Real Effects of Academic Research: Comment

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A fundamental issue which remains unresolved in the economics of technology is the identification and measurement of R&D spillovers, or the extent to which a firm is able to exploit economically the investment in R&D made by another company. In a 1989 paper in this *Review*, Adam Jaffe extended his pathbreaking 1986 study measuring the total R&D "pool" available for spillovers to identify the contribution of spillovers from university research to "commercial innovation" (Jaffe, 1989 p. 957). Jaffe's findings were the first to identify the extent to which university research spills over into the generation of inventions and innovations by private firms.

To measure technological change, Jaffe relies upon the number of patented inventions registered at the U.S. patent office, which he argues is "a proxy for new economically useful knowledge" (Jaffe, 1989 p. 958). In order to relate the response of this measure to R&D spillovers from universities, Jaffe modifies the "knowledge production function" introduced by Zvi Griliches (1979) for two inputs:

$$(1)\quad \log(P_{ik}) = \beta_{1k}\log(I_{ik}) + \beta_{2k}\log(U_{ik}) + \beta_{3k}[\log(U_{ik})\times\log(C_{ik})] + e_{ik}$$

where P is number of patented inventions, I represents the private corporate expenditures on R&D, U represents the research expenditures undertaken at universities, C is a measure of the geographic coincidence of university and corporate research, and e represents stochastic disturbance. The unit of observation is at the level of the state, i, and what Jaffe terms the "technological area," or the industrial sector, k. In addition, Jaffe includes the state population (Pop_{ik}) in his estimating equation in order to control for the size differential across the geographic units of observation.

Jaffe's (1989) statistical results provide evidence that corporate patent activity responds positively to commercial spillovers from university research. Not only does patent activity increase in the presence of high private corporate expenditures on R&D, but also as a result of research expenditures undertaken by universities within the state. The results concerning the role of geographic proximity in spillovers from university research are clouded, however, by the lack of evidence that geographic proximity *within the state* matters as well. According to Jaffe (1989 p. 968), "There is only weak evidence that spillovers are facilitated by geographic coincidence of universities and research labs within the state."

While Jaffe's (1989) model is constructed to identify the contribution of university research to generating "new economically useful knowledge" (p. 958), F. M. Scherer (1983), Edwin Mansfield (1984), and Griliches (1990) have all warned that measuring the number of patented inventions is not the equivalent of a direct measure of innovative output. For example, Ariel Pakes and Griliches (1980 p. 378) argued that "patents are a flawed measure (of innovative output); particularly since not all new innovations are patented and since patents differ greatly in their economic impact." In addressing the question "Patents as indicators of what?" Griliches (1990 p. 1669) concludes that "Ideally, we might hope that patent statistics would provide a measure of the (innovative) output.... The reality, however, is very far from it. The dream of

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TABLE 1—COMPARISON AMONG PATENT, UNIVERSITY RESEARCH, AND INNOVATION MEASURES

Measure	Mean	Standard deviation	Minimum	Maximum	Number of innovations yielded per unit of input
University research expenditures (millions of dollars)	98.8	144.0	12.0	710.4	1.3
Drugs	28.5	35.3	2.2	142.3	3.3
Chemicals	5.7	9.7	0.5	46.7	1.9
Electronics	21.0	49.2	0.3	239.0	2.8
Mechanical	12.7	25.6	0.9	126.1	3.5
Corporate patents	879.4	975.7	39.0	3,230.0	0.148
Drugs	71.7	99.4	1.0	418.0	0.132
Chemicals	201.2	249.0	6.0	908.0	0.054
Electronics	225.0	295.3	7.0	1,142.0	0.263
Mechanical	300.8	319.9	20.0	993.0	0.146
Innovations	130.1	206.4	4.0	974.0	—
Drugs	9.5	16.0	0.0	75.0	—
Chemicals	10.9	17.7	0.0	80.0	—
Electronics	59.2	100.5	1.0	475.0	—
Mechanical	44.5	79.7	0.0	416.0	—

Notes: All dollar figures are millions of 1972 dollars. Data on university research funds by state are available for the four broad technical areas of drugs and medical technology; chemicals; electronics, optics and nuclear technology; and mechanical arts. These groups, along with the data for university research expenditures and corporate patents, are from Jaffe (1989).

getting hold of an output indicator of inventive activity is one of the strong motivating forces for economic research in this area."

The use of patent counts to identify the effect of spillovers from university research might be expected to be particularly sensitive to what Scherer (1983 p. 108) has termed the "propensity to patent." Just as Albert N. Link and John Rees (1990) found that small new entrepreneurial firms tend to benefit more than their established larger counterparts from university research spillovers, Griliches (1990) and Scherer (1983) both concluded that the propensity to patent does not appear to be invariant across a wide range of firm sizes.

A different and more direct measure of innovative output was introduced in Acs and Audretsch (1987), where the measure of innovative activity is the number of innovations recorded in 1982 by the U.S. Small Business Administration from the leading technology, engineering, and trade journals in each manufacturing industry. A detailed description and analysis of the data can be found in Acs and Audretsch (1988, 1990). Because each innovation was recorded subsequent to its introduction in the market, the resulting data base provides a more direct measure of innovative activity than do patent counts. That is, the innovation data base includes inventions that were not patented but were ultimately introduced into the market and excludes inventions that were patented but never proved to be economically viable enough to appear in the market.

The extent to which university-research spillovers serve as a catalyst for private-corporation innovative activity can be identified by using the direct measure of innovative activity in the model introduced by Jaffe in equation (1). This enables a direct comparison of the influence of university R&D spillovers on innovation with the results that Jaffe reported using the patent measure.

Table 1 compares the mean measures of university research expenditures and corporate patents for all 29 states used by Jaffe with the mean number of innovations per state. It should be noted that, while Jaffe's university-research and patent measures are

TABLE 2—A COMPARISON BETWEEN REGRESSION RESULTS USING JAFFE'S PATENT MEASURE AND THE INNOVATION MEASURE

	All areas		Electronics		Mechanical arts	
Independent variable	Patents (i)	Innovations (ii)	Patents (iii)	Innovations (iv)	Patents (v)	Innovations (vi)
$\text{Log}(I_i)$	0.668 (8.919)	0.428 (4.653)	0.631 (5.517)	0.268 (1.370)	0.643 (6.712)	0.649 (4.720)
$\text{Log}(U_{ik})$	0.241 (3.650)	0.431 (6.024)	0.265 (2.598)	0.520 (2.977)	0.059 (0.490)	0.329 (1.999)
$\text{Log}(U_{ik}) \times \text{Log}(C_i)$	0.020 (0.244)	0.173 (1.914)	.063 (0.531)	0.272 (1.331)	−0.046 (−0.406)	0.224 (1.436)
$\text{Log}(\text{Pop}_i)$	0.159 (1.297)	−0.072 (−1.287)	0.076 (1.263)	0.076 (0.742)	0.177 (3.767)	−0.143 (−2.051)
$\hat{S}$:	0.444	0.451	0.203	0.348	0.181	0.247
R^2:	0.959	0.902	0.992	0.951	0.994	0.974
N:	145	125	29	29	27	27

Note: Numbers in parentheses are t statistics.

based upon an eight-year sample (1972–1977, 1979, and 1981), the innovation measure is based upon a single year, 1982. Both the number of innovations per university research dollar (millions) and the number of innovations per patent vary considerably across the four industrial sectors included in Jaffe's sample. The number of innovations yielded per dollar of university research is apparently highest in the mechanical industries and lowest in the chemical industries. As in Acs and Audretsch (1988), the amount of innovative activity yielded per patent is highest in the electronics sector and lowest in chemicals.

While Jaffe (1989) was able to pool the different years across each state observation in estimating the production function for patented inventions, this is not possible using the innovation measure, due to data constraints. Thus, it is important first to establish that Jaffe's (1989) results do not differ greatly from estimates for a single year. This is done in equation (i) of Table 2, where Jaffe's (1989) patent measure for 1981 is used in the same estimating equation found in his table 4B, based on all (technological) areas. All of the data sources and a detailed description of the data and measures can be found in Jaffe (1989). Using the patent measure for a single year yields virtually identical results to those based on the pooled estimation reported in Jaffe's article. That is, both private corporate expenditures on R&D and expenditures by universities on research are found to exert a positive and significant influence on patent activity. Similarly, both the geographic coincidence effect and the population variables have positive coefficients. The estimated coefficient of 0.668 for $\log(I_i)$ in equation (i) of Table 2 is remarkably close to the coefficient of 0.713 estimated by Jaffe using the pooled sample. We conclude that using a single estimation year does not greatly alter the results obtained by Jaffe (1989) using several years to measure the extent of patent activity.

The number of 1982 innovations is substituted for the number of registered patents as the dependent variable in equation (ii) of Table 2, which estimates the impact of spillovers on all technological areas combined.[1] There are two important differences that emerge when the innovation measure is used instead of the patent measure. First, the elasticity of $\log(U_{ik})$ almost doubles,

[1]The sample sizes differ between the patent and innovation estimations because the observations with the value of zero had to be omitted.

from 0.241 when the patent measure is used in equation (i) to 0.431 when the innovation measure is used in equation (ii). That is, the impact of university spillovers is apparently greater on innovations than on patented inventions. Second, the impact of the geographic coincidence effect also is much greater on innovation activity than on patents, suggesting that spillovers from geographic proximity may be more important than Jaffe (1989) concluded.

Jaffe (1989) also estimated knowledge-production functions for what he calls specific technical areas.[2] Equations (iii) and (iv) in Table 2 compare the estimations based on the patent and innovation measures for the electronics area, and equations (v) and (vi) compare the estimations based on the two measures for the mechanical-arts area. The patent and innovation measures yield somewhat different results. For the electronics area, expenditures on R&D by private corporations are found to have a positive and significant influence on patents but not on innovative activity. By contrast, in the mechanical-arts area, both patent and innovative activity respond positively to private R&D spending. This may reflect the difference in what Sidney G. Winter (1984) termed the "technological regime" between the electronics and mechanical-arts areas. That is, under the "entrepreneurial regime," the underlying technological information required to produce an innovation is more likely to come from basic research and from outside of the industry. By contrast, under the "routinized regime," an innovation is more likely to result from technological information from an R&D laboratory within the industry. Since the electronics area more closely corresponds to Winter's notion of the entrepreneurial regime, while the mechanical-arts area more closely resembles the routinized regime, it is not surprising that company R&D expenditures are relatively less important and university expenditures on research are relatively more important in producing innovations in electronics but not in the mechanical arts. Further, as Mansfield (1984 p. 462) noted, innovations may have a particular tendency not to result from patented inventions in industries such as electronics: "The value and cost of individual patents vary enormously within and across industries.... Many inventions are not patented. And in some industries, like electronics, there is considerable speculation that the patent system is being bypassed to a greater extent than in the past."

Substitution of the direct measure of innovative activity for the patent measure in the knowledge-production function generally strengthens Jaffe's (1989) arguments and reinforces his findings. Most importantly, use of the innovation data provides even greater support than was found by Jaffe: as he predicted, spillovers are facilitated by the geographic coincidence of universities and research labs within the state. In addition, there is at least some evidence that, because the patent and innovation measures capture different aspects of the process of technological change, results for specific sectors may be, at least to some extent, influenced by the technological regime. Thus, we find that the importance of university spillovers relative to private-company R&D spending is considerably greater in the electronics sector when the direct measure of innovative activity is substituted for the patent measure.

[2]The technological areas are based on a technological classification and not on an industrial classification. For further explanation see appendix A in Jaffe (1989).

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