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Jeffrey I. Bernstein

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M. Ishaq Nadiri

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C. V. STARR CENTER
FOR APPLIED ECONOMICS

NEW YORK UNIVERSITY
FACULTY OF ARTS AND SCIENCE
DEPARTMENT OF ECONOMICS
WASHINGTON SQUARE
NEW YORK, N.Y. 10003

INTERINDUSTRY R&D SPILLOVERS, RATES OF RETURN, AND PRODUCTION IN HIGH–TECH INDUSTRIES

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Jeffrey I. Bernstein[*]
M. Ishaq Nadiri[**]

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[*] Department of Economics, Carleton University, Ottawa, Canada
[**] Department of Economics, New York University, New York, USA

Abstract

This paper presents estimates of the productivity and factor bias effects of interindustry R&D spillovers for five high–tech industries. Each industry is distinguished as a separate spillover source. The industries are each affected by R&D spillovers and are themselves spillover sources. Thus a spillover network between the industries is estimated.

Private and social rates of return to R&D capital are calculated. The private rates of return are generally greater than the returns to physical capital. In addition, the social rates of return are greater than the private rates. The results show that there are significant differences between industries as to their importance as sources of R&D spillovers.

1. Introduction*

Firms undertaking R&D investment are unable to completely appropriate all of the benefits from their R&D projects. Schumpeter [1950], Schmookler [1966], Rosenberg [1974], Griliches [1979] and Spence [1984] have pointed out that the degree of appropriability can influence both the causes and consequences of R&D investment. R&D investment by a firm reduces its own production cost and, as a result of spillovers, costs of other firms are also reduced. Moreover, as noted by Evenson and Kislev [1973], in order for firms in the economy to benefit from R&D spillovers, these firms must themselves invest in R&D.

R&D spillovers reduce production cost and affect the structure of production of the spillover recipients. Levin and Reiss [1984], with a cross section sample of manufacturing firms, estimated that a one per cent increase in the R&D spillover caused average cost to decline by .05 per cent. Jaffe [1986], also with a cross section sample of manufacturing firms, estimated that when the spillover increased by one per cent profit increased by .3 per cent. Bernstein and Nadiri [1987] focused on the intraindustry spillovers of four manufacturing industries. Generally, average cost declined by .2 per cent in response to a one per cent growth in R&D spillovers. Bernstein and Nadiri also estimated that production structures were affected by intra–industry spillovers. Reductions in factor demand occurred as a result of increases in R&D spillovers.

A common feature of the previous empirical studies was the measurement of R&D spillovers as a single variable. This meant that individual firms or industrial sources of spillovers could not be distinguished as to their relative significance in influencing production cost and factor demand. The first purpose of this paper is to investigate the effects of interindustry R&D spillovers in five high–tech industries where each industry is treated as a separate spillover source. This treatment of R&D spillovers allows us to estimate a matrix characterizing the sources and beneficiaries of each interindustry spillover.

R&D spillovers create a dichotomy between private and social rates of return to R&D capital. The second purpose of this paper is therefore to compute both the social and private rates of return to R&D capital. The private return is endogenous in this model because R&D capital is treated as a quasi–fixed factor. This return is measured as the variable cost reduction in an industry due to its own R&D capital expansion. The social rate of return to an industry's R&D capital consists of the private rate plus the interindustry marginal cost reductions due to the spillovers generated by the industry's R&D capital. Since each industry has the potential to cause distinct spillovers on each of the other industries, the spillover components of the social rates of return are decomposed by externality–receiving industries.

In the next section of the paper the empirical specification of the model is described. In the third and fourth sections the data and estimation results are discussed. The fifth section relates to the estimation of the cost–reduction and factor–biasing effects associated with the interindustry R&D spillovers. Section six contains the estimates of the private and social rates of return, as well as the industrial decomposition of the social returns to R&D capital. Lastly, the results are summarized in the concluding section.

2. Cost, Factor Demand, and Interindustry Spillover

Production cost and factor demands of an industry are influenced by R&D capital accumulated by other industries. The existence of these spillovers and their effects on production processes can be estimated by specifying a variable cost function for each industry,

$$(1) \qquad \ln c_v/w_m = \beta_0 + \beta_\ell \ln \omega_\ell + \beta_p \ln \omega_p + \beta_y \ln y + \beta_i \ln K_r^i + \beta_{\ell p} \ln \omega_\ell \ln \omega_p + \beta_{\ell y} \ln \omega_\ell \ln y + \beta_{\ell i} \ln \omega_\ell \ln K_r^i + \beta_{py} \ln \omega_p \ln y + \beta_{pi} \ln \omega_p \ln K_r^i + \beta_{yi} \ln y \ln K_r^i + (\ln K_r^i + \beta_{\ell s} \ln \omega_\ell + \beta_{ps} \ln \omega_p) \sum_{\substack{j=1 \\ j \neq i}}^{N} \beta_{ij} \ln K_r^j + u_c ,$$

where c_v is variable cost, w_m is the factor price of materials: $\omega_\ell = w_\ell / w_m$, where w_ℓ is the wage rate, $\omega_p = w_p / w_m$, where w_p is the rental rate on physical capital, y is output, K_r^i is the industry's own R&D capital and K_r^j is the jth industry's R&D capital, N is the number of industries, and u_c is the error term.

The variable cost function is a generalized Cobb–Douglas or truncated translog, since there are no own or squared second order terms in the function.[1] The function is also nonlinear in the parameters because of the R&D spillovers. Each industry's R&D capital generates a distinct influence on the variable cost and factor demands of every other industry. In previous empirical work the spillover was represented by the sum or weighted sum of R&D expenditures or R&D capital (see Levin and Reiss [1984], Jaffe [1986], Bernstein and Nadiri [1987]). In this model there are N−1 spillovers for each industry and the sum of these spillovers or the pool of knowledge is given by $\sum_{\substack{j=1 \\ j \neq i}}^{N} \beta_{ij} \ln K_r^j$. The pool of knowledge is determined by the estimation of the model. Since each spillover interacts with the industry's own R&D capital, this implies that in order for an industry to benefit from R&D spillovers, it must be undertaking R&D projects itself.[2]

The existence of the parameters $\beta_{\ell s}$ and β_{ps} enables the spillover to affect the labor, physical capital, and materials cost shares. We can see this by using Shephard's Lemma,

$$(2) \qquad s_\ell = \beta_\ell + \beta_{\ell p} \ln \omega_p + \beta_{\ell y} \ln y + \beta_{\ell i} \ln K_r^i + \beta_{\ell s} \sum_{\substack{j=1 \\ j \neq i}}^{N} \beta_{ij} \ln K_r^j + u_\ell .$$

$$(3) \qquad s_p = \beta_p + \beta_{\ell p} \ln \omega_\ell + \beta_{py} \ln y + \beta_{pi} \ln K_r^i + \beta_{ps} \sum_{\substack{j=1 \\ j \neq i}}^{N} \beta_{ij} \ln K_r^j + u_p ,$$

where $s_\ell = w_\ell v_\ell / c_v$ is the labor variable cost share, v_ℓ is the labor demand, $s_p = w_p v_p / c_v$ is the physical capital variable cost share, v_p is the physical capital demand, the materials cost share is $s_m = 1 - s_\ell - s_p$ by definition and u_ℓ and u_p are the error terms. The two parameters $\beta_{\ell s}$ and β_{ps} create the nonlinearity in the model, and in conjunction with the other spillover parameters (β_{ij}'s) determine the factor biases associated with the R&D spillovers.

The error terms $u^T = [u_c, u_\ell, u_p]$ for each industry are assumed to be jointly normally distributed, with zero expected value, $E(u) = 0$, and with positive definite symmetric covariance matrix, $E(u\ u^T) = \Omega$. The errors are assumed to be optimizing errors such that observed shares are normally symmetrically distributed about the optimal shares and the variable cost function.

The equilibrium characterized by equations (1), (2) and (3) is short–run. R&D capital is assumed to be a quasi–fixed factor because of the development costs which generate lags in the completion of R&D projects. Thus short–run cost is not minimized with respect to R&D capital.

The variable cost or productivity effects associated with each of the R&D spillovers are

$$(4) \qquad \partial \ln c_v/\partial \ln K_r^j \;=\; \beta_{ij}(\ln K_r^i + \beta_{\ell s} \ln \omega_\ell + \beta_{ps} \ln \omega_p), \quad j \neq i, \; j=1,\ldots,5.$$

The productivity effects are not constant but depend on the R&D capital of the spillover–receiving industry, along with the relative factor prices. The parameter β_{ij} defines the distinct effect that the R&D capital from industry j exerts on the ith receiving industry.

The parameters $\beta_{\ell s}$, β_{ps} transform the industry–specific productivity effects of the spillovers into factor bias effects. A spillover effect is factor using, reducing or neutral, depending on the sign of the right side of (5),

$$(5) \qquad \partial s_k/\partial \ln K_r^j \;=\; \beta_{ks}\, \beta_{ij} \quad k = \ell,p,m, \quad i \neq j, \quad j = 1,\ldots,5 \;,$$

where $\beta_{ms} = -(\beta_{\ell s} + \beta_{ps})$. If a variable factor cost share increases (decreases, or does not change), then the interindustry spillover is variable factor–using (reducing, or neutral). The effect on each variable factor demand consists of the sum of the productivity and factor bias effects

$$(6) \qquad \partial \ln v_k/\partial \ln K_r^j \;=\; \partial \ln c_v/\partial \ln K_r^j + \beta_{ks}\, \beta_{ij}/s_k \qquad k = \ell,p,m, \quad i \neq j, \quad j=1,\ldots,5.$$

As for the bias effects, the variable factor demand effects can be positive, negative or zero. It is possible for the variable factors to be complementary, substitutable or independent of each of the interindustry R&D spillovers.

3. The Data

Five high-technology industries were analyzed in this paper: chemical products (SIC 28), nonelectrical machinery (SIC 35), electrical products (SIC 36), transportation equipment (SIC 37), and scientific instruments (SIC 38). The sample period was 1958 to 1981 and most of the data for these industries were obtained from published sources of the Bureau of Economic Analysis (BEA).

Output (y) was measured as gross output in 1982 dollars. Labor (v_ℓ) was measured as total manhours. It was obtained by multiplying production manhours by the ratio of total number of workers to the number of production workers. It was assumed that the number of hours worked by non-production workers equalled the number of hours worked by production workers. The wage rate (w_ℓ) or factor price of labor was defined as the ratio of adjusted total payroll to total manhours. Since the BEA data on wages do not contain the supplementary labor to obtain adjusted total payroll, we multiplied total payroll by the ratio of labor compensation to wage and salaries, which were obtained from the National Income and Products Account (NIPA).

The physical capital stock (K_p) was measured as net capital stock. The R&D capital stock (K_r) was constructed by assuming depreciation occurred by declining balance at a rate of 10 per cent. The benchmark year for R&D capital stock was 1957; the benchmark capital stock was obtained by dividing constant dollar R&D expenditures (obtained from the National Science Foundation [NSF]) by the sum of the depreciation rate and the growth rate of physical capital. The latter growth rate was obtained from the regression $\ln v_p(t) = \alpha + \beta t$ which was estimated over the period 1947 to 1956. The R&D deflator used to construct constant dollar R&D expenditures was obtained from Mansfield [1985] for the period 1969 to 1981. For the period 1957 to 1968, the Mansfield deflator was linked to Schankerman's [1979] R&D deflator which extends from 1957 to 1975. The growth rate of Schankerman's deflator was computed and linked to the Mansfield index in 1969. For the years 1969–1975 when the two indexes overlapped, they were very similar.

The after–tax rental rates or factor prices of physical and R&D capital were derived from the formula

$$w_p = p_p(\rho + \delta_p)(1 - \eta_\rho - u_c z)$$

where p_p is the physical capital deflator defined implicitly as the ratio of current to constant dollar physical investment expenditures; ρ is the interest rate which was taken to be the rate on Treasury notes of 10 year maturity (obtained from the Citibase data set); δ_p is the physical capital depreciation rate which was defined as constant dollar replacement investment divided by the net capital stock. The net capital stock series for each industry was calculated by the perpetual inventory method, u_c is the statutory corporate income tax rate; η_ρ is the effective investment tax credit rate on physical capital investment which was obtained from Jorgenson and Sullivan [1981]. For the period 1958 to 1980 the rate was the average of the effective rates calculated for different types of physical capital, and for the year 1981 η_ρ was assumed to be 8 percent, which was the average of the rates for the different classes of physical capital (see Hulten and Robertson [1982]); z is the present value of capital consumption allowances (CCA), $z = \alpha(1-\theta\ \eta_\rho)/(\rho+\alpha)$, where α is the CCA rate which was measured by dividing capital consumption allowances (obtained from the Quarterly Financial Report [QFR]) by the book value of fixed assets (also form the QFR), $\theta = .5$ in 1962 and 1963 under the Long Amendment and $\theta = 0$ otherwise. The rental rate on R&D capital was defined as

$$w_r = p_r(\rho + \delta_r)(1 - u_c - \eta_r)$$

where p_r is the R&D deflator; $\delta_r = .1$; η_r is the incremental R&D tax credit which was introduced in 1981 and defined as 25 percent of the excess of current R&D expenditures over the average of the previous three years.

The price of materials (w_m) was obtained by first defining the nominal value of materials as the difference between the nominal value of gross output and the nominal value added. Next real value added was derived by deflating nominal value added by the value added deflator (from NIPA). Real materials was defined as gross output minus real value added. The materials price was then implicitly calculated as the ratio of nominal materials to real materials. Since we defined the rental rates in after tax terms, both the factor prices of labor and materials were multiplied by one minus the corporate income tax rate.

In order to avoid double counting with respect to the R&D capital input, R&D labor costs (i.e., the wages and salaries of scientists and engineers and supporting personnel) were subtracted from labor cost. Adjusted labor cost was then deflated by the wage rate to get the labor input corrected for R&D. There was no correction made to physical capital since R&D expenditures only include current and not capital expenditures.

The 1981 values of the major variables for each of the industries used in the model are presented in Table 1. From this table the input–output ratios are quite different across industries with the R&D capital to output ratio ranging from a low .22 for nonelectrical machinery to a high of .72 for transportation equipment. The last column in this table shows the percent of each industry's R&D expenditures out of total R&D expenditures by all industries. By adding the last column we find that the industries analyzed in this paper account for almost 85 percent of R&D expenditures in 1984.

Table 1

Industry Variables

Industry	Var. Cost ($\times 10^6$ current $)	Output ($\times 10^6$ 1972 $)	Labor ($\times 10^6$ manhrs.)	Phys. Cap. ($\times 10^6$ 1972 $)	R&D Cap. ($\times 10^6$ 1972 $)	R&D Exp/ Total R&D Exp. (% in 1984)
	Variables (1981 values)					
Chemical Products	84540	70185	1561	68185	18579	11.3
Non-Electrical Machinery	88766	93622	4399	41592	21132	13.5
Electrical Products	60100	78170	3324	29412	40450	21.2
Transportation Equipment	100609	95827	2954	47571	69225	31.2
Scientific Instruments	17374	26048	1022	8419	8678	6.9

4. Estimation Results

Equations (1), (2) and (3) were estimated for each of the five industries. The sample period for the estimation was 1958 to 1981. The Full Information Maximum Likelihood estimator was used and the convergence criteria was .001. Each industry's own R&D capital and each of the spillovers were lagged one period in the estimation to make sure all R&D capital stocks were exogenous in the model.[3]

The estimation results are presented in Table 2. For each of the industries the standard errors of the estimates of each of the equations are small. Various parameters in the variable cost function were constrained to be zero in order to make sure the regularity conditions for variable cost minimization were satisfied. The variable cost function for each industry was increasing in output, increasing concave in the variable factor prices, decreasing and convex in the industry's own R&D capital. These regularity conditions were satisfied at each point in the sample.[4] The estimation of the model for each industry proceeded in the following manner. First, each spillover source industry was included in the model individually, next pairs of spillover source industries were included, then groups of three and lastly all four spillover source industries were included in the estimation. The criteria for accepting an industry as a spillover source were the satisfaction of the regularity conditions pertaining to the variable cost function and the statistical significance of the parameters. The estimation results were quite stable in the sense that when a specific spillover source industry generated by itself either a statistically insignificant effect or caused the violation of regularity conditions, these problems also occurred when the specific industry was grouped with the other source–industries. Thus the empirical results were robust, both in an economic and statistical sense, as to the acceptance of a particular industry as a source of spillover for each receiving industry.

Table 2

Estimation Results

Parameter	Industry Chemical Products (standard errors in parentheses)	Electrical Products
β_0	5.3948 (0.9342)	0.8652 (0.5159)
β_ℓ	0.7686 (0.05759)	0.6319 (0.09935)
β_p	-0.2697 (0.09929)	-0.4685 (0.1149)
β_i	-1.2114 (0.1788)	-0.07787 (0.08277)
$\beta_{\ell p}$	0.05290 (0.007683)	0.02679 (0.01346)
$\beta_{\ell i}$	0.08719 (0.01741)	-0.01970 (0.00912)
β_{pi}	-0.2107 (0.03470)	0.04600 (0.01146)
$\beta_{\ell s}$	-2.2688 (0.2461)	0.0* (0.0)
β_{ps}	4.0800 (0.3547)	0.0* (0.0)
β_{i38}	0.06638 (0.00970)	-0.01118 (0.00405)
Standard Error of Equation:		
Variable Cost	0.03090	0.04540
Labor Share	0.008571	0.01647
Phys. Cap. Share	0.01738	0.02039
Log of Likelihood Function	199.461	196.908

* Constrained to be zero.

Table 2 (continued)

Estimation Results

Parameter	Industry Non-Electrical Machinery (standard errors in parentheses)
β_0	-5.2195 (0.7530)
β_ℓ	0.6826 (0.0665)
β_p	-0.007169 (0.07406)
β_i	1.1207 (0.1877)
$\beta_{\ell p}$	0.05712 (0.01628)
$\beta_{\ell i}$	-0.1396 (0.01691)
β_{pi}	0.1904 (0.02041)
$\beta_{\ell s}$	-1.6683 (0.2772)
β_{ps}	2.7282 (0.2822)
$\beta_{128}, \beta_{136}, \beta_{137}$	-0.02185 (0.00355)
Standard Error of Equation:	
Variable Cost	0.02297
Labor Share	0.008213
Phys. Cap. Share	0.009600
Log of Likelihood Function	223.233

Table 2 (continued)

Estimation Results

Parameter	Industry	
	Transportation Equip.	Scientific Instruments
	(standard errors in parentheses)	
β_0	-31.6414 (10.8217)	-1.7148 (0.5964
β_y	4.1899 (0.9891)	0.8662 (0.07126)
β_ℓ	0.2974 (0.1205)	0.8261 (0.1313)
β_p	0.6395 (0.1639)	-0.02042 (0.04924)
β_i	2.7094 (0.9811)	0.7500 (0.2011)
$\beta_{\ell y}$	-0.03639 (0.01845)	0.0^{**} (0.0)
$\beta_{\ell p}$	0.08307 (0.01660)	-0.03535 (0.01502)
β_{pi}	0.09498 (0.01859)	-0.09961 (0.02599)
β_{py}	-0.08064 (0.02285)	0.0^{**} (0.0)
β_{pi}	-0.08415 (0.02375)	0.1303 (0.00964)
β_{iy}	-0.2998 (0.09050)	0.0^{**} (0.0)
$\beta_{\ell s}$	-2.9539 (0.7038)	-0.7484 (0.5548)
β_{ps}	5.6743 (0.9591)	1.9105 (0.3713)
β_{i35}	0.02292 (0.00462)	$.NA^*$
$\beta_{i28}, \beta_{i36}, \beta_{i37}$	$.NA^*$	-0.01666 (0.00361)

Table 2 (continued)

Estimation Results

	Industry	
	Transportation Equip.	Scientific Instruments
	(standard errors in parentheses)	
Standard Error of Equation:		
Variable Cost	0.02128	0.03097
Labor Share	0.0073	0.01653
Phys. Cap. Share	0.00986	0.00628
Log of Likelihood Function	225.052	201.989

* NA means not applicable ** Constrained to be zero.

The estimates of the spillover parameters in Table 2 (β_{ij}, $\beta_{\ell s}$, β_{ps}) show that one industry generates R&D spillovers on chemical products, electrical products and transportation equipment, while three industries generate spillovers on scientific instruments and nonelectrical machinery. In the latter case the spillover estimates of the β_{ij} parameters were equal for each industry. We were not able to reject the hypothesis for scientific instruments and nonelectrical machinery that $\beta_{i28} = \beta_{i36} = \beta_{i37}$. The values of the likelihood function were not significantly affected when the parameters were not constrained to be equal in each of the two industries. Moreover, from the standard errors of the estimates of the spillover parameters, it is clear that variable cost and production in each of the industries are affected by interindustry R&D spillovers.

We also tested the hypothesis of long–run equilibrium, by using the test statistic developed by Schankerman and Nadiri [1986]. This test is related to the Hausman [1978] specification test. Long–run equilibrium for an industry is defined by equations (1), (2) and (3) along with the envelope condition

$$(7) \qquad -s_r = \beta_i + \beta_{\ell i} \ln \omega_\ell + \beta_{pi} \ln \omega_p + \beta_{yi} \ln y + \sum_{\substack{j=1 \\ j \neq i}}^{N} \beta_{ij} \ln K_r^i + u_r,$$

where $s_r = w_r v_r / c_v$ is the ratio of R&D capital cost to variable cost. Equation (7) is actually a stochastic version of the envelope condition. For each industry, equation set (1), (2), (3) and (7) was estimated. Let β_c be the parameter vector from equation (1), let β_f be the parameter vector from equation (2) and (3) and let β_r be the parameter vector from equation (7). The cross equation parameter restrictions between equations (1), (2) and (3) are maintained in both the short and long–run equilibria so that $\beta_f \subset \beta_c$. Next partition the parameter vector $\beta_c = (\beta_c^1, \beta_c^2)$ where β_c^1 appears in both equations (1) and (7) and β_c^2 appears in equation (1) but not (7). Hence estimating equation (7) along with (1), (2) and (3) imposes the restriction that $\beta_c^1 = \beta_r$. The test statistic for this set of restrictions is $M = (\tilde{\beta} - \hat{\beta})^T \hat{V}^{-1} (\tilde{\beta} - \hat{\beta}) \approx X^2(q)$, $\tilde{\beta}$ is the consistent estimator of equations (1), (2) and (3), while $\hat{\beta}$ is the consistent estimator of equations (1), (2), (3) and (7). $\hat{V}$ is the consistent estimator of V, with $V = V_s - V_L$, where V_s is the asymptotic covariance matrix from $(\tilde{\beta} - \beta)$ and V_L is the asymptotic covariance matrix from $(\hat{\beta} - \beta)$. The M statistic is asymptotically distributed as a chi–square distribution with q degrees of freedom, where q is the number of parameters in equation (7). The results of our test are that: for chemical products $M = 35.359 > \chi^2_{4,0.005} = 14.860$; for nonelectrical machinery $M = 23.732 > \chi^2_{4,0.005} = 14.860$; for electrical products $M = 43.947 > \chi^2_{4,0.005} = 14.860$; for transportation equipment $M = 23.102 > \chi^2_{5,0.005} = 16.750$; and lastly for scientific instruments $M = 40.870 > \chi^2_{4,0.005} = 14.860$; . Hence for each industry the hypothesis of long–run equilibrium is rejected. R&D capital, besides generating spillovers, was also distinct from the other factors of production because it was not part of short–run cost minimization.

5. The Effects of R&D Spillovers

From the parameter estimates for each industry given in Table 2, we can discuss the effects of R&D spillovers on variable cost, variable factor share and each variable factor demand by using equations (4), (5) and (6). These results are presented in Table 3. First, for the chemical products industry the R&D capital spillover emanated from the scientific instruments industry. Variable cost declined over the sample period as a result of the spillover. A one percent increase in the spillover caused variable cost in this industry to decline by .21 percent in 1961 and by .09 percent in 1981.

The spillover from the scientific instruments industry also affected factor demand in the chemical products industry. The demand for both labor and materials declined in response to the spillover suggesting that these two factors were substitutes for the R&D capital spillover. However, the demand for physical capital increased in response to the spillover. Physical capital was a complement to the spillover. The percentage change in the demand for materials was quite inelastic over the sample. A one percent increase in the spillover caused materials to decrease by .27 percent in 1981. The spillover effect on labor demand was slightly inelastic or unit elastic with a 1981 elasticity of 1.09 percent. There was a strong complementarity between physical capital and the spillover as there was an elastic effect of 3.9 percent in 1961 and 1.42 percent in 1981.

The factor cost shares were affected by the spillover in the chemical products industry since $\beta_{\ell s}$ and β_{ps} along with β_{ij} were statistically different from zero. Hence there were factor biases associated with the spillover. The evidence shows that the spillover was labor and material-reducing, while physical capital-using.[5]

Table 3

Spillover Effects on Variable Cost and Factor Demand

Receiving Ind.	Source Ind.	Year	Var.Cost	Labor	Phys.Cap.	Materials
Chemical Products	Scientific Inst.	1961	-0.2082	-0.8251	3.9184	-0.3824
		1971	-0.1328	-0.7974	2.5055	-0.3120
		1981	-0.0893	-1.0879	1.4197	-0.2688
Non-Elect. Machinery	Chemical Prods.	1961	-0.0293	0.0591	-1.7399	0.0126
	Elect. Prods.	1971	-0.0357	0.0564	-1.9686	0.0005
	Transp. Equip.	1981	-0.0584	0.0469	-0.6891	-0.0170
Electrical Products	Scientific Inst.	1961	-0.1090	-0.1090	-0.1090	-0.1090
		1971	-0.1168	-0.1168	-0.1168	-0.1168
		1981	-0.1187	-0.1187	-0.1187	-0.1187
Transport. Equipment	Non-Elect. Mach.	1961	-0.1134	-0.3597	3.6369	-0.2037
		1971	-0.1062	-0.3464	4.5435	-0.1966
		1981	-0.0924	-0.3632	1.3982	-0.1865
Scientific Instruments	Chemical Prods.	1961	-0.0510	-0.0247	-1.2396	-0.0121
	Elect. Prods.	1971	-0.0592	-0.0308	-0.8461	-0.0220
	Transp. Equip.	1981	-0.0780	-0.0449	-0.3911	-0.0408

The variable cost of nonelectrical machinery industry was affected by the R&D capital spillover from three industries: chemical products, electrical products and transportation equipment. In addition, each of these spillover source industries generated cost and production effects which were statistically the same. A one percent increase in the spillover caused variable cost to decrease by .03 percent in 1961 and .06 percent in 1981. Each factor demand was also affected by the spillovers. However, the response of the demand for labor and materials with respect to changes in spillovers was very inelastic. The percentage changes in materials over the sample were both positive and negative. Labor demand increased in response to a one percent increase in the spillover by .05 percent in any one year in the sample. With respect to both labor and materials, the spillover was factor–using. However, the spillover caused substantial reductions in the demand for physical capital. A one percent increase in the spillover caused the demand for physical capital to decrease by .69 percent in 1981, signifying the presence of a substitutional relationship, which was physical capital–reducing.

The electrical products industry was affected by the R&D capital from the scientific instruments industry. A one percent increase in the spillover caused variable cost to decline by about .12 percent in any year in the sample period. However, because $\beta_{\ell s}$ and β_{ps} were not statistically different from zero, we could not discern any factor bias effects of spillover in this industry. Thus the spillover elasticities on the factor demands were the same as the elasticity on variable cost.

Transportation equipment was also affected by a spillover from nonelectrical machinery. The spillover generated a decrease in variable cost of about .11 percent in any year in the sample. The demand for labor and materials decreased very little in response to the spillover which was labor and material–reducing. There was a strong complementarity between physical capital and the spillover was physical capital–using.

Scientific instruments, like nonelectrical machinery, was influenced by the R&D capital from three industries and indeed the same three industries. In addition, the spillover effects were also the same across the three source industries. Variable cost declined in response to the spillover, with an elasticity in 1981 of .08 percent. The demands for both labor and materials declined in response to the spillover but the elasticities were highly inelastic. In fact, although these two factor demands decreased, their variable cost shares increased so that the spillover was labor and material–using. There was quite a substantial decline in the demand for physical capital as the spillover elasticities were 1.24 percent in 1961 and .40 percent in 1981. Hence for the scientific instruments industry the spillover was physical capital–reducing.

Our empirical results point to some general findings. First, variable cost for each industry was reduced by R&D capital spillovers. Second, the spillover for each receiving industry emanated from a very narrow range of industries included in our sample. There was only a single spillover source for three industries, while for the other two industries, although they were affected by the three industries, the spillover effects were equal across source–industries. Third, in four of the five industries, there were factor bias effects associated with the spillovers. The bias effects for labor and materials were always in the same direction and in the opposite direction to physical capital. The fourth result was that in the two industries (chemical products and transportation equipment) with factor bias effects from a single spillover source, the spillover was physical capital–using and labor and material–reducing. In the two industries (nonelectrical machinery and scientific instruments) affected by multiple spillover sources the spillover was physical capital–reducing and labor and material–using.

6. Rates of Return to R&D Capital

The existence of R&D spillovers implies that there are two rates of return to R&D capital. The private rate of return is defined by the real value of the variable cost reduction due to an increase in an industry's own R&D. Thus

$$(8) \qquad \rho^i = -(\partial c_v^i/\partial K_r^i)p_r^i \qquad i = 1....,N$$

where ρ is the gross private rate of return and p_r is the price of R&D capital. Notice that given the form of the variable cost function (equation (1)) the private rate of return to R&D capital is not constant over the sample period. In addition, since the model is characterized by a short–run equilibrium then the rate of return on R&D capital is endogenous and not assumed to be related to its rental rate. However, for physical capital, since it is part of short–run cost minimization, its gross rate of return is exogenous and given by w_p^i/p_p^i which is the ratio of the rental rate to the purchase price for physical capital. In Table 4, we present the estimated private rates of return to R&D capital and physical capital. In four of the five industries the gross private rate of return on R&D capital was on average over the sample period 1.5 to 2 times greater than the rate of return on physical capital. In addition, in these four industries the private rate of return on R&D were generally the same and ranged from .15 to .20. In the transportation equipment industry the rates of return on the two types of capital were virtually equal.

The second rate of return to R&D estimated in this paper is the social rate of return. This rate differs from the private rate because of the existence of R&D spillovers. The social rate is defined inclusive of the spillover and it is equal to the

Table 4

Private Rates of Return

Industry	Year	R&D Capital	Physical Capital
Chemical Products	1961	0.194	0.067
	1971	0.132	0.082
	1981	0.133	0.135
Non-Electrical Machinery	1961	0.160	0.075
	1971	0.267	0.085
	1981	0.240	0.136
Electrical Products	1961	0.201	0.075
	1971	0.150	0.084
	1981	0.224	0.139
Transportation Equipment	1961	0.085	0.071
	1971	0.095	0.086
	1981	0.119	0.117
Scientific Instruments	1961	0.168	0.080
	1971	0.173	0.083
	1981	0.161	0.118

private rate plus the sum of the marginal real interindustry variable cost reductions. Thus

$$\gamma^{i} = \rho^{i} - \sum_{\substack{j=1 \\ j\neq i}}^{N} (\partial c_{v}^{j}/\partial K_{r}^{i})/p_{r}^{i} \qquad i = 1,\ldots,N$$

where γ is the social rate of return to R&D capital.

In Table 5 we present the social rates of return and their decomposition. First, the R&D capital from chemical products generates spillovers on nonelectrical machinery and scientific instruments. Indeed, in 1981 the marginal interindustry spillover from chemical products to nonelectrical machinery and scientific instruments generated returns of .126 and .032, respectively. When these rates of return are added to the private rate of return to R&D capital from chemical products, we arrive at the social rate of return. From the last column in Table 5, we note that the social rate of return to R&D capital in the chemical products industry was .29 in 1981. Indeed, over the sample period the social rate was 1.5 to 2 times the private rate of return to R&D capital.

The nonelectrical machinery industry only generated a spillover on the transportation equipment industry. However, the effect was quite large so that the social rate of return on R&D capital in the nonelectrical machinery industry was 2 to 3 times the private rate of return. The R&D capital from electrical products and transportation equipment each affected the same industries as the chemical products industries. In both cases the social rate was greater than the private rate but only by about 10 to 20 percent. The last industry is scientific instruments, which affected the chemical products and electrical products industries. The R&D capital from scientific instruments generated substantial spillover effects on these two industries. In fact, the social rate of return was around 10 times the private rate.

Table 5

Social Rate of Return

Industry Source	Year	Receiving Industries					Social R of R
		Ch.Pr.	N-El. Ma.	El.Pr.	Tr.Eq.	Sc. In.	
Chemical Products	1961		.062			.025	0.281
	1971		.058			.020	0.210
	1981		.126			.032	0.291
Non-Elect. Machinery	1961				.418		0.577
	1971				.316		0.583
	1981				.210		0.450
Electrical Products	1961		.024			.010	0.235
	1971		.024			.008	0.182
	1981		.062			.016	0.302
Transp. Equipment	1961		.014			.006	0.105
	1971		.013			.004	0.112
	1981		.035			.009	0.163
Scientific Instruments	1961	.926		.522			1.615
	1971	.505		.429			1.107
	1981	.657		.471			1.289

Abbreviations

Ch. Pr. = Chemical Products
N-El. Ma. = Non-Electrical Machinery
El. Pr. = Electrical Products
Tr. Eq. = Transportation Equipment
Sc. In. = Scientific Instruments
Social R of R = Social Rate of Return

The results on the social rates of return point out that each industry was a R&D capital spillover source. Four of the five industries generated spillovers on two industries. Our results on the differences between social and private rates of return were consistent with the findings of Mansfield et al. [1971], Jaffe [1986] and Bernstein and Nadiri [1987]. However, the results show clearly that it is important to distinguish among industries as sources of R&D spillovers.

7. Summary and Conclusion

Production models which included interindustry R&D spillovers were estimated for each of five high–tech industries. The spillovers affected the variable cost and variable factor demands of the receiving industries. Both productivity and factor bias effects associated with the spillovers were estimated. The empirical results indicated that each industry obtained reductions in its variable cost from the R&D spillovers of other industries. Each receiving industry was affected by a unique industrial spillover source. Variable cost reductions ranged from about .1 percent to .2 percent as a result of a one percent increase in the spillover. In four of the five industries factor biases occurred as a result of the spillovers. The factor biases of labor and materials always moved together and opposite to the factor bias of physical capital. Industries affected by more than one spillover source (nonelectrical machinery and scientific instruments) had R&D spillovers which were physical capital–reducing, while for chemical products and transportation equipment the spillover was physical capital–using.

The private rates of return to R&D capital were estimated. Four of the five industries had private rates which were about .15 to .20. In these industries the private rate on R&D capital was 1.5 to 2 times greater than the rate of return to physical capital. In the transportation equipment industry the private rate of return to R&D capital was about .10 which was equal to the return on physical capital.

The social rates of return to R&D capital differed substantially among the industries. Each industry generated spillovers and all the industries, except nonelectrical machinery, generated spillovers on two industries. The electrical products and transportation equipment industries generated extra returns resulting in social rates which were only 10 to 15 percent greater than their respective private returns to R&D

capital. The social rates for the chemical products and nonelectrical machinery industry were 1.5 to 2 times the private rate. The most significant spillover source was the scientific instruments industry which had a social rate of return 10 times the private rate. In this paper we have estimated the spillover network linking the receiving and sending industries. Our results show that there were significant differences among the industries as both spillover senders and receivers.

In this paper we have estimated a spillover network linking the receiving and sending industries. The findings suggest that there were significant differences among industries as both spillover senders and receivers. Several issues would be of interest for further research. First, we would like to investigate the spillover linkages among other two–digit manufacturing industries. Second, we would like to treat physical capital as an additional quasi–fixed input. Another issue of importance is to analyze the inducement effect of the spillovers due to the R&D activities of other industries on a specific industry's own R&D capital. Lastly, the existence of significant intra and interindustry spillovers has important implications both with respect to tax policy in R&D investment and for competition policy relating to joint R&D ventures, which have yet to be investigated.

Notes

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[1] The translog variable cost function was estimated but we were unable to find parameter estimates which satisfied the regularity conditions for this function.

[2] Physical capital and certain types of labor could also be quasi–fixed. However, the focus of the paper is on R&D capital. The model captures the relative inflexibility of R&D capital compared to other factors of production.

[3] We could not adopt longer lags for the spillovers because of the lack of time series data. We will also test the parameter restrictions implied by the envelope condition and thereby test the hypothesis of long–run equilibrium. Lagging R&D capital permits the estimators in both the short and long–run contexts to be the same and statistically consistent.

[4] The variable cost function was assumed to be homogeneous of degree one in the variable factor prices. This was a maintained hypothesis as relative variable factor prices affected variable cost. This assumption was reasonable to maintain because it implied that each variable factor demand depended on relative and not nominal

prices.

[5] Besides looking at the product of β_{ij} with each of $\beta_{\ell s}$, β_{ps} and $\beta_{ms} = -(\beta_{\ell s} + \beta_{ps})$, if the factor demand elasticity is positive or if negative smaller in absolute value than the cost elasticity, then the spillover is factor–using, otherwise it is factor–reducing.

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