Channels of R&D Spillovers: An Empirical Investigation*

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Abstract

R&D spillovers are, potentially, a major source of endogenous growth in various recent "new growth theory" models. The purpose of this paper is to investigate empirically the effectiveness of various channels of R&D spillovers. The analysis is based on a survey conducted among 358 Swiss R&D executives representing 127 different lines of business, mainly in the manufacturing sector. The results can be summarized as follows:

1. Undertaking independent R&D was perceived by the R&D executives questioned as the most effective channel of R&D spillovers at the intra-industry level. This was followed by reverse engineering for product innovations and the utilization of publications and information from technical meetings for process innovations.

2. Learning methods that rely on interpersonal communication were judged as moderately effective in the following order of importance: 1. publications and technical meetings, 2. conversations with employees from innovating firms, and 3. hiring away employees from innovating firms. Especially the last method is not valued as effective in the Swiss context.

3. Learning methods related to the patent system - licensing technology and patent disclosures in the patent office were seen as moderately effective or not effective at all .

4. The effectiveness of the various channels of R&D spillovers varies from one industry to another.

5. Finally results of the methods of multivariate statistical analysis (correlation, principal components and cluster analysis) suggested that the various channels of R&D spillovers could be reduced to subgroups, so that patterns of learning of competitive technology could be established.

Key words: Knowledge spillovers, technological opportunities, technical knowledge, firm learning, appropriability, Swiss firms.

Channels of R&D Spillovers: An Empirical Investigation

1 Introduction

The emerging new theory of economic growth has reemphasized two major points: "1. technical change is the result of conscious economic investments and explicit decisions by many different economic units, and 2. unless there are significant externalities, spillovers, or other sources of social increasing returns, it is unlikely that economic growth can proceed at a constant, undiminished rate into the future." (Griliches 1992:29; see also Grossman/Helpman 1993). For both points R&D spillovers are of great importance; they are seen as a major source of technological opportunities for economic units engaged in innovative activities and as a vehicle allowing the economic system to escape the fate of diminishing returns. R&D spillovers arise because of the inability of economic units to capture all the benefits of their innovations. The problem of appropriability arises unless intellectual property rights or other mechanisms (i.e. lead time and related first mover advantages, see Levin et al. 1987, Harabi 1995b) enable economic units to appropriate a sizable proportion of the benefits of their innovations. Griliches identifies two distinct notions of R&D spillovers, which are often confused in the literature (see Griliches 1979 and 1992). One is knowledge spillovers, which refer to the effect of research performed in one economic unit (firm, industry and country) in improving technology in a second economic unit. The other is that inputs purchased by one economic unit from another economic unit embody quality improvements that are not fully appropriated by the selling economic unit; it is these unappropriated quality improvements that are experienced by the selling and purchasing firms as spillovers. In addition, R&D spillovers occur at four different levels: firm, industry, nation and world levels[1]. Various surveys of the empirical literature in this field of economic research have shown that "R&D spillovers are both prevalent and important" (Griliches 1992: 29, see also Schankerman 1979, Mohnen 1989, Huffman and Evenson 1991, Mairesse and Mohnen 1990, Mairesse and Sassenou 1991, Nadiri 1993). Or: "As to the existence and magnitude of R&D spillovers, the evidence points to sizable spillover effects both at the firm and industry levels. These effects are also present and likely to grow rapidly among firms in different countries. The

[1] Recent examples of empirical studies on R+D spillovers at the firm and industry level are Adams/Jaffe (1994), Audretsch/Vivarelli (1994), Bernstein (1989). Recent papers on international R+D spillovers are Bernstein/Mohnen (1994) and Coe/Helpman (1993).

spillover effects of R&D are often much larger that the effects of own R&D at the industry level." (Nadiri 1993:35)

The purpose of this paper is to investigate empirically the effectiveness of different channels of knowledge spillovers (the first notion of R&D spillovers according to Griliches) at the industry level using data from Switzerland. In Section 2 I present briefly these data and the related results. A summary and some concluding remarks will follow (Section 3).

2 Channels of R&D Spillovers: An Empirical Investigation of Swiss Industry

In the summer of 1988, experts were asked to answer questions related to the issue of the effectiveness of various channels of R&D spillovers in Swiss industry. Many of these questions had already been put to American experts by the Yale-team (s. Levin et al. 1983). The original Yale-questions were slightly modified in their contents and form in order to take account of the Swiss context and the German language. Since an adequate completion of the questionnaire required solid knowledge of the technology as well as of the market conditions in a certain line of business, the experts questioned were mainly R&D executives of selected firms.

The sample frame for the survey was formed by R&D experts working in 1157 firms, firms which were characterized as "firms actively engaged in R&D" (in a publication of the head office of the Swiss Federation for Trade and Industry, see Schweizerischer Handels- und Industrieverein 1987:11). Experts in 217 firms located in the French and Italian-speaking parts of the country could not complete the German-language questionnaire and were dropped from the survey. Nonetheless, experts in the larger firms in these regions (who could read German) did take part. Of the 940 experts included in the survey, 358, or 38 percent, completed the questionnaire. These 358 experts were active in 127 different lines of business (as defined by the Swiss Federal Office of Statistics, 1985). Taking the industrial structure of their activities at the 2-digit level, 38% of the respondents worked in the machinery and metals industry, 23% in the electrotechnics industry, 10% in the chemicals industry, 2% in the watch-making industry, 3% in the textile/clothing industry, 6% in the food industry, 5% in the synthetics/paper industry; additionally, 4% of the responses came from the construction industry, 7% from technical services and 3% from private research laboratories (see Harabi 1995c for a detailed description of this survey).

According to the statistical tests (fitness tests) conducted, the sample described above is statistically representative of the distribution of industries in the Swiss manufacturing sector, but not representative of firm size. Proportionally more R&D experts from large firms participated in the survey than experts from small and medium-sized firms.

A final point concerning the data should be kept in mind while reading and interpreting the results listed below: All the survey-data used in this paper were derived from subjective judgments based on imperfect information. (For a discussion of some of the methodological issues relevant here see Levin et al. 1987:791-793, Cockburn 1992 and Harabi 1995c).

2.2 Results

2.2.1 Overall Results

Table 1 shows the experts' responses to the question (see also Levin et al. 1983:7f.): "By the following seven means a firm may acquire technical knowledge of new or improved products developed by a competitor. How effective are these different means in your line of business?

1. Acquisition of knowledge through licensing of the technology
2. Acquisition of knowledge through patent disclosures
3. Acquisition of knowledge through publications and open technical meetings
4. Acquisition of knowledge through informal conversations with employees of the innovating firm
5. Hiring away R&D employees with experience at competing firms
6. Acquiring the product and reverse engineering it
7. Acquisition of knowledge through independent R&D"

This question was asked once for product innovations and once for process innovations. The answers were to be given on a scale from 1-7: 1 = not at all effective, 4 = moderately effective, 7 = very effective.

Table 1: Effectiveness of Alternative Means of Acquiring Technical Knowledge about Process and Product Innovations (1 = not at all effective; 7 = very effective)

	Mean (standard error)		Q1(25%)-Q3(75%)	
	Processes	**Products**	**Processes**	**Products**
1. Licensing Technology	3.83* (0.14)	3.92* (0.14)	2.7 - 5.0	2.5 - 5.0
2. Patent Disclosures	3.42 (0.13)	3.54 (0.13)	2.7 - 4.0	2.5 - 4.5
3. Publications or Technical Meetings	4.58 (0.11)	4.42 (0.12)	4.0 - 5.3	4.0 - 5.0
4. Conversations with Employees of Innovating Firms	4.40 (0.12)	4.24 (0.12)	3.5 - 5.0	3.0 - 5.0
5. Hiring Employees of Innovating Firms	3.62 (0.14)	3.67 (0.14)	2.5 - 4.7	2.8 - 4.8
6. Reverse Engineering of Product	4.20 (0.14)	4.60* (0.15)	3.0 - 5.0	3.5 - 6.0
7. Independent R&D	5.18* (0.13)	5.30* (0.13)	4.3 - 6.0	5.0 - 6.3

* The responses to this question vary significantly from industry to industry (level of significance: 0.05)
Q1: First quartile Q3: third quartile

The first two columns of Table 1 indicate the unweighted averages of the answers and the standard errors (in parentheses). Columns 3 and 4 indicate the distribution of these averages. Q1 stands for the first quartile; similarly, Q3 represents the third quartile. That means the middle 50% of all the answers lies between these two values. The results of this table can be summarized as follows[2]:

Undertaking independent R&D activities is perceived as the most effective method of acquiring technical knowledge about product and process innovations developed by a competitor. R&D activities are therefore very important not only for developing one's own product and process innovations but also for monitoring competitors and absorbing the latest technological trends on the market. This result confirms what Cohen and Levinthal (1989) called "the two faces of R&D: innovation and learning".

"Reverse engineering" is seen as the second most important method of acquiring technical information about competitive technology for product innovations. The utilization of publications and information from technical meetings is seen as the second most important method for process

[2] The results of this table are presented in the same way as those of the Yale study (s. Levin 1988). The reader can therefore directly compare the results of the two studies.

innovations. In addition, "reverse engineering" appears to be more effective for acquiring technical knowledge about process innovations than acquiring technical knowledge about product innovations.

Learning methods that rely on interpersonal communication are seen as moderately effective (average score: 4). These methods are: 1. publications and technical meetings, 2. conversations with employees from innovating firms, and 3. hiring away employees from innovating firms. Especially the last method is not highly valued in the Swiss context.

Finally, learning methods related to patents and to patent office (methods No.1 and 2) were seen as "moderately effective" or "not effective". While the relative ineffectiveness of method No. 1 is - from the perspective of cost/benefit analysis of firms - quite understandable (firms are not always interested in licensing a new technology - especially in its early stages - just in order to learn about it), is the relative ineffectiveness of the second method quite striking. Firms seem to ignore the existence of technical information services of the Swiss patent and other European and international patent offices. This empirical result coming from Swiss R&D experts confirms the statement of the president of the European Office: "About 90% of all man's technical know-how is contained in patent documents. Unfortunately, this rich store is still used exclusively for patent grant purposes. Industry and research make far too little use of it. It is estimated that about 30% of all R&D investment could be saved if the prior art information available in patent documentation were used systematically. The vast amount of money saved could then be put to better use." (Braendli 1993: 4-5).

2.2.2 Interindustry Differences

The overall results presented so far should not obscure the fact that there are interindustry differences with respect to the effectiveness of the different means of learning about competitive technology. Statistical tests, analysis of variance for example, show that significant interindustrial differences (significance level 0.05) regarding the effectiveness of the means "licensing technology", "reverse engineering" and "independent R&D" (points 1, 6 and 7 in Table 1) exist. These interindustrial differences are further examined below.

The general empirical finding that licensing technology and patent disclosures as means of learning about competitive technology are either "not effective" or just "moderately effective" is confirmed when results are disaggregated at lower levels of industry classification. Viewing the results at the 2-digit level, the following observations can be made (see Table 2):

- Licensing technology as a means of learning about competitive technology was regarded as not effective in textile/clothing, construction, and in synthetics/paper industries. In the other industries, especially food and chemicals, licensing technology was seen as moderately effective.
- Patent disclosures as a means of learning about competitive technology was perceived as moderately effective only in the chemicals, machinery and metal processing industries and in private research laboratories.

Table 2: Effectiveness of Licensing Technology and Patent Disclosures as Means of Acquiring Technical Knowledge about Product Innovations (1 = not at all effective; 7 = very effective)

Industry	**T1F1**		**T1F2**	
	M*	**S****	**M***	**S****
Machinery and Metal Processing	4.30	1.9	3.90	1.5
Electronics	4.02	1.7	3.73	1.7
Chemicals	4.51	1.6	4.26	1.3
Watches	4.20	2.0	3.40	1.3
Textile and Clothing	2.81	1.5	3.40	1.7
Food	4.70	1.7	3.40	1.8
Synthetics and Paper	3.52	2.0	3.40	1.8
Construction	3.10	1.7	2.90	1.3
Technical Services	4.30	1.7	3.40	2.0
Private Research Laboratories	4.40	1.7	3.75	1.7
Overall Industry Mean	**3.93**	**1.6**	**3.54**	**1.4**

T1F1: Licensing Technology
T1F2: Patent Disclosures
* Arithmetic Mean ** Standard Deviation

As to the industry-specific effectiveness of interpersonal channels of learning (methods 3, 4 and 5 in Table 1) the following observations can be made (see Table 3):

- Publications and technical meetings as means of acquiring technical knowledge about product innovations developed by competitors were perceived as either "moderately effective" or even "effective" in all industries. The only exception was the construction industry. Especially the experts from private research laboratories, technical services, food and watch industries rated these means above average.

- Informal conversations with employees from innovating firms as a method of learning about competitive technology was seen as relatively ineffective by experts from the chemicals and watch industries only.
- Finally, all experts - with a few exceptions - did not consider hiring away employees from innovating firms an effective means of acquiring technical knowledge about competitive product innovations. The reason for this striking result might be the following: although the experts questioned might evaluate "hiring away employees from innovating firms" per se as an effective means of acquiring technical knowledge about competitive technology, they do not take it into account in practice due to cultural and other reasons related to the conditions of the small and relatively transparent labor market in Switzerland. The only interesting exceptions are experts from technical services, who gave it a score of 5.

Table 3: Effectiveness of Interpersonal Means of Acquiring Technical Knowledge about Process and Product Innovations (1 = not at all effective; 7 = very effective)

Industry	**T1F3**		**T1F4**		**T1F5**	
	M*	**S****	**M***	**S****	**M***	**S****
Machinery and Metal Processing	4.43	1.5	4.40	1.7	4.00	2.0
Electronics	4.50	1.4	4.60	1.5	4.22	1.9
Chemicals	4.40	1.4	3.70	1.5	3.30	1.6
Watches	5.00	0.7	3.20	1.5	3.00	1.6
Textile and Clothing	4.00	1.4	4.30	1.8	2.60	1.5
Food	5.25	1.5	4.70	1.6	3.50	1.9
Synthetics and Paper	4.20	1.1	4.70	1.8	4.20	1.8
Construction	3.70	1.5	4.20	1.6	4.00	1.9
Technical Services	5.00	1.5	4.50	1.2	5.00	1.6
Private Research Laboratories	5.33	1.9	4.50	2.0	3.75	2.2
Overall Industry Mean	**4.50**	**1.3**	**4.30**	**1.4**	**3.70**	**1.6**

T1F3: Publications or Technical Meetings
T1F4: Conversations with Employees of Innovating Firms
T1F5: Hiring Employees of Innovating Firms
* Arithmetic Mean ** Standard Deviation

Table 4 shows that experts from the chemicals industry, technical services and private research laboratories evaluated reverse engineering as a relatively ineffective means of learning about competitive technology, while experts from the other industries, especially from the watch and food industries, considered this method of learning as effective.

Table 4: Effectiveness of Reverse Engineering as a Means of Acquiring Technical Knowledge about Process and Product Innovations (1 = not at all effective; 7 = very effective)

Industry	Process		Product	
	M*	S**	M*	S**
Machinery and Metal processing	4.00	1.8	4.50	1.7
Electronics	4.33	1.6	4.80	1.6
Chemicals	3.63	1.7	3.90	1.9
Watches	5.50	1.2	6.20	1.0
Textile and Clothing	4.50	1.9	4.70	1.9
Food	5.00	1.5	5.25	1.6
Synthetics and Paper	4.60	1.7	4.70	1.6
Construction	4.14	2.2	4.60	2.2
Technical Services	3.70	1.9	4.00	1.6
Private Research Laboratories	3.44	2.4	3.50	2.3
Overall Industry Mean	**4.20**	**1.6**	**4.60**	**1.6**

* Arithmetic Mean ** Standard Deviation

In comparison to reverse engineering interindustry differences in the effectiveness of independent R&D as a means of learning about competitive technology are less striking. With the exception of the textile/clothing industry, experts from all other industries saw independant R&D as an effective channel of knowledge spillovers.

Table 5: Effectiveness of Independent R&D as a Means of Acquiring Technical Knowledge about Process and Product Innovations (1 = not at all effective; 7 = very effective)

Industry	Process		Product	
	M*	S**	M*	S**
Machinery and Metal Processing	5.3	1.4	5.6	1.3
Electronics	5.6	1.1	5.8	1.1
Chemicals	5.4	1.4	5.3	1.6
Watches	5.3	1.6	5.3	1.6
Textile and Clothing	4.2	1.5	4.5	1.9
Food	5.7	1.6	6.0	1.5
Synthetics and Paper	4.9	2.0	5.0	1.9
Construction	4.8	1.7	5.0	1.7
Technical Services	4.9	2.0	5.4	1.7
Private Research Laboratories	5.4	2.5	5.5	1.8
Overall Industry Mean	**5.2**	**1.4**	**5.3**	**1.4**

* Arithmetic Mean ** Standard Deviation

In summary, many methods of learning about product and process innovations developed by competitors exist. Their effectiveness varies from industry to industry, however. Of all means of acquiring technical knowledge about competitive technology, independent R&D and reverse engineering seem to be the most effective in all industries surveyed (see Table 6).

Table 6: List of the two most Effective Means of Acquiring Technical Knowledge about Product Innovations in ten different Industries (2-digit)

Industry	First Means	Second Means
Maschinery and Metal Processing	Independent R&D	Reverse Engineering
Electronics	Independent R&D	Reverse Engineering
Chemicals	Independent R&D	Licensing Technology
Watches	Reverse Engineering	Independent R&D
Textile and Clothing	Reverse Engineering	Conversations with Employees of Innovating Firms
Food	Independent R&D	Publications or Technical Meetings
Synthetics and Paper	Independent R&D	Conversations with Employees of Innovating Firms
Construction	Independent R&D	Reverse Engineering
Technical Services	Independent R&D	Hiring Employees of Innovating Firms
Private Research Laboratories	Independent R&D	Publications or Technical Meetings

2.2.3 Channels of R&D Spillovers: the Patterns

So far, the different methods of learning about competitive technology have been analyzed and the empirical results concerning their effectiveness have been presented separately. Now two questions can be raised: first, do dependencies between these different means of acquiring technical knowledge exist? and second, - based on these dependencies - can clusters of industries related to their learning patterns be constructed? In order to answer these two questions empirically, the usual methods of multivariate statistics, above all correlation, principal components and cluster analysis, were used.

The results of the correlation analysis are summarized in Tables 7 and 8. These tables show correlations among the seven different means of learning about competitive product innovations (Table 7) and process innovations (Table 8). In each cell of the two matrices the first entry indicates correlation coefficients of individual responses; the second entry indicates correlation coefficients of (4-digit) industry means. The results can be interpreted as follows:

1. For both product and process innovations a statistically significant correlation between the first two learning methods, "licensing technology" and "patent disclosures" (variables IF1 and IF2) exists. This result suggests that before licensing technology, licensees gather information about this technology through patent disclosures.
2. The expected link between the three interpersonal channels of learning about competitive technology is confirmed empirically: A statistically significant correlation between the three variables "Publications or Technical Meetings", "Conversation with Employees of Innovating Firms" and "Hiring Employees of Innovating firms" (variables IF3, IF4 and IF5) exists.

3. Reverse engineering correlates with almost all other means of learning. This results leads one to believe that the decision to gather information about a product through reverse engineering is backed by various information channels.
4. Independent R&D correlates only with reverse engineering. This pinpoints the already mentioned double function of R&D: it is a major tool for both one's own innovation and for learning about competitive technology.

Table 7: Correlation Matrix of Alternative Means of Acquiring Technical Knowledge about Product Innovations (First entry in each cell indicates correlation of individual responses (n = 358). Second entry indicates correlation of industry means (n= 127))

	IF.1	IF.2	IF.3	IF.4	IF.5	IF.6	IF.7
IF.1 Licensing Technology	1.00/ 1.00						
IF.2 Patent Disclosures	0.31*/ 0.39*/	1.00/ 1.00					
IF.3 Publications or Technical Meetings	0.08/ 0.16	0.34*/ 0.40*	1.00 1.00				
IF.4 Conversations with Employees of Innovating Firms	0.03/ 0.09	0.25*/ 0.25*	0.30*/ 0.47*	1.00/ 1.00			
IF.5 Hiring Employees of Innovating Firms	0.24*/ 0.15	0.10/ 0.10	-0.02/ 0.15	0.38*/ 0.34*	1.00/ 1.00		
IF.6 Reverse Engineering of Product	0.09/ -0.04	0.22*/ 0.14	0.14*/ 0.32*	0.26*/ 0.31*	0.32*/ 0.30*	1.00/ 1.00	
IF.7 Independent R&D	0.04/ 0.17	0.01/ 0.06	0.10/ 0.14	0.05/ 0.15	0.03/ 0.11	0.18*/ 0.29*	1.00/ 1.00

* Significant at the 0.01 level

Table 8: Correlation Matrix of Alternative Means of Acquiring Technical Knowledge about Process Innovations (First entry in each cell indicates correlation of individual responses (n = 358). Second entry indicates correlation of industry means (n= 127))

	IF.1	IF.2	IF.3	IF.4	IF.5	IF.6	IF.7
IF.1 Licensing Technology	1.00/ 1.00						
IF.2 Patent Disclosures	0.34*/ 0.39*	1.00 1.00					
IF.3 Publications or Technical Meetings	0.12/ 0.09	0.30*/ 0.24*/	1.00 1.00				
IF.4 Conversations with Employees of Innovating Firms	0.04/ 0.06	0.23*/ 0.26*	0.27*/ 0.32*	1.00/ 1.00			
IF.5 Hiring Employees of Innovating Firms	0.27*/ 0.17	0.17*/ 0.17	0.06/ 0.10	0.34*/ 0.27*	1.00/ 1.00		
IF.6 Reverse Engineering of Product	0.03/ - 0.05	0.14* 0.20	0.14/ 0.27*	0.25*/ 0.22	0.29*/ 0.30*	1.00 1.00	
IF.7 Independent R&D	0.01/ 0.13	0.01/ 0.06	0.02/ 0.20	0.07/ 0.07	- 0.01/ 0.05	0.14/ 0.23*	1.00/ 1.00

* Significant at the 0.01 level

In summary, the results of the correlation analysis suggest that the seven different channels of learning about product and process innovations developed by competitors can be reduced to three subgroups: the first one includes the patent-oriented methods (method 1 and 2), the second one includes the interpersonal methods and the third one includes reverse engineering and independent R&D. These findings will now be further analyzed using other statistical techniques: principal components and cluster analysis.

The principal components analysis generally transforms a given set of variables (here: the seven means of learning about competitive technology) into a new set of compounded variables (principal components) that are mutually orthogonal (not correlated). The results of this analysis - using aggregated data at the 4-digit level - are summarized in Table 9. The first three columns show the weights associated with the first three principal components when the seven questions relating to effectiveness of the means of learning about process innovations are analyzed separately from the seven questions relating to product innovations. The next three columns report the results of a principal components analysis on the entire set of fourteen questions. With both approaches, the results suggest that the seven means of learning can be reduced to three dimensions (principal components). The first principal component loads most heavily on interpersonal channels of spillover and on reverse engineering (means 4, 5 and 6 are here especially relevant). The second component loads mainly on learning through patent disclosures and licensing technology (patent related channels of spillover), and the third loads almost exclusively on independent R&D and to a lesser degree on reverse engineering.

Despite this clear interpretation of the results of the principal component analysis, the data do not reduce very satisfactory to just three dimensions. As Table 9 indicates, when the process and product questions are analyzed separately, the first three components explain only 65 percent of the variance in the responses to seven questions, and when the two sets of questions are combined, three components explain only 60 percent of the variance.

Table 9: Principal Components Analysis of Alternative Means of Acquiring Technical Knowledge about Product and Process Innovations

	Processes and Products separately			Processes and Products together		
	Coefficients of 1st, 2nd and 3rd principal component			Coefficients of 1st, 2nd and 3rd principal component		
Process Innovations						
1. Licensing Technology	- 0.06	0.89	0.07	- 0.07	0.84	0.18
2. Patent Disclosures	0.33	0.72	0.05	0.39	0.70	-0.09
3. Publications or Technical Meetings	0.48	0.11	0.43	0.56	0.14	0.07
4. Conversations with Employees of Innovating Firms	0.71	0.12	0.04	0.63	0.09	-0.01
5. Hiring Employees of Innovating Firms	0.66	0.19	-0.21	0.56	0.11	-0.02
6. Reverse Engineering of Product	0.65	- 0.13	0.38	0.66	- 0.14	0.36
7. Independent R&D	- 0.04	0.09	0.89	0.07	0.05	0.89
Cumulative variance explained	**0.25**	**0.45**	**0.61**	-	-	-
Product Innovations						
1. Licensing Technology	- 0.11	0.89	0.27	- 0.04	0.85	0.13
2. Patent Disclosures	0.25	0.79	-0.10	0.30	0.70	- 0.12
3. Publications or Technical Meetings Innovating Firms	0.63	0.43	- 0.17	0.59	0.33	0.01
4. Conversations with Employees of Innovating Firms	0.77	0.18	- 0.08	0.72	0.14	0.00
5. Hiring Employees of Innovating Firms	0.58	0.02	0.19	0.60	0.05	0.01
6. Reverse Engineering of Product	0.70	- 0.14	0.32	0.70	- 0.16	0.30
7. Independent R&D	0.14	0.09	0.90	0.10	0.09	0.92
Cumulative variance explained	**0.27**	**0.49**	**0.64**	**0.24**	**0.43**	**0.57**

The interpretation that the seven channels of spillover can be reduced to three subgroups was nonetheless reinforced by a cluster analysis. The cluster analysis classified in this case the 127 surveyed industries according to mean responses to the seven questions concerning the means of learning about competitive technology[3] . As reported in Table 10, three clusters were found for both product and process innovations. In the area of process innovations the first cluster consists of 46 industries where none of the methods of learning were seen as particularly effective (the mean score is below 4 for the six first methods and 4.6 for the last one). The second cluster includes 47 industries that reported that patent related methods of learning are not effective. Industries in this cluster rely on interpersonal means of learning, reverse engineering and independent R&D. Finally, the 31 industries of the third cluster consider "licensing technology" and "independent R&D" as the

[3] The procedure used here is the SAS procedure called "FASTCLUS". It is a non-hierarchical method for determining disjunct clusters on the basis of Euclidean distances: The observations (here: the 127 industries) are classified in such a way that each observation is attributed to one single cluster only (see SAS User's Guide: Statistics, version 5, 1985:377-402).

most effective mechanisms of learning about competitive technology. The remaining methods are on the average considered moderately effective. (In comparison with the other clusters they are more effective than in the first and less effective than in the second cluster).

Table 10: Clusters of Industries on the Basis of the Effectiveness of Alternative Means of Acquiring Technical Knowledge about Process and Product Innovations

	CLUSTER		
	1	2	3
Process Innovations			
Number of Industries:	46	47	31
Mean Score:			
1. Licensing Technology	3.34	3.39	5.20
2. Patent Disclosures	2.49	3.70	4.31
3. Publications or Technical Meetings	3.96	5.20	4.61
4. Conversations with Employees of Innovating Firms	3.55	5.05	4.62
5. Hiring Employees of Innovating Firms	2.61	4.00	4.61
6. Reverse Engineering of Product	3.20	5.50	3.64
7. Independent R&D	4.61	5.60	5.40
Product Innovations			
Number of Industries:	75	14	36
Mean Score:			
1. Licensing Technology	3.25	5.28	4.77
2. Patent Disclosures	3.48	4.81	3.16
3. Publications or Technical Meetings	4.37	5.71	4.00
4. Conversations with Employees of Innovating Firms	4.05	6.22	3.84
5. Hiring Employees of Innovating Firms	3.09	5.19	4.28
6. Reverse Engineering of Product	4.78	5.63	3.73
7. Independent R&D	5.05	5.30	5.83

Comparing the cluster assignment for product innovations with the cluster assignment for process innovations, one can conclude that they are different in the cases of the first and second and similar in the case of the third cluster see (Table 10). R&D experts from industries in the first cluster found "reverse engineering" and "independent R&D" as effective - the average score is around 5. Industries of the second cluster rely upon all channels of spillovers, including the patent-related ones, in order to learn about competitive products.

3 Summary and Conclusion

R&D spillovers are, potentially, a major source of endogenous growth in various recent new growth theory models. The purpose of this paper was to investigate empirically the effectiveness of various channels of R&D spillovers. The analysis was based on a survey conducted among 358 Swiss R&D

executives representing 127 different lines of business, mainly in the manufacturing sector. The results can be summarized as follows:

1. Undertaking independent R&D was perceived by the R&D executives questioned as the most effective channel of R&D spillovers at the intra-industry level. This was followed by reverse engineering for product innovations and the utilization of publications and information from technical meetings for process innovations.

2. Learning methods that rely on interpersonal communication were judged as moderately effective in the following order of importance: 1. publications and technical meetings, 2. conversations with employees from innovating firms, and 3. hiring away employees from innovating firms. Especially the last method is not valued as effective in the Swiss context.

3. Learning methods related to the patent system - licensing technology and patent disclosures in the patent office - were seen as moderately effective or not effective at all .

4. The effectiveness of the various channels of R&D spillovers varies from one industry to another.

5. Finally, results of the methods of multivariate statistical analysis (correlation, principal components and cluster analysis) suggested that the various channels of R&D spillovers could be reduced to subgroups, so that patterns of learning of competitive technology could be established.

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