for years and even decades to come.

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Foreign Direct Investment Behavior of Multinational Corporations

Bruce A. Blonigen*

There is increasing recognition that understanding the forces of economic globalization requires looking first at foreign direct investment (FDI) by multinational corporations (MNCs): that is, when a firm based in one country locates or acquires production facilities in other countries. While real world GDP grew at a 2.5 percent annual rate and real world exports grew by 5.6 percent annually from 1986 through 1999, United Nations data show that real world FDI inflows grew by 17.7 percent over this same period! Additionally, MNCs mediate most world trade flows. For example, Bernard, Jensen, and Schott find that 90 percent of U.S. exports and imports flow through a U.S. MNC, with rough-

ly 50 percent of U.S. trade flows occurring between affiliates of the same MNC, or what is termed “intra-firm trade”.¹

Despite the obvious importance of FDI and MNCs in the world economy, research on the factors that determine FDI patterns and the impact of MNCs on parent and host countries is in its early stages. The most important general questions are: what factors determine where FDI occurs, and what impacts do those MNC operations have on the parent and host economies? As I discuss in a recent survey of the empirical literature addressing the first question — the determinants of FDI decisions — the answers are not straightforward.² In particular, the literature has shown that we cannot simply conclude that factors such as exchange rates or tax policies have an unambiguous general impact on FDI patterns. Instead, meaningful insights come from developing

hypotheses about, say, when a factor should matter for FDI, or even just a particular form of FDI, and then finding creative ways to test these hypotheses in the data.

Exchange Rates and FDI

One good example of this is the effect of exchange rate movements on FDI. For years, the conventional theory was to compare FDI to bonds, for which exchange rate movements do not affect the investment decision. A depreciation of the currency in the host country reduces the amount of foreign currency needed to purchase the asset, but it also reduces the nominal return one receives in the foreign currency. Thus, the rate of return for the foreign investor does not change. Empirical studies of FDI seemed to confirm this, often finding insignificant effects of exchange rates. In contradiction to this, the popular press

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