COUPLING PATTERNS IN SCIENCE AND TECHNOLOGY

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Technology transfer is a term which has been applied to a wide range of activities associated with the movement of knowledge--in the crude state as ideas or embodied in literature or in hardware, across institutional and organizational interfaces. This wide compass has the advantage, appropriate to such a subject, of promoting cross-fertilization between studies of the various forms of technology transfer. It has the disadvantage that the lack of consistent definitions can hinder the processes of conceptualization and analysis.

One particular class of technology transfer, which has been the subject of a great deal of study, has been concerned with the interface between science and technology. The motivations for the study of the relationship between science and technology have varied. In recent years, governments concerned at the size and rate of growth of the science budget, and the limited degree of accountability for this expenditure, have been demanding a clear demonstration of the mechanism and the amount by which scientific research contributes to industrial growth and economic prosperity. In many countries industry has shown a concern with increasing the efficiency of its own investments in research as well as expanding access to science and technology developed outside the firm.

The most cited studies of the link between fundamental scientific research and industrial technology have been Project Hindsight (1) and TRACES (2) which are too well known to require detailed elaboration here. The methodological assumptions common to these studies are that innovations can be considered as composed of a series of R & D events and that the contribution of science to technology can be assessed by tracing the origin of these events. A more recent TRACES study (3) has overcome some of the objections to this approach (4), but has clung to the 'critical events' methodology.

Similar assumptions are evident in the arguments of scientists engaged in the defence of the science budget (e.g. see Perutz (5)) by tracing the technological consequences of specific scientific discoveries. However, science is only one of many inputs to successful innovation and hence it cannot claim for itself complete responsibility for such technology, or demand that it be judged only on the basis of its successes.

The other major field of investigation of the interface between science and technology has been in the form of empirical studies of the innovation process which have incidentally examined the contribution of science. (6,7,8) These studies have produced a considerable array of findings but there has been general agreement that the previously accepted linear model of the interaction between science and technology, i.e., that technology is the direct application of basic science, is not valid; in fact, science plays little part, at least directly, in the vast majority of technological innovations.

It is apparent that the results of any study of the science-technology interface and the flow of information between the two sectors will depend critically on what is accepted as the demarcation between them. Science and technology can be considered distinct in the sense that it is possible to identify two professional groups whose activities are describable in terms of the attitudes, values and norms of scientists and technologists, respectively. However they cannot be distinguished in terms of method, as recent studies of the form of progress in science (9) and in technology (10) suggest that within somewhat different constraints, both the academic scientist and the innovator in industry approach the definition and resolution of problems in very similar ways, each relying on an extensive background of craft knowledge and using a combination of understanding and heuristic to achieve the desired goal.

On this subject of definitions, both the 'tracing' and the 'innovation' types of studies are unified in their acceptance of fundamental knowledge as the only, or at least the most important, output of science. This view of science is based, however, on an outdated conception of it as a systematised body of knowledge. A cursory examination of the activities of scientists today shows that the majority are not engaged solely, or even primarily, in the pursuit of fundamental knowledge, even within universities. The pressures exerted on science by its very success, its growth, its professionalization and its politicization have combined to alter its nature substantially.

Hence any examination of the transfer of knowledge between science and technology, and vice-versa--which is based on the equation of science with knowledge production and technology with knowledge application -- is clearly innappropriate for the contemporary situation. Rather, knowledge is both produced and applied in a variety of institutions such as universities, independent research institutes, industry and government. Each of these has a different function, operates under different constraints and within different environments. Nevertheless for the effective achievement of national goals they must interact positively as elements of a research-production system. On this basis the major problem may be seen as that of identifying means of reducing institutional barriers and assuring effective coupling between the various elements.

A recent study of the information used in the resolution of technical problems arising during the course of development of a wide range of innovations in British industry has allowed the examination of a variety of factors affecting the transfer of information between these various institutions.

DESCRIPTION OF THE STUDY

This study was oriented towards answering the question, "What types of information are used in the resolution of technical problems arising during the development of an innovation in British industry and how is it transferred from source to user?" The form of the question exposes some of the assumptions underlying the investigation. Firstly, it is assumed that in its pursuit of technological innovation industry encounters technical problems the solutions of which are describable in terms of certain information inputs. No attempt was made to synthesise these inputs into the creative insight which, in fact, is the solution. Secondly, by focussing on the resolution of technical problems per se, one is clearly, and from the outset, avoiding the difficult question of whether the process of problem-resolution will subsequently lead to a "successful" technological" innovation - that is, one which is commercially successful for the firm in question. The solution of technical problems is a necessary but not sufficient condition for successful technological innovation. Many other factors, financial and organizational, must be fused with technological capability and market need before one can begin to analyse the mercurial notion of success in this context. In fact, most of the products whose development provided the data for this study now appear to have at least been successfully marketed. But their subsequent fate will not influence its conclusions.

Unlike many of the recent empirical studies which have set out to determine the relative contributions of science and technology to technological innovation, we have attempted primarily, to describe the characteristics of the information which have contributed to the resolution of technical problems and secondarily to determine, if any of these are further describable as scientific or technological information.

The study is structured around the notion of problem-solving. It draws primarily on that view of organizational activity which regards members of organizations as decision makers and problem-solvers and this, in turn, suggests that the individual, or team, in the process of problem-solving, might be the most suitable unit to focus on. (11) However, the type of technical problem which arises in industry is characteristically different from those conventionally used in the study of problem-solving behaviour. "For a technical problem there is often no correct, or even best, solution in the long run. In fact, there is frequently no terminal state : both problems and solutions are themselves often dynamic. (12) Also, the criteria for evaluation of a potential solution are not absolute - they are ultimately a matter of judgment and different individuals evaluate them differently. Nevertheless, the resolution of technical problems can be viewed as the assemblage and evaluation of information and we have chosen this perspective for the examination of the roles of science and technology in technological innovation. The problem-solver is regarded as operating within an informational matrix which comprises knowledge and skills with respect to the technology in which he is currently engaged as well as the backlog of previous experience, educational as well as industrial. In the event of a technical problem, the problem-solver can be considered, ideally, to approach the solution by moving from the familiar to the unfamliar and from the routine to the novel. In the course of this process he may need to extend his informational resources, first of all by consulting sources readily available to him - such sources include colleagues, books, periodicals, among others. If these sources prove inadequate the problem-solver will begin to consider sources less familiar or less readily available. It should be emphasized that the problem-solver can, and in practice frequently does, solve, or more appropriately, resolve the problem by redefining it in accord with the information he possesses.

A number of variables were developed to describe the characteristics of the information inputs. The first of these was the general source of the information, by which the information was sub-divided according to whether the problem-solver obtained the information from sources outside the company, from sources within the company, or possessed the information himself at the start of the innovation. The general source was further categorised into the specific source which described where the problem-solver obtained the information. No attempt at further tracing to ultimate origins was made. Other variables, adapted from Marquis and Myers (13), described the nature or content of the information, the channels by which it reached the problem-solver, and the impact the information made on the particular technical problem. Measures of various characteristics of the organization, the innovation, and the education and experience of the problem-solver were also obtained.

A feature of this study concerns the choice of recent or on-going developments. Using this criterion of selection many of the problems involved in the reconstruction of past events are avoided. In most cases, it was possible to interview the individuals who were directly concerned in the problem solution about events which were relatively fresh in their memories. Also, data gathered in this way are more likely to be descriptive of the contemporary institutional situation of science and technology and so may provide more relevant information for policy makers who seek to influence the environment in which science and technology are produced, and the transfer of technology occurs.

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The three categories of general source contributed approximately equal numbers of information inputs to the resolution of technical problems. In terms of examining coupling between science and technology, it is the information from outside the company which is of greatest interest. The various categories of specific source together with the distribution of information inputs among them are shown in Table 1.

Recent studies of technological innovation have made use of the concept of technology transfer to describe how information, often crucial to the success of an innovation, is acquired by the innovating firm. The general consensus has been that technology transfer occurs most efficiently through person-to-person contact : technology transfer 'on the hoof' (8,14) By contrast, this study concludes that information from outside the firm is transferred equally by inspection of the literature and person-to-person contact. More specifically, the ratio of scientific information transferred by the literature to that transferred by contact with individuals was found to be 54 : 53 while that for technological information was 95 : 98. However the personal contact was often necessary in order to interpret or 'translate' the literature.

Table 1

Specific Source of Information with Respect to General Source

Number of Information Inputs

Outside Company	No.	%	Inside Company	No.	%
Trade Literature	43	14	Analysis and Experiment	183	69
Technical Lit.	22	7	Superior	25	9
Scientific Lit.	36	12	Colleague	17	6
Text Books	8	2	Other Dept.	17	6
Handbooks	20	7	Other Division	7	3
Reps. & Customers	20	7	Company Manual	9	4
Supplier Cos.	39	13	Company Report	6	2
Universities	30	1	Internal Library or Reference System	3	1
Professional Institutions	3	1			
British Standards	12	4			
Exhibitions	2	1			
Consultants (commercial)	12	4			
Government Agencies	11	4			
Field Tests	8	3			
Conferences	4	1			
Research Assns.	24	8			
Patents	6	2			

In the following paragraphs, the discussion will center on the use of and contribution made by information inputs transferred along these two main routes : literature and personal contact. After this, some attempt will be made to relate the use of information sources to the educational background of the problem-solver and to characteristics of the organization.

Literature

The major form of printed matter that contributed scientific information to the resolution of technical problems was the primary and secondary scientific literature. This literature consists of publications of original research and reviews of particular fields of scientific interest. This type of information made up about 30% of the total scientific inputs and was also the third most commonly used source from outside the company (see Table 1). Examination of the use of this information in individual innovations, however, revealed that in over half of the innovations no use was made of the scientific literature at all (Table 2). This phenomenon in which the scientific literature was used frequently or not at all has been denoted by the phrase 'zero or multiple coupling' and will be discussed more fully below.

The information inputs obtained from the scientific literature mainly described either the properties, composition or characteristics of materials and components or provided theories and general principles. It is of particular significance that of the information from ten major external sources, that provided by the scientific literature had the greatest impact on the resolution of technical problems; that is, it contributed most directly to the solution adopted. These results which were derived by correlating characteristics of information inputs from outside the company with the specific source of the information are presented in Table 3.

Table 2

Distribution of Use of Outside Company Sources

Source	Number of Innovations having specified number of Information Inputs								
	0	1	2	3	4	5	6	>6	
Trade Literature	7	10	9	2	1	1	0	0	
Technical Literature	18	5	4	3	0	0	0	0	
Scientific Literature	20	5	0	1	0	0	3	1	(10)
Textbooks	26	2	0	2	0	0	0	0	
Handbooks	18	6	4	2	0	0	0	0	
Reps. & Customers	18	7	2	3	0	0	0	0	
Supplier Companies	13	7	7	1	1	0	0	1	(11)
Universities	18	2	6	2	1	0	1	0	
Consultants	24	3	1	1	1	0	0	0	
Research Assoc.	25	2	0	0	0	1	1	1	(11)

The majority of scientific literature used was in the form of reports of original research work, mostly carried out in universities and was not directed toward achieving anything related to the innovation in which it was subsequently used. The average age of the literature (from the date of publication) was 12.2 years with a standard deviation of 9.1 years. Moreover, 26 of the 36 inputs from the scientific literature had been produced within the decade previous to the innovation. As the average time elapsed since the problem-solver left the education system was 17 years (with a standard deviation of 7.7 years) it is apparent that the problem-solver does rely on information generated by scientific research, and that he continues to obtain such new information after he completes his formal education. These results are in direct contrast to the widely accepted "education cycle" hypothesis (15), which states that there is a time delay of the order of twenty to thirty years between most basic research and its technological application.

Table 3

Comparison of Characteristics of Outside Information Inputs with the Specific Source of the Information

	Number of Information Inputs								
	Source								
Characteristics	A	B	C	D	E	F	G	H	I
Nature									
Existence or availability of equipment or materials with particular capabilities	20	5	1	9	7	9	2	1	4
Properties, composition, characteristics of materials or components	14	7	17	7	5	6	4	3	7
Test procedures and techniques	1	3	1	5	1	3	1	3	1
Operating guidelines, required specifications, technical limitations	1	1	2	0	2	2	0	2	0
Location of information	1	1	0	0	1	4	7	1	3
Theoretical basis, explanatory general principle	3	2	13	4	1	2	5	0	3
Design-based information	3	3	1	3	1	9	4	2	4
Existence of specialist facilities/services	0	1	1	0	2	4	7	0	2
Mechanism									
Search expt.	39	20	35	28	0	1	6	1	5
Sought help	0	1	1	0	16	31	20	11	11
Other's initiative	3	0	0	0	3	6	4	0	6
Serendipity	1	0	0	0	1	0	0	0	0
Non-specific search	0	0	0	0	0	1	0	0	2

A = Trade Lit., B = Tech.Lit., C = Sci.Lit., D = Textbooks, E = Reps. & Customers, F = Supplier Cos., G = University, H = Consultants, I = Research Associations

The other printed sources of scientific information inputs were textbooks describing scientific theories and principles, and scientific handbooks providing data and characteristics of fundamental or natural materials. The use of these sources also displayed the characteristic 'zero or multiple' coupling.

Another major vehicle of information transfer by means of printed matter was the technical literature. A technical journal was defined as one containing articles of a technical nature, advertisements of products and processes and general news of relevance to a single or a group of industries. Its aims are different from those of the scientific literature; it attempts, not only to provide new knowledge, but, more than the scientific literature, to provide a focus for groups, which may reside in diverse industries, facing common technical problems. The technical literature was used in a large proportion of the innovations studied and provided a wide range of information which was, of course, generally available throughout the industry.

By comparison the trade literature - that disseminated by firms to provide information about their products - in the form of catalogues was the major single source of technical information from outside the company (see Table 1). It was used in almost all innovations (see Table 2) and, not unexpectedly, provided in particular information about the existence or availability of materials or equipment with particular properties (Table 3). It was apparent that many of the technical problems encountered during the innovation process involve finding a material or a component with suitable properties to fulfil a specific purpose and the search strategy is to determine, firstly, if there is a suitable product already on the market.

Personal Contact

The other major form of coupling of science to technology occurred through the contact of the problem-solver with members of the scientific community. The scientists themselves were located in a variety of institutions including universities, government laboratories and research associations.

Of particular interest here is the close coupling of the problem-solver with scientists working in universities. As can be seen from Table 1, contact with these scientists provided an important source of information from outside the firm. The pattern of person-to-person contact in the transfer of scientific information was similar to that which occurred in the use of scientific literature. That is, less than one half of the innovations depended for their completion on information acquired by contact with scientists but those that did obtained a number of information inputs from the same or a related source (see Table 2).

Information was obtained from universities through a number of modes of interaction : occasionally by employing academic scientists directly as consultants and by supporting research in a university which was relevant to company interests, but more frequently by requesting advice and assistance, and by the use of specialist facilities such as instruments or libraries. As we have remarked, these modes of coupling did not occur as single isolated events in the course of problem-solving. Rather, they tended to occur frequently or not at all. The establishment of coupling between a firm and a university characteristically followed a 'cascading' pattern; originating perhaps with the firm hiring a graduate from the university or sponsoring research there through the gradual establishment of closer relations, culminating in a real mutual understanding of interests and needs. Scientists at universities were used largely in a supportive role-- attesting to the feasibility of a proposed solution or providing details of the location of specific information or specialist facilities and services of direct relevance to the problem under consideration. Such a pattern corresponds very closely to that uncovered in Project Sappho (16) : that successful innovations exhibited a closer coupling with the scientific community regarding the specific projects than did unsuccessful innovations. Of course, some relationship must exist prior to the innovation in order to provide the opportunity for this more specific form of coupling.

The essentially supportive role of person-to-person contact with scientists in universities is illustrated by the finding that the impact of the information transferred was not in the provision of basic ideas for the innovation. Rather, the scientist tended to respond to a previously posed problem and while he was in some cases able to provide the solution directly, he was more frequently able to suggest alternative ways in which the problem might be tackled or to narrow the range of considerations or to provide equipment and procedures with which to test the feasibility of an industrially-generated solution. It frequently happened that once started on the path suggested by the scientists the solution followed with few major stumbling blocks.

The research associations provided an extreme sample of the 'zero or multiple use' of information sources which we have described previously. This source provided the fifth highest number of information inputs (Table 1) but was, in fact, used in only five of the innovations - three of these five firms made extensive use of this source (Table 3). While the number of innovations involved with this source is too small to admit any generalizations to be made, it may be relevant that only medium-and low-research intensity industries made use of the research associations. This would suggest, and such comments were made more than once during the interviews, that firms, lacking an 'in-house' capability, rely on expertise and the facilities of the research associations when they do decide to develop a new product.

The type of information which this source provided was a mixture of the scientific and the technological and involved the properties or characteristics of materials, design information and the location of specific pieces of information. Thus, the research associations appear to play a role complementary to that of the universities and, because they are situated within both the scientific and technological communities, would appear to be in a unique position to promote coupling between the scientific community and industry.

Contacts in industry such as sales representatives, customers, and the technical sales staff in supplier companies were one of the two major sources of technological information from outside the company and were used by the vast majority of problem-solvers during the process of innovation though in most cases only once or twice. It comes as no surprise to learn that many of the information inputs are acquired from trade sources, but the pattern of use so different from that for scientific information is of interest. It would appear that because of the structure of the industrial community the problem-solver can initiate short-term coupling with other members to obtain specific information or assistance but that little or no long-term benefits ensue from such a relationship.

The Role of Education

It might be expected that the education of the problem-solver would considerably affect both the type and the source of information he characteristically seeks. Examination of the use of general sources of information in terms of the qualifications of the problem-solvers revealed that problem-solvers with all standards of educational qualification contributed approximately the same total number of information inputs except for the three problem-solvers with O-levels. However, comparison of the use of the three general sources shows that those with a university education and particularly those with a Ph.D. relied much more on external sources of information while those with an industrial education depended on information they already possessed (see Table 4). In particular, the problem-solver with a university education used the scientific literature, commercial consultants and scientists in universities to obtain information to solve technical problems.

The only external source used significantly more by those with an industrial education were the experts in companies supplying them with raw materials. Hence the reliance of the problem-solver with a university education on sources of information outside the company would appear to be closely related to the sources of information he learns about during his education, i.e., the scientific literature and the availability of expertise in universities.

The sources of personal expertise relied on by the problem-solver with an industrial education were identified as education, experience in industry, trade contacts and regular browsing of trade literature. Hence those with an industrial education rely more on their education and experience to solve technical problems whereas those with a university education use it to extend their resources.

Table 4

Comparison of Use of the Various Sources of Information Inputs with the Education of the Problem-Solver

	Number of Information Inputs Educational Qualifications					
	O-level	Batchelor degree	Ph.D.	ONC	HNC	Grad. Inst.
a. General Source						
Outside Company						
Total	17	195	86	34	103	39
Mean	5.7	9.8	14.3	8.5	10.3	7.8
Inside Company						
Total	15	228	49	43	78	45
Mean	5.0	11.4	8.2	10.8	7.8	9.0
Personal						
Total	13	187	56	56	144	78
Mean	4.3	9.4	9.3	14.0	14.4	15.6
Totals						
Number	45	610	191	133	325	162
Mean	15.0	30.5	31.8	33.3	32.5	32.4
b. Specific Source						
Outside Company						
Trade Literature	0	18	4	5	13	3
Technical Lit.	2	7	5	0	7	1
Scientific Lit.	0	31	2	0	1	2
Textbooks	0	5	0	0	3	0
Handbooks	0	7	2	1	8	3
Reps & Customers	0	8	2	3	6	0
Supplier Customers	3	13	4	3	16	0
Universities	2	15	3	0	6	4
Consultants	0	13	8	1	1	0
Research Ass.	0	22	12	11	11	0

Organizational Characteristics

High research-intensity industries, i.e., science-based, could be expected to show different patterns of coupling and information use than low research-intensity, i.e., craft-based industries. Reference to Table 5a shows that use of the three general sources does not vary significantly from a random distribution for the high and medium research-intensity industries, but the low research-intensity industries relied far more on external than on internal sources. Having only a small R D capability, they are forced to use external sources of information in order to carry through an innovation. Table 5b shows that these industries show a distinct bias towards the use of trade contacts such as sales representatives and customers, and also consultants and research associations compared with the more research intensive industries.

Table 5

Comparison of Use of the Various Sources of Information Inputs with the Research Intensity of the Industry

	Number of Information Inputs Research Intensity		
	High	Medium	Low
a. General Source			
Outside company	163	74	63
Inside company	156	74	37
Personal	208	75	37
b. Specific Source			
Outside company			
Trade literature	26	8	9
Technical literature	12	9	1
Scientific literature	25	7	4
Textbooks	4	1	3
Handbooks	12	5	3
Reps. Customers	7	8	5
Supplier Cos.	22	7	10
Universities	20	5	5
Consultants	4	2	6
Research Assocs.	0	16	8

Other significant findings were that the more active the strategy of innovation adopted, the more the problem-solver relied on scientific literature to resolve technical problems; the larger the scale of the innovation, the more sources of information from outside the company were used. Also the added literature, both scientific and technical, rather than personal contact, provided the major sources of information.

CONCLUSIONS

The mode of coupling of the industrial community with scientific sources has been shown to be distinctly different from that with technological sources. Scientific sources were used either not at all or to a considerable extent, i.e., zero or multiple interaction; whereas the pattern of use for technological sources was distributed more evenly at a medium level throughout the innovations studied. This pattern of 'zero or multiple' use for scientific sources has been found in the use of scientific literature reporting original research, scientific handbooks and textbooks, and in the contact of the problem-solvers with the scientific community in universities and in research associations. Similarly, the pattern of "even" use of technological sources was found for both the use of technological literature and contact with the technological community. It would appear that the cost of establishing coupling with science is, or is perceived to be, higher than that required for technology, but that once this barrier is overcome, a cascading expansion of coupling occurs leading to a considerable contribution of information resolving technical difficulties and promoting effective innovation. Hence it is apparent that different strategies for coupling need to be adopted depending on the nature of the information sought and its likely location. One particular key to successful coupling with both the scientific community and its literature would appear to be the possession of a university education. A number of mechanisms to promote this coupling have been described in recent publications. (17, 18, 19)

Effective performance of a national research-production system depends not only on each element efficiently executing its appropriate functions but also on the coupling between these elements at both policy and execution levels. In most countries there would appear to be the potential for a considerable return by investing greater resources in improving this coupling. Hence efforts must be directed to developing environments in the various institutions conducive to coupling without, however, unduly interfering in the internal mechanisms of them. However, it must be remembered that coupling is most effective at the informal and personal levels. While opportunities can be provided for this kind of personal interaction to be initiated, it cannot be legislated into existence.

In recent years considerable effort has been devoted to the development of sophisticated information systems. The assumption underlying this approach to information problems is that information is an essentially passive element; thus improving technology transfer is merely the problem of delivering the appropriate units of information when required to the researcher or innovator. However, as this study has shown, the most effective coupling occurs when an active approach is adopted on both sides of the interface. Even when the ultimate source of particular information is in literature, the coupling agent often has played a vital role in suggesting that literature because of his familiarity with it and his awareness of the problem, or he has translated a particular piece of information contained in the literature into a form in which it is directly applicable to the industrial innovator's problem. It is the promotion of an active rather than a passive conception of coupling in all the institutions of the research-production system that holds the greatest prospect for the improvement of technology transfer.