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Productivity Growth and R&D Spillovers from University to Industry

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Abstract

This paper examines the link between Japanese universities' education and research and productivity growth in industry, using a newly available data set on 12 Japanese industries for the period between 1973 and 1998. We obtain empirical evidence showing that the supply of highly educated human capital from universities to industry plays an important role in the productivity growth of Japanese manufacturing industry during 1973－1985. We confirmed that the rate of return to R&D spillovers from universities has declined in recent years.

Key words: total factor productivity, inter-industry R&D spillover, university-industry R&D spillovers

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1. Introduction

It has been widely acknowledged that universities play an important role in economic and productivity growth, not only as producers of new technology and knowledge, but also by creating human capital in the form of highly skilled labor. A large number of empirical and theoretical studies on the relationship between economic performance and the role of universities have been conducted in the past, but few studies have been able to evaluate the two economic benefits of universities – the production of knowledge/technology and the creation of human capital – simultaneously.

There are two major approaches to the theoretical and empirical examination of the relationship between university research and productivity growth. The first approach looks at knowledge as a public good and analyses the effects of spillovers from universities on productivity growth in industry from this angle (Jaffe 1989; Florax and Forlmer, 1992; Mansfield 1991; etc.). Studies following this approach try to quantify the impact of knowledge spillovers from universities on productivity growth in a particular firm or industry. In addition, these studies demonstrate that knowledge flows from academia to industry via various channels: R&D collaboration, publications in technical and scientific papers (Jaffe *et al.*, 1993), the mobility of star scientists between university and industry (Zuker *et al*., 2002), consulting activities of researchers (Mansfield and Lee, 1996), licensing, patent citations, etc. However, studies so far have overlooked the R&D that is “embodied” in university graduates and which contributes to human capital.

The second approach to examining the relationship between university R&D and productivity growth relies on new endogenous growth theory and the Solow model augmented with human capital, which give prominence to the central role of education in economic growth (Lucas, 1988). However, studies using this approach so have not considered the knowledge spillovers from universities.

The purpose of this paper is to investigate the contribution of Japanese universities’ education and research activities to productivity growth in industry, using a newly available data set on 12 Japanese industries for the period between 1973 and 1998. The contribution of this paper is that we separate the effect of university R&D spillovers on productivity growth into two channels: (a) the effect of university R&D that is “embodied” in graduates on human capital; and (b) knowledge diffusion. In addition, we compare the contributions to productivity growth of R&D and inter-industry R&D spillovers on the one hand and R&D spillovers from universities on the other.

The remainder of the paper is organized as follows. Section 2 describes the extended model of the R&D－productivity relationship used for the empirical estimation. Data sources and variables used in this study are explained in section 3. The empirical findings are summarized in section 4, while section 5 offers concluding remarks.

2. The empirical model

In order to estimate the effects of inter-industry spillovers and spillovers from universities, we use the Cobb-Douglas production function extended with R&D stocks, inter-industry R&D spillovers and R&D spillovers from universities. Suppressing time subscripts, output for industry i can be expressed as:

$$Q_i = Z_i^{\eta_z} R_i^{\alpha} S_i^{\beta} U_i^{\gamma} e^{\mu t} \qquad (1)$$

where *Z*, *R*, *S*, *U* are conventional inputs, industrial R&D stock, inter-industry spillover R&D stock, and R&D spillovers from universities, respectively. μ reflects the disembodied rate of technical change. Taking the logs of both sides of (1), first differencing, and using the notation $\frac{\dot{X}}{X} = \frac{\partial \ln X}{\partial t}$ yields:

$$\frac{\dot{Q}_i}{Q_i} = \mu + \eta_z(\frac{\dot{Z}_i}{Z_i}) + \alpha(\frac{\dot{R}_i}{R_i}) + \beta(\frac{\dot{S}_i}{S_i}) + \gamma(\frac{\dot{U}_i}{U_i}) \qquad (2)$$

Growth accounting conventionally derives total factor productivity growth from equation (2) by subtracting the second term on the right-hand-side from both sides:

$$TFPG_i = \frac{\dot{Q}_i}{Q_i} - \eta_z (\frac{\dot{Z}_i}{Z_i}) = \mu + \alpha(\frac{\dot{R}_i}{R_i}) + \beta(\frac{\dot{S}_i}{S_i}) + \gamma(\frac{\dot{U}_i}{U_i}) \qquad (3)$$

We can interpret α, β, and γ in equation (3) as the elasticity of output with respect to own R&D stock, inter-industry R&D spillover stock, and R&D spillover stock from universities, respectively. From the definition of output elasticity, it follows that equation (3) can be rewritten as:

$$TFPG_i = \mu + \rho(\frac{\dot{R}_i}{Q_i}) + \rho_s (\frac{\dot{S}_i}{Q_i}) + \rho_u (\frac{\dot{U}_i}{Q_i}) \qquad (4)$$

ρ and ρ_s are the rates of return to R&D and R&D spillovers, respectively. The rate of return to R&D is interpreted as the marginal product of the R&D stock.

We assume no depreciation of the R&D stock. In this case, we obtain the following empirical specification for estimating the rate of return to R&D and R&D spillovers:

$$TFPG_i = \mu + \rho(\frac{E_i}{Q_i}) + \rho_s (\frac{E_{si}}{Q_i}) + \rho_u (\frac{E_{ui}}{Q_i}) + \varepsilon_i \qquad (5)$$

where E reflects the flow of R&D. Equation (5) is used to estimate the effects of R&D and R&D spillovers.

3. Definition of variables and outline of data sources

3.1 *Total factor productivity growth (TFP)*

We measure TFP as follows:

$$\ln(\frac{TFP_{t+1}}{TFP_t}) = \ln(\frac{Q_{t+1}}{Q_t}) - [0.5*(S_{L,t+1} + S_{L,t})]\ln(\frac{L_{t+1}}{L_t}) - [0.5*(S_{K,t+1} + S_{K,t})]\ln(\frac{K_{t+1}}{K_t})$$
$$- [0.5*(S_{M,t+1} + S_{M,t})]\ln(\frac{M_{t+1}}{M_t})$$

where Q, L, K, and M stand for output, labor input, capital stock, and materials. We use labor input adjusted for labor quality and capital stock adjusted for capacity utilization. S_L, S_K, and S_M represent the shares of labor, capital, and materials in total cost. The Japan Industrial Productivity Database (JIP database) provides all the data needed for constructing TFP growth.[1]

3.2 *R&D expenditures*

Data on an industry's R&D expenditures (cost based) are taken from the *Report on the Survey of Research and Development*, Management and Coordination Agency. We convert the series in nominal terms into 1990 prices using the R&D deflators in the JIP database.

Data on R&D expenditures by science field in universities are also taken from the

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[1] A detailed description of the JIP database is provided by Fukao,et al. (2003).

Report on the Survey of Research and Development; the data were converted to real values, with 1990 as the base year, using the university R&D deflators provided in the *White Paper on Science and Technology.* In order to identify whether the spillovers from universities are due to research activities or due to education activities, we divided universities' total R&D expenditures into expenditures on intramural R&D and expenditures related to providing education, e.g. expenditures on, administrative functions, libraries, etc.[2] We use once-lagged industrial R&D and thrice-lagged university R&D, though there is no consensus among researchers what the correct length of the lag should be.

Table 3-1 presents the trends of industrial R&D and university R&D over the period of 1970–1998; it also shows the composition by kind and science field of university total R&D expenditures. Industrial and university R&D expenditures increased at annual rates of 5.7% and 6.6%, respectively. These growth rates are substantial compared to the 3.5% growth rate of overall real GDP over the sample period.[3] We can observe that the share of intramural R&D expenditures for research activities declined, while the share of expenditures for educational and administrative activities increased over the sample period. Finally, the table 3-1 also shows that the distribution of university R&D expenditures by science field is skewed: R&D expenditures

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[2] This division is based on the breakdown in the *Report on the Survey of Research and Development* of universities' total R&D expenditure into intramural R&D expenditures and various other types of expenditures which support R&D activities – such as libraries – but are equally used for educational purposes.

[3] The growth rate of overall real GDP is calculated from the JIP database.

on three science fields – the humanities and social sciences, engineering and technology, and medical sciences – accounted for 77% of total university R&D expenditures. In contrast, expenditure on research in the natural sciences accounted for only 5%.

(Insert Table 3-1)

3.3 *Inter-industry R&D spillovers*

We consider two different R&D spillovers: knowledge R&D spillover and rent R&D spillover. The knowledge R&D spillover from industry *j* to industry *i* is given by:

$$SK_i = \sum_{j \neq i}^{N} \varpi_{ij} R_j$$

where R_j represents the R&D expenditure of industry *j*.

The uncentered correlation approach suggested by Jaffe (1986) is used as a weighted function. We define the weight of technological proximity between industry *i* and industry *j* as follows:

$$\varpi_{ij} = \frac{f_i f_j^{'}}{((f_i f_i^{'})(f_j f_j^{'}))^{1/2}}$$

We denote by f_i the vector of R&D expenditures allocated by industry *i* across 26 research fields. If industry *i*'s and industry *j*'s allocation of R&D expenditures across research fields perfectly coincide, ϖ_{ij} takes on the value 1. If they do not overlap at all, it takes on the value 0. The average inter-industry R&D proximity for the period 1970–1998 is given in table 3-2, together with a list of the industries examined in this study. About 64% of total Japanese industrial R&D is spent by only three sectors: the electrical machinery, the transportation equipment, and the chemical products industries. It is necessary to look at the technological proximity of between other industries and the three industries, which are important knowledge sources of Japanese industry. We can observe that the electrical machinery industry is closely related to the precision instruments industry (technological proximity index: 0.355), followed by the non-ferrous metals and products (0.309) and the printing and publishing (0.309) industries. The research efforts of the transportation equipment industry are most closely related to general machinery (0.217), fabricated metal products (0.134), and non-ferrous metals and products (0.064). Finally, the chemical industry is the most important knowledge source for the following industries: textiles (0.456), food (0.328), and petroleum and coal products (0.227).[4]

(Insert Table 3-2)

Following Wolff and Nadiri (1993), rent R&D spillover is measured as:

$$SR_i = \sum_{j \neq i}^{N} b_{ji}^0 R_j$$

where b_{ji}^0 is the proportion of industry *j*'s sales accounted for by its sales to industry *i*. b_{ji}^0 has zero diagonal elements to eliminate double counting of own R&D expenditures.

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[4] The technological proximity values calculated in our study are consistent with Odagiri and Kinukawa (1997).

3.4 *University-industry R&D spillovers*

3.4.1 Spillovers through human capital

We assume that new knowledge from universities is embodied in university graduates. The productivity of an industry increases through the employment of human capital in the form of highly skilled workers. Lucas (1988) suggests that the ability to develop and implement new technology depends on the average level of human capital in the economy. Fukao and Kwon's (2003) study supports this argument, showing that Japan's economic growth performance until 1990 was primarily underpinned by the improvement in labor quality.

In order to examine the mechanism that contributed to the improvement in labor quality, we take into account the effect of R&D that is "embodied" in university graduates. We do so by calculating a weight function that incorporates the share of each industry in the employment of new graduates from each science field. These science fields are the humanities and social sciences, natural sciences, engineering and technology, agricultural sciences, medical sciences, education, home sciences and others. The data are taken from *the Report on the Survey of Schooling*.

(Insert Table3-3)

Table 3-3 shows the period average share of each industry in the employment of new graduates from each science field. Lumping graduates from the different sciences together shows that only 15.8% of graduates go into manufacturing industry, while the corresponding figure for natural, engineering and technology, agricultural, and medical graduates is 35.8%. Natural science, engineering and technology graduates show a greater preference to work in manufacturing than students from other fields. As table 3-3 shows, new graduates of the natural sciences and engineering and technology mainly enter the electrical machinery industry, while agricultural and medical graduates work for the chemical industry.

The R&D spillover to industry i through the hiring of graduates from university science field k was calculated as:

$$U_i = \sum_{k \neq i}^{N} h_{ki} U_k$$

where U_k stands for universities' expenditure on science field k, and h_{ki} is the proportion of graduates from science field k going into industry i .[5]

The knowledge transfer from universities, as mentioned above, corresponds to the concept of rent R&D spillovers. That is, this spillover occurs when the industry can employ new graduates at a wage lower than marginal productivity. This implies that the extent of R&D

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[5] It should be noted that this study excludes the employment of master's and Ph.D.graduates, although their contribution to spillover effects is more important than that of undergraduates.

We estimate two regressions, one where we use universities' total expenditure on science field k, and one where we use only their educational expenditure.

spillovers from universities is proportional to the demand for educated workers in an industry.

3.4.2 Spillovers through technological proximity

Another knowledge spillover from universities is related to the diffusion of knowledge. We assume that the level and extent of knowledge diffusion from universities is dependent on the "technological" closeness between a university and an industry. This closeness is measured in the same way as inter-industry knowledge R&D spillovers above. We use the uncentered correlation coefficient between university researchers and total regular industry researchers rather than R&D expenditures. Research areas are classified into 15 science fields: (1) humanities and social sciences, (2) mathematics and physics, (3) chemistry, (4) biology, (5) geology, (6) mechanical engineering, shipbuilding and aeronautical engineering, (7) electrical engineering and telecommunications engineering, (8) civil engineering and architecture, (9) mining and metallurgy, (10) textile technology, (11) agriculture, forestry, veterinary and animal husbandry, (12) fishery, (13) medicine and dentistry, (14) pharmacy, and (15) others.

The R&D spillover to industry *i* through knowledge diffusion from university is given by:

$$U_i = \varpi_{ui} UR$$

where UR represents universities' intramural R&D expenditures. This measurement of knowledge spillover only represents the likelihood of knowledge spillover from universities.

Table 3-4 presents the coefficients of the technological proximity of each industry and universities' R&D from 1975 to 1998. Contrary to our expectations, the technological proximity between industry and universities is low in the chemical and the transportation equipment industries, while it is high for the printing and publishing and the precision instruments industries.

(Insert Table 3-4)

4. Empirical findings

In order to analyze the contribution of university R&D spillovers to industries' TFP growth, equation (5) is estimated. Through LM (Lagrange multiplier) test, we can confirm that the variance for each of the panels is different. Using likelihood test, we can also confirm that the stochastic error term of the panels is correlated. Therefore, we estimate the empirical model using feasible GLS with cross-sectional correlation. As industry-specific effects in the data are rejected by the F-test, these are ignored. In order to control for differences in price movements and in business cycles between industries, all regressions include a dummy variable for years. We also estimate all twelve equations using the seemingly unrelated regression model by relaxing the constraint that all industries have the same parameter vector. We present the results of the FGLS estimates for a system in tables 4-3 and 4-4.

It is commonplace but important to note that in order for universities to produce highly trained graduates, they must be engaged in leading-edge research themselves. Above, we divided universities' total R&D expenditures into intramural R&D expenditure and expenditure for teaching activities. This now allows us to distinguish which of the two contributes (more) to productivity growth in Japanese industry. Moreover, in order to examine whether the same pattern prevailed throughout the period, we divided the data into two sub-periods, 1973–85 and 1985–98.

Details of this approach and our results are displayed in the following tables. Table 4-1 shows the definition of the variables used and some summary statistics. Table 4-2 provides the correlation matrix, and tables 4-3 and 4-4 present the estimation of spillovers effects from university to industry. Estimation results based on sub-samples are also shown.

(Insert Table 4-1)

(Insert Table 4-2)

We first turn our attention to explaining the estimation results of spillover through human capital (regression I). Then, we present the results estimated when separating universities' expenditures into those on R&D and education activities (regression II).

(Insert Table 4-3)

Contrary to our expectations, the coefficient in regression I on spillovers through human capital is negative and insignificant. This finding suggests that high productivity growth through rapid human capital accumulation is not sustainable in the long-run because of diminishing rates of return.

As expected, the rate of return to industrial R&D is statistically significant and large. The estimated rate of return to R&D of 28% is larger than that found in previous estimates: Goto and Suzuki (1989) estimated a return of 26%, while Odagiri (1985) obtained 3%. This coefficient can be interpreted as the excess rate of return, because it includes the effect of inter-firm R&D spillovers. This indicates that inter-firm R&D spillovers have played a pivotal role in Japan's productivity growth.

We obtain an insignificant negative rate of return to inter-industry rent R&D spillovers in the full sample. This result is not consistent with previous studies. However, Yamada *et al.* (1991), analyzing inter-industry spillover through R&D embodied intermediate goods in Japanese manufacturing industries, similarly found a significant negative coefficient. We also obtain a statistically insignificant negative rate of return to inter-industry knowledge R&D spillovers. These results may be caused by sector aggregation, which appears to be too broad to capture inter-industry R&D spillovers.

The regression results for the sub-sample period 1973—85 differ markedly from the estimation results of the overall sample: the estimated return to R&D spillovers from universities through human capital is large and significant. We can see that productivity growth in Japanese manufacturing industry during 1973—85 is substantially dependent on the supply of university R&D embodied in highly skilled labor. Conversely, we find that the effect of R&D spillover through human capital is significantly negative in the more recent period 1986—1998. A notable difference is that the coefficients on inter-industry R&D spillovers during 1973—85 are positive and the effect of inter-industry knowledge R&D spillovers is statistically significant.

The estimated rate of return to R&D in the period 1973—85 is insignificant, but in the period 1986—98 it is very large and highly significant. This implies that the rate of return to R&D increased partly at the expense of falling spillover effects. These findings indicate that the recent decline in productivity growth in the Japanese economy may have been caused by the depletion of inter-industry and industry-university technological cross-fertilization.

In order to examine the assumption that all twelve industries have different slope parameters on R&D spillovers, we estimate a twelve equation seemingly unrelated regression model. We find that the coefficients on university R&D spillovers are mostly positive except in the food and the precision instruments industries, while the transport equipment and the electrical machinery industries are especially dependent on human capital embodied university

R&D. The estimation results show that the R&D spillover from university has a greater impact in heavy industries than light industries. In contrast with the pooled estimation result, the estimated rate of return to R&D is largely insignificant. The coefficients on the rate of return to R&D are positive in product-oriented industries; on the other hand, the coefficients obtained for process-oriented industries have a negative sign, but are mostly insignificant. These are unexpected results.

The effects of rent R&D spillover are significantly positive in four industries: textiles, printing and publishing, chemical products, and precision instruments. These industries benefit through the purchase of knowledge-embodied intermediate goods from other industries.

In most industries, the coefficients on the other inter-industry R&D spillover variables are negative. This indicates that knowledge transfers from other industries cannot substitute for own R&D. Thus, in order to enhance their productivity, firms must engage in their own R&D to create new knowledge and expand the technological opportunities within their industries.

(Insert Table 4-4)

Table 4-4 shows the estimation results of regression II where we distinguish between universities’ research and education activities. The key coefficients in our estimation are those on *URDSPKI* and *URDSPE*. *URDSPKI* represents R&D spillovers through technological proximity and *URDSPE* represents R&D spillovers through human capital. In the overall sample, knowledge spillover is based on the similarity of the skill mix of the university and industry. The coefficient has the expected positive sign, but is far from statistically significant. The estimated coefficient on *URDSPKI* in the sub-period samples is positive but also insignificant. As endogenous growth theory has shown, knowledge spillovers do not suffer from declining rates of return. Therefore, to ensure sustained long-run growth of the economy, the Japanese government should promote greater knowledge spillovers from universities to industry.

As in regression I, the effects of R&D spillovers through human capital on productivity growth are negative and insignificant in the full sample. We also obtain similar results for the sub-sample periods. The estimated results for the different industries are identical with the results of regression I except for the transportation equipment and the precision instruments industries. We can see that the coefficient on inter-industry R&D spillovers is changed by the introduction of *URDSPKI* in the empirical model.

As a consequence, we confirm that industrial R&D, including inter-firm R&D spillovers, contributed to productivity growth in Japan’s manufacturing industries. R&D spillover through human capital from universities contributed to productivity growth during

1973–85. However, inter-industry R&D spillovers had a negative impact on productivity growth in the more recent period.

5. Conclusion

This paper investigated the contribution of university education and research on productivity growth in Japanese manufacturing industry. In particular, we aimed to provide greater insight into the way universities contributed to productivity growth by separating universities' activities into education and research.

Our results showed that the supply of highly educated human capital from universities to industry played an important role in productivity growth in Japanese manufacturing industry during the phase when the Japanese economy was still catching up with the advanced nations of the West. However, we were also able to confirm that the rate of return to R&D spillovers through human capital has declined in recent years. This finding indicates that it is impossible to accomplish sustained long-run economic growth through human capital in Japan. For the Japanese economy to achieve sustained long-run growth, it is necessary for Japanese universities to become producers of new knowledge.

We also confirmed the significant negative relationship between inter-industry R&D

spillovers and productivity growth in Japanese manufacturing industry in recent years. This indicates that the significant slowdown in productivity growth in Japan may have been caused by the exhaustion of technology opportunities between industries.

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Table 3-1. Industrial R&D, university R&D and the composition of university R&D

Year	Industrial R&D (cost based): million yen	University R&D expenditures: million yen	University R&D expenditures by type		University R&D expenditures by science fields							
			Intramural R&D expenditures (%)	Expenditures for education (%)	Humanities and social sciences (%)	Natural sciences (%)	Engineering and technology (%)	Agricultural sciences (%)	Medical sciences (%)	Education (%)	Home science (%)	Others (%)
1970	2013984	1203042	58	42	22	5	19	5	30	6	5	8
1975	2440642	2130689	51	49	22	5	17	4	36	4	5	5
1980	3041915	3240197	45	55	20	5	16	3	40	4	6	5
1985	5063841	4295908	44	56	21	5	15	3	41	5	5	5
1990	7660493	5345900	43	57	22	5	16	3	40	4	5	5
1995	8058963	6621944	44	56	23	6	16	3	40	3	5	4
1998	9288131	6955135	45	55	24	5	16	3	40	3	4	4
Annual growth rate (%)	5.69	6.57										

Source: *Report on the Survey of Research and Development*, Management and Coordination Agency, and *Report on the Survey of Schooling*, Ministry of Education.

Table 3-2. Average inter-industry R&D proximity matrix(1970-1998)

Code	Industry	1	2	3	4	5	6	7	8	9	10	11	12
1	Food	1											
2	Textiles	0.153	1										
3	Printing and publishing	0.027	0.053	1									
4	Chemical products	0.328	0.456	0.052	1								
5	Petroleum and coal products	0.033	0.117	0.041	0.227	1							
6	Iron and steel	0.005	0.029	0.081	0.032	0.030	1						
7	Non-ferrous metals and products	0.003	0.041	0.126	0.042	0.137	0.108	1					
8	Fabricated metal products	0.008	0.034	0.043	0.036	0.029	0.127	0.162	1				
9	General machinery	0.013	0.052	0.217	0.036	0.021	0.189	0.070	0.188	1			
10	Electrical machinery	0.002	0.059	0.309	0.035	0.051	0.106	0.309	0.132	0.185	1		
11	Transportation equipment	0.003	0.071	0.026	0.007	0.003	0.039	0.064	0.134	0.217	0.061	1	
12	Precision instruments	0.011	0.051	0.251	0.054	0.041	0.091	0.149	0.077	0.339	0.355	0.078	1

Table 3-3. Graduates' fields of study and subsequent employment, by industry: 1973-1998 (%)

Code	Industry	Humanities and social sciences	Natural sciences	Engineering and technology	Agricultural sciences	Medical sciences	Home sciences	Education	Others
1	Food	2.5	2.1	1.2	15.9	1.5	0.5	5.5	0.9
2	Textiles	1.5	0.7	1.1	0.6	0.2	0.4	3.3	2.7
3	Printing and publishing	2.2	1.3	0.8	0.5	0.1	1.1	1.2	3.7
4	Chemical products	2.2	9.0	5.1	7.2	22.9	0.5	2.1	1.1
5	Petroleum and coal products	0.3	0.4	0.4	0.2	0.0	0.1	0.2	0.1
6	Iron and steel	0.5	0.5	1.2	0.2	0.0	0.1	0.3	0.1
7	Non-ferrous metals and products	0.3	0.4	1.0	0.1	0.0	0.1	0.2	0.2
8	Fabricated metal products	0.7	0.6	2.3	0.3	0.0	0.1	0.3	0.4
9	General machinery	1.4	2.1	7.4	1.3	0.1	0.4	0.8	0.9
10	Electrical machinery	2.9	11.1	17.4	0.6	0.2	0.9	1.8	2.4
11	Transportation equipment	1.3	1.3	5.7	0.5	0.1	0.4	0.6	1.2
12	Precision instruments	0.7	2.9	3.4	0.4	0.2	0.3	0.4	0.7
	Manufacturing	19.1	35.7	51.4	30.3	25.6	5.6	18.4	20.1

1) The figures represent the shares of students from a particular field of study that chose to work in a particular industry. For example, 51.4% of engineering graduates ended up finding employment in manufacturing industry. The figures represent the averages for the period 1973-1998.

Table 3-4. University-industry technological proximity

Code	Industry	1975	1980	1985	1990	1995
1	Food	0.134	0.132	0.129	0.143	0.178
2	Textiles	0.164	0.132	0.133	0.132	0.180
3	Printing and publishing	0.196	0.158	0.162	0.141	0.159
4	Chemical products	0.098	0.090	0.088	0.091	0.100
5	Petroleum and coal products	0.066	0.060	0.059	0.074	0.076
6	Iron and steel	0.103	0.096	0.099	0.107	0.121
7	Non-ferrous metals and products	0.133	0.122	0.114	0.133	0.149
8	Fabricated metal products	0.135	0.122	0.116	0.101	0.117
9	General machinery	0.117	0.115	0.106	0.106	0.118
10	Electrical machinery	0.137	0.125	0.116	0.124	0.141
11	Transportation equipment	0.118	0.110	0.104	0.093	0.104
12	Precision instruments	0.175	0.163	0.148	0.145	0.153
	Unweighted mean	0.131	0.119	0.114	0.116	0.133

Table 4-1. Definitions of variables and summary statistics

Variables	Definitions	Obs.	Mean	Std.Dev.	Min	Max
TFPG	TFP growth	312	0.006	0.035	-0.198	0.240
RDOWN	Industrial R&D intensity	312	0.021	0.021	0.001	0.090
RDSPKI	Inter-industry knowledge R&D spillover intensity	312	0.068	0.124	0.003	0.957
RDSPRI	Inter-industry rentR&D spillover intensity	312	0.003	0.002	0.000	0.007
URDSPH	R&D spillover intensity through human capital from universities	312	0.005	0.006	0.000	0.032
URDSPKI	R&D spillover intensity through skill mix from universities	312	0.021	0.022	0.004	0.118
URDSPE	R&D spillover intensity through education from universities	312	0.003	0.004	0.000	0.023

Table 4-2. Correlation matrix

	TFPG	RDOWN	RDSPKI	RDSPRI	URDSPH	URDSPKI	URDSPE
TFPG	1						
RDOWN	0.1029*	1					
RDSPKI	-0.0287	0.3605*	1				
RDSPRI	-0.0344	0.2445*	0.2487*	1			
URDSPH	0.0684	0.6727*	0.2136*	-0.0772	1		
URDSPKI	0.0139	0.3040*	0.7142*	0.1698*	0.2257*	1	
URDSPE	0.0586	0.5735*	0.0882	-0.1599*	0.9724*	0.1027*	1

Note: * significant at the 10% level

Table 4-3. Regression results I

	_cons		**RDOWN**		**RDSPRI**		**RDSPKI**		**URDSPH**		**No. of obs**
1. Full sample	0.011		0.281		-1.208		-0.001		-0.206		312
	(4.83)	***	(3.08)	***	(-1.60)		(-1.50)		(-0.97)		
By Period											
2.1973-1985	0.006		0.150		1.880		0.055		0.572		156
	(1.70)	*	(1.29)		(1.42)		(1.86)	*	(1.64)	*	
3.1986-1998	-0.019		0.307		-1.602		-0.011		-0.373		156
	(-8.96)	***	(4.12)	***	(-2.93)	***	(-2.49)	**	(-2.27)	**	
By industry											
4. Food	0.005		0.278		-1.090		-0.018		-0.165		
	(1.28)		(1.97)	**	(-0.94)		(-1.08)		(-0.35)		
5. Textiles	0.001		0.186		0.604		-0.021		0.232		
	(0.25)		(1.51)		(1.97)	**	(-1.35)		(0.63)		
6. Printing and publishing	0.001		0.176		0.604		-0.021		0.240		
	(0.29)		(1.42)		(2.01)	**	(-1.33)		(0.67)		
7. Chemical products	0.002		0.140		0.521		-0.019		0.357		
	(0.51)		(1.02)		(1.75)	*	(-1.16)		(0.97)		
8. Petroleum and coal products	0.006		0.002		-1.644		-0.043		2.685		
	(1.60)		(0.01)		(-1.76)	*	(-2.23)	**	(2.60)	***	
9. Iron and steel	0.008		-0.040		-1.718		-0.039		2.797		
	(2.14)	**	(-0.31)		(-2.37)	**	(-2.68)	***	(3.46)	***	
10. Non-ferrous metals and products	0.012		-0.177		-2.168		-0.044		3.389		
	(2.69)		(-1.20)		(-2.77)	***	(-2.85)	***	(3.84)	***	
11. Fabricated metal products	0.010		-0.131		-2.055		-0.043		3.229		
	(3.38)		(-1.31)		(-4.09)	***	(-4.19)	***	(5.66)	***	
12. General machinery	0.017		-0.322		-0.369		-0.007		1.698		
	(1.65)		(-1.14)		(-0.34)		(-0.31)		(1.37)		
13. Electrical machinery	0.003		0.046		-4.284		-0.064		5.303		
	(0.18)		(0.12)		(-3.73)	***	(-2.44)	**	(4.23)	***	
14. Transportation equipment	0.056		-2.085		-5.976		0.033		9.028		
	(2.18)	**	(-2.26)	**	(-4.01)	***	(0.59)		(4.98)	***	
15. Precision instruments	0.087		-0.040		14.255		0.002		-13.218		
	(2.23)	**	(-0.04)		(4.37)	***	(0.03)		(-3.81)	***	

Note: 1) The dependent variable is TFPG.

2) The numbers in parentheses are z-statistics in regressions 1―3, and t-statistics in regressions 4―15, respectively.

3) *P=.10, **P=.05, ***P=.01 (two-tailed test).

4) The regressions of the full sample and by period include year dummies.

5) Regressions 1―3 are estimated using feasible GLS with cross-sectional correlation across panels, while regressions 4―15 are estimated using FGLS for the system.

Table 4-4. Regression results II

	_cons		RDOWN		RDSPRI		RDSPKI		URDSPKI		URDSPE	
1. Full sample	0.011		0.287		-1.375		-0.014		0.014		-0.379	
	(4.26)	***	(3.25)	***	(-1.78)	*	(-1.19)		(0.22)		(-1.33)	
By Period												
2.1973-1985	0.005		0.210		1.766		0.038		0.058		0.434	
	(1.28)		(1.81)	*	(1.26)		(0.98)		(0.72)		(0.90)	
3.1986-1998	-0.019		0.282		-1.471		-0.012		-0.002		-0.463	
	(-9.06)	***	(3.80)	***	(-2.60)	***	(-1.08)		(-0.02)		(-2.01)	**
By industry												
4. Food	0.004		0.279		-1.207		-0.029		0.084		-0.368	
	(1.05)		(2.11)	**	-(1.03)		(-1.23)		(0.68)		(-0.58)	
5. Textiles	0.000		0.198		0.429		-0.035		0.107		0.300	
	(-0.07)		(1.76)	*	(1.05)		(-1.59)		(0.92)		(0.67)	
6. Printing and publishing	0.000		0.186		0.388		-0.033		0.109		0.350	
	(-0.05)		(1.64)	*	(0.97)		(-1.52)		(0.95)		(0.80)	
7. Chemical products	0.001		0.132		0.307		-0.035		0.142		0.455	
	(0.32)		(1.05)		(0.76)		(-1.58)		(1.22)		(1.01)	
8. Petroleum and coal products	0.008		0.140		-2.276		-0.029		-0.024		3.189	
	(1.59)		(1.04)		(-1.73)	*	(-1.24)		(-0.17)		(2.27)	**
9. Iron and steel	0.015		-0.009		-3.445		-0.018		-0.069		4.541	
	(1.56)		(-0.04)		(-1.76)		(-0.57)		(-0.36)		(2.13)	**
10. Non-ferrous metals and products	0.022		-0.152		-4.160		-0.007		-0.115		5.435	
	(3.07)	***	(-1.15)		(-3.09)		(-0.36)		(-0.91)		(3.64)	***
11. Fabricated metal products	0.073		-0.714		-14.122		0.061		-0.785		16.560	
	(3.90)	***	(-2.38)	**	(-4.92)	***	(1.62)		(-3.19)	***	(5.12)	***
12. General machinery	0.123		-1.568		-26.696		0.147		-1.076		30.196	
	(1.93)	*	(-1.46)		(-3.16)	***	(1.38)		(-1.61)		(3.13)	***
13. Electrical machinery	0.031		-0.428		-4.219		0.018		0.215		5.415	
	(0.34)		(-0.26)		(-0.39)		(0.13)		(0.26)		(0.43)	
14. Transportation equipment	-1.002		11.303		162.832		-0.988		10.546		-182.689	
	(-3.15)	***	(1.35)		(4.00)	***	(-1.74)	*	(3.10)	***	(-4.18)	***
15. Precision instruments	-0.034		9.489		-340.014		0.046		-9.077		340.554	
	(-0.29)		(4.00)	***	(-26.11)	***	(0.31)		(-9.63)	***	(26.30)	***

See notes Table 4-3.