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Science-Industry Interaction In The Process Of Innovation - The Importance Of Boundary-Crossing Between Systems

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Abstract:

Applying recent theoretical concepts of social systems to innovation networks of firms leads to the presumption that linking firms to non-business systems stimulates innovativeness more than remaining within the business system's set of routines. Crossing the border to science, in particular, increases the diversity of firms' innovation partners and respective innovation stimuli which, in turn, improves the capability of firms to introduce more advanced innovations. This contention is supported by a statistical analysis using data from a research project on innovation systems in several European regions. The results demonstrate that partners from science are more important than the firms' customers for the introduction of products which are new to the market.

1. Introduction

The intention for this article is to discuss different views of the innovation system concept. We will focus on the question whether innovation is favoured more by internal interaction within the business sector or by interaction with science, crossing the border to a different system. Recent theoretical concepts of social systems lead us to the contention that there is not a single specific ‘innovation system’, but, on the contrary, it is the exchange between actors belonging to different social systems which has a positive influence on firms’ innovativeness. We will show that the key advantage of engaging in external relations for realizing innovation projects is based on diversity, i.e., linking up to different systems instead of remaining within a system’s set of routines. In this article we will concentrate on the interaction between industry and science. We will, in particular, analyse characteristic differences in the types of innovation networks established for different levels of innovation activities, distinguishing between ‘incremental’ innovations and products which are ‘new to the market’. We assume, further, that the more far-reaching innovations are favoured by external relations to partners from the science system whereas minor innovations are more likely to be influenced by partners from the same system, i.e., the business sector. This will be tested using data from the European research project “Regional innovation systems: Designing for the future” (REGIS, see acknowledgement).

In this article the term ‘innovation’ concerns only products, including goods as well as services. Process and organizational innovations are not considered. The dichotomy ‘new for the firm’ versus ‘new to the market’ will be the basic criterion in this article to differentiate between levels of innovativeness. The innovation category ‘new for the firm only’ comprises modifications and improvements of existing products or services as well as products or services which are new in the firm’s range, extending it or substituting certain items. Usually it is incremental innovation with small-step technical changes applying widely available knowledge. If the innovation is successful, the competitive position of the firm within the same market will be improved. Products or services which are ‘new to the market’, on the contrary, offer functions which are, at that time, not available elsewhere on the market. Therefore such products do not face a competing product, leading to a temporary monopoly in certain, often very small and specialized markets. Usually such innovations require more than incremental development. Nevertheless, the range of technical progress linked to this type of innovation is very broad. The most radical innovations may even be the basis for new technological trajectories, defining the technological opportunities for further innovations, the development of complementary applications, and the emergence of a group of related markets (Dosi 1988; Nelson and Winter 1977).

2. The 'system' concepts in innovation theory

Views about the character of the innovation process have changed considerably in the past years. Both the traditional Schumpeterian and the linear product cycle model have been found inadequate. Innovation is neither an exclusive internal activity of firms in order to achieve monopolistic advantages (Schumpeter 1934), nor does it follow a mechanistic sequence from research to production and to the market, in which research is the main driving force, as the linear model and product cycle theory argue. Increasingly, innovation is regarded as an evolutionary, non-linear, and interactive process between the firm and its environment (Kline and Rosenberg 1986; Dosi 1988; Malecki 1997).

The concept of non-linearity implies that innovation is stimulated and influenced by many actors and sources of information, both inside and outside the firm. It is not only determined by scientists and engineers working in R&D or the top-management. In addition, there are interactions feeding back the experience of production, marketing, and of customers into earlier phases of the innovation process.

Interactivity of the innovation process refers to the internal collaboration between several departments of a company (R&D, production, marketing, distribution, etc.) as well as to external cooperations with other firms (especially with customers and suppliers), knowledge providers (like universities and technology centres), finance, training, and public administration. A wide range of partners may contribute to a firm's capacity to innovate.

It is in this context that the concept of 'innovation systems' has been introduced (Lundvall 1992; Edquist 1997). Initially, this concept has been applied to the national level. The studies have shown that innovation systems differ significantly between countries, depending on their economic structure, knowledge base, and institutional specificities (Nelson 1993). More recently, there has been a growing interest in innovation systems at the regional level (Autio 1998; Braczyk et al. 1998; Cooke et al. 2000). Questions raised are to which extent innovation systems can be found also at the regional level, how they are functioning, and how they are linked with systems at higher spatial levels. The importance of the regional level results from the fact that the transfer of tacit knowledge is tied to individuals which requires either face-to-face interaction or the mobility of personnel, both predominantly done within rather narrow spatial limits. The systems approach has reasonably extended the old linear model of innovation in conceptualizing 'innovation' as interactive, having feedback loops from market to R&D and reverse, being characterized by learning processes, and involving external institutions and actors. Kline and Rosenberg (1986) have captured these interdependencies in their so-called "chain link model of innovation".

Lundvall et al. (1992) discussed the concept of a national innovation system for the first time in a more comprehensive analysis. It was based on the following definition (1992, p. 2): "A system of innovation is constituted by elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge." For a comparative analysis of several national case studies Nelson and Rosenberg (1993, p. 4) also used the term 'innovation system', being "a set of institutions whose interactions determine the innovative performance of ... firms". From their point of view it is not necessary "that the system (is) consciously designed, or even that the set of institutions involved works together smoothly and coherently". But also more recent investigations of innovation systems do not change this concept of interacting elements substantially. Edquist (1997, p. 14) proposes to specify an innovation system by including "in it all important economic, social, political, organizational, institutional, and other factors that influence the development, diffusion, and use of innovations". He wants to avoid to exclude "potentially important determinants (to understand and explain innovation) a priori". This reflects a tendency to broaden the system to include any possible source of influence without dealing with the question where an innovation system starts and ends. This becomes especially obvious with the last definition we will quote here. Padmore et al. (1998, p. 606) argue that "a system approach accepts that in principle 'everything interacts with everything' but recognizes that in practice, some interactions matter more than others." Edquist

(1997, p. 27) frankly admits that no innovation systems approach was so far able to "provide a sharp guide to what exactly should be included in a '(national) system of innovation'; they do not define the limits of the systems in an operational way." Referring to his own approach he argues that "there is simply no given demarcation between a system and its surrounding context".

The definitions quoted above show that the models of innovation systems are based on a rather traditional view of systems as interaction networks. Models of national and regional systems of innovation are conceptualized in a cybernetic way of related actors influencing each other. This basic concept has not been changed since it originated. The system models are not operationalized in the important respect of the boundary of a certain social system, the specific features making the distinction between this system and another. Instead of conceptualizing the innovation system along the element/relation dichotomy, we will therefore use the system/environment dichotomy of social systems theory as a basis for the discussion of the role of inter-system exchange in stimulating innovation.

3. The concept of 'self-referential' systems in social theory

In the 1980s a new systems concept - originally formulated from the biologists Maturana and Varela (1987) analysing the independent character of cellular organization - has spread in sociology which is based on the assumption that social systems are autonomous self-referential entities. This means, basically, that the behaviour of a social system is independent in interpreting external influences, organizing its internal structure, and behaving in the context of its environment. External stimuli cannot determine the system's responses. Insofar, the system is closed. Nevertheless, it interacts in numerous ways with its environment, using as well as providing resources and information. In this respect, the system is open. As a consequence, the environment restricts the set of alternatives of any system. Ultimately it may even destroy the system, but it can never control its behaviour.

Accordingly, the research focus has shifted to the question how the system maintains its independence and how it interacts with its environment. The central dichotomy is not between 'element' and 'relation' but between 'system' and 'environment'. In social systems theory there is an increasing interest in systems concepts based on self-reference and self-organization. Older concepts of social systems, on the contrary, operationalized the system along the functions which are necessary to maintain a certain structure which was taken for granted or to adapt its structure to a changing environment. Eventually, the question was raised for the functional role of systems per se. The formation of systems is seen now as a way to reduce the complexity of the world human beings are confronted with. The reality an individual has to cope with is less complex within a system, because it can and must use the common set of interpretations concerning the part of reality which is relevant for the system. The interpretations are valid for all members of the system which, on the one hand, reduces ambiguity, but on the other hand, restricts alternative interpretations of the system-specific reality (Willke 1993).

It was primarily Luhmann (1991, 1996) who has introduced the concept of ‘autopoiesis’ into the social sciences. He deals with the questions how social systems separate themseleves from the environment, how they maintain a boundary between their entity and the surrounding world. Being convinced that the autopoietic model of self-organization is not restricted to cellular processes, he operationalizes this concept for social systems. Of course, there are no direct analogies to the biological processes of cellular metabolism. But it is possible to transfer the principle - the reproduction of the elements of the system through the elements themselves. Social systems require therefore elements which are specific for this type of system only. Luhmann argues that this element is ‘communication’. Within a certain social system there is a common standard of communication in order to interpret internal processes and relations to the environment. This makes a social system distinct from its environment and other systems. Accordingly, any social system is distinguishable by different modes of interpretation, decision rules, objectives, and specific communicative standards (channels, methods, technical means, and so on). The common understanding of activities within the system, of influences on the system, and of behaviour against the environment separates the system from the environment. Communication is reproduced through the continuous process of sending or disseminating and processing relevant information. The central mechanism to separate system-relevant from irrelevant information is a system-specific medium (the most often quoted example is ‘money’ for the business system). It contains only the system-specific information and it is coded in an unambiguous way so that it is understood by all individuals involved in the system. This enables a continuous chain of communication relations and, as a consequence, the continuous reproduction of the social system.

It is important not to confuse systems and organizations. Many processes of change observed in social entities are changes in organizations not systems. The terms ‘system’, ‘institution’, and ‘organization’ are ambiguous concepts depending on the theoretical context in which they are used. There are no generally accepted definitions in social science. We apply the term ‘system’ to entities based on common standards of communication and information, a common set of interpretations, and a shared view of values and meaning (‘*Sinn*’). In some sociological concepts ‘institution’ is operationalized in a very similar way (Reinhold et al. 1992). To keep a clear distinction between the terms ‘system’ and ‘institution’, we are going to use ‘institution’ (and ‘organization’ as a synonym) for entities which are based on membership, specific tasks of the members (participants), certain methods to perform these tasks, explicit and impersonal rules, power to enforce the rules, and a formalized structure (Reinhold et al. 1992). From this clarification follows that any individual is involved in several systemic contexts performing as many roles. Individuals are not the specific elements of systems, these are communications. But they are the actors maintaining the communicative process and serving as the nodes for the interpenetration of those systems they are participating in. In the case of individuals the involvement in many systems is necessary. In the case of institutions/organizations relations to more than one system are not necessary, but, actually, organizations linked to several systems are more the rule than the exception.

4. Why there is not a single ‘system of innovation’

The self-referential model of social systems leads us to a critique of the current innovation systems approach. There is not one system aiming at innovation but, on the contrary, several social systems participating in the process of innovation. A differentiated innovation system would have to have common sets of interpretations, the same decision rules, shared objectives, and identical ways of communication. Due to the fact, however, that there are very diverse actors taking part in the process of innovation - clearly reaching beyond industry - such a level of concurrence does not exist. There are important non-business and non-profit elements in an innovation system, in particular science and politics. We are confronted with a situation where, at least, three different social systems - ‘business’, ‘science’, and ‘policy’ - with different modes of interpretation, decision rules, objectives, and specific communicative standards are interacting. The business system is profit-oriented and communicates via the price mechanism. The science system aims at the production of knowledge and communicates via publications. In fact, the specific advantage of what is usually called ‘innovation system’ is not being a system in the meaning of a separate and autonomus entity, but the process of collaboration between actors who often belong to different systems. It is the exchange of formerly unrelated information that reinforces innovativeness. Crossing the border between different systems stimulates changes in the systems in general. In the particular case of industry-science interaction this might, among other things, result in product innovation.

As far as the perspectives guiding R&D are concerned, there are differences between scientists and researchers working at universities, in contract research organizations, or in companies. These differences, however, are due to different organizational contexts and not to systemic differences. Both academic scientists and researchers in profit-oriented companies are involved in the science system. The difference results from the additional participation in other systems. Company or contract researchers have also to consider the business system’s ways of operation. Usually, the organization provides rules how the two systems’ perspectives have to be integrated by their employees engaged in R&D. The most obvious differences concern the disclosure of knowledge and the reward systems. “Pure” scientists focus on publications while company and contract researchers focus on patents and commercially useful results (Dasgupta and David 1992). For researchers involved in both systems it can be very difficult to manage the conflicting interests of making R&D-results public versus restricting access through patents or secrecy. Related to this, industry research has a more pronounced interest in applied short-term research, and it is usually more flexible and willing to engage in interdisciplinary R&D than university science which tends to be more rigid (Meyer-Krahmer 1997). It is necessary, therefore, to distinguish between scientists who are able to follow exclusively the science system’s perspectives (mainly working at universities) on the one hand and company or contract researchers who have to integrate the science and business systems' perspectives (either by themselves or by organizational rules) on the other.

It is very important to distinguish the relation between systems from the relation between or within organizations. The science and the business systems are based on different modes of interpretation, decision rules, objectives, and ways of communication. There is no overlapping of the systems, but there is interaction between the systems, either within one organization or between several organizations. This difference is rarely considered when arguing for the emergence of a new form of science - the so-called "entrepreneurial science" as a new type of science-industry interaction (Etzkowitz et al. 2000). The concepts 'system' and 'organization' are confused, neglecting that it is the clear distinction between the two ideal types of organizations 'university' and 'firm' which gets more and more blurred through profit-oriented contract research institutions, but not the distinction between the systems' operating principles.

From the perspective of self-referential systems theory the major impulse from the science system to initiate innovation in the business system is either due to the provision of new information, not accessible or available within industry, or the collaborative generation of new knowledge. Cooperation can also trigger the change of traditional perspectives, decision rules, and objectives of firms without actually adding knowledge. Inter-system communication can raise interest to discuss the objectives per se or their practical usefulness, i.e., an appropriate relation between objectives and results. Changes can be stimulated also in technical and organizational respects. Of course, all this is not restricted to one participating organization - the firm - only. It is obvious that interaction between science and industry also stimulates change in universities and research organizations. In any case, the stimulating effect is eventually a consequence of adding novelty and diversity to a specific organization's rules, modes of behaviour, and technologies.

It is interesting that 'diversity' is rarely discussed in this way in the literature on innovation systems. The importance of diversity is recognized, but usually restricted to the number of industrial sectors, types of outputs (products), processes, institutions, and organizations (Saviotti 1997). Diversity is not discussed under the perspective that it results from the interaction of systems based on different operational principles. In the context of ‘learning’ the role of diversity is recognized: “Diversity affects innovation because it affects technical, organisational and institutional learning and contributes to the knowledge base of the economy.” “Diversity generates novelty and affects the learning capability of the economy.” (Johnson 1992, p. 37). But it is not recognized that much of this diversity comes from different systems perspectives.

The process of systems mutually influencing each other but maintaining their separate entity throughout this process can be called ‘border-crossing’. Of course, interaction between different systems can also become routinized. In the context of innovation this might reduce the potential to stimulate change. This is a likely consequence of continuous relations between the same persons over a long period of time, because the novelty of exchanged information usually decreases once partners become locked into well-established routine interactions. It follows that interaction between science and industry per se is not a guarantee for increased innovativeness. Routine relations like testing performed by research laboratories on behalf of firms do not add much to the firms’ capacity to innovate. Also in the case of inter-system innovation partnerships the organizational relations have to be kept flexible through weak ties to a broad range of innovation partners (Granovetter 1973; Grabher 1993; Meyer-Krahmer and Schmoch 1998).

5. Innovativeness of firms and interaction with the science system

So far the discussion of innovation networks and systems has been theoretical, we turn now to empirical evidence deduced from data collected in the REGIS-research project (see acknowledgements) which investigated to what extent and in what forms innovation systems exist in several European regions. We have used the survey data for Wales (UK), Wallonia (Belgium), Baden-Württemberg (Germany), Styria (Austria), the Basque country (Spain), Aveiro (Portugal), and Tampere (Finland). The regional surveys were conducted in 1996. The statistical analysis is based on firms which are independent regarding their innovation activities (single firms, headquarters, and subsidiaries if they have sufficient autonomy to decide on innovation projects on their own). Overall, 517 observations (78% of all respondents) meet this condition (64 in

Wales, 65 in Wallonia, 76 in Baden-Württemberg, 84 in Styria, 72 in the Basque country, 43 in the region of Aveiro, and 113 in the Tampere region).

Table 1: Types of innovation and the use of innovation partners

	All firms	*Firms with products which are*	
		new for the firm only	*new to the market*
Number of firms:	517	149	206
Frequency of partners in %:			
Customers	33.5	38.3	33.0
Suppliers	21.9	18.1	24.8
Consultants	7.9	4.7	10.2
Technology transfer org.	5.2	6.7	4.9
Contract research org.	5.8	6.0	5.8
Universities	8.9	5.4	12.6

Source: REGIS-survey (1996).

The level of innovativeness of the firms responding to the REGIS-survey is, in general, high. Many firms, more than a third of the total, claimed to have introduced products which were new to the market in the past three years. These firms outnumber clearly those which have changed their product range only according to the firms' standards. These are the incremental innovators which are approximately as frequent as firms without any innovations.

The data about the frequency of external innovation partners confirm other results (Fritsch and Lukas 1997; Sternberg 1998): The most important partners are from the business sector, customers first, suppliers second. All other types of partners are far less frequent. The low importance of technology transfer organizations is especially remarkable. Overall, the willingness to cooperate seems to be rather low, especially outside the value chain or, more precisely, the firms' long established customer-supplier relations. As far as cooperations with science are concerned, there is some evidence that they are more widespread than it appears from our data. The analysis of Fritsch and Schwirten (1998) of interactions between science institutions (universities, technical colleges, and contract research organizations) and firms in certain German regions shows that the majority of research institutions (74% in the case of universities, 91% in the field of contract research) has relations to industry while approximately a third (34%) of the firms has relations to science. That interactions with science are more frequent in their study than in the REGIS-survey can be partly explained by the broader range of types of interaction. The REGIS-data in Table 1 refer to cooperations in the innovation process while the data of Fritsch and Schwirten include also transfers of personnel, training, and occasional informational contacts.

Between the two categories of innovative firms there are some characteristic differences: Incremental innovators rely more frequently on their customers as innovation partners than firms with products which are new to the market; as far as suppliers and consultants are concerned, it is the other way round. The more advanced innovators are also interacting more often with universities, they are the most frequently used innovation partners behind customers and suppliers. For incremental innovators, on the contrary, universities as well as all other types of innovation partners except customers and suppliers play a negligible role.

The location patterns of the innovation partners support the view that providers and mediators of technology and know-how are rather close to the firms (see Table 2). This applies most of all to consultants and technology transfer agencies. But also as far as the research sector is concerned partners are often located in the same region, but here the national level is still at least as important. On the contrary, customers and suppliers are primarily located within the home country and countries of the European Union, regional customers and suppliers are less frequent. This shows that interactions with science and technology often require personal collaboration favoured by short distances which enables frequent contacts. Obviously, proximity is less important in the case of relations within the business sector. But nevertheless, in spite of modern ICTs, 43% of the respondents indicated that proximity is important for their innovation partnerships.

Table 2: Location of the innovation partners

	Regional	*National*	*EU*	*Global*
Share of partners located on a certain spatial level in the total number of the respective partners (in %):				
Customers	38.7	59.0	61.8	28.3
Suppliers	38.9	53.1	53.1	14.2
Consultants	63.4	46.3	34.1	14.6
Technology transfer org.	88.9	40.7	29.6	11.1
Contract research org.	53.3	66.7	23.3	10.0
Universities	60.9	60.9	19.6	8.7

Source: REGIS-survey (1996).

Using the data set of the REGIS-survey we have tested the hypothesis that firms which involve partners from science in their innovation processes are more likely to be able to realize advanced innovations (i.e., being new to the market) instead of innovations which are only new for the firm. Accordingly, partners from the business system were expected to be more relevant for incremental innovation. Included in this analysis are only firms which have been innovative with respect to their products in the past three years - in total 318 valid cases. As far as the statistical method is concerned, we have applied a Logit-model to relate the probability of having introduced a certain type of product innovation to the presence or absence of certain external innovation partners.

The dependent variable in our Logit-model is binary: ‘introduction of a product innovation which is new to the market’ or ‘any kind of change in the product range of a firm without being new to the market’ (called ‘new for the firm’). All innovation categories refer to a time period of three years, i.e., includes product or service innovations which have been introduced in the past three years. The group of variables we are interested in represents certain types of innovation partners. These variables are discrete; cooperation partners are either present or absent. Due to the fact that innovativeness is also influenced by other factors, we have further controlled for firm size, region, and industry. The size of a firm is described by the number of employees. For the two other features dummies were used. The benchmarking base is the most innovative region (Baden-Württemberg) and industry (electrical equipment/electronics) respectively.

Table 3 shows the results of the Logit-model: Direction and strength of the influence of the independent variables on the dependent innovation variable (β), the significance of this influence measured by the t-value and the corresponding probability-value (representing the significance based on the t-distribution), and the goodness of fit of the whole model, measured by the Log-likelihood ratio, ρ^2 and the adjusted ρ^2 (the latter considering the number of independent variables). The meaning of ρ^2 is similar to the r^2 in regression analysis (Maier and Weiss 1990).

Table 3: The influence of partners and firm characteristics on innovativeness

	Products new to the market / products new for the firm only			
	β (1)	t-value	Probability	Significance (2)
Important innovation partners:				
Customer firms	-0.262	-0.683	0.247	
Supplier firms	0.908	2.210	0.014	**
Consultants	1.225	2.142	0.016	**
Technology transfer organizations	-0.541	-0.739	0.230	
Contract research organizations	-0.483	-0.771	0.222	
Universities	0.994	1.677	0.047	**
Characteristics of the firms:				
Employment	0.000	1.013	0.155	
Region:				
Austria (Styria)	-1.215	-1.799	0.036	**
Belgium (Wallonia)	-0.891	-1.606	0.054	*
Finland (Tampere)	-2.040	-4.238	0.000	***
Spain (Basque country)	-2.839	-3.678	0.000	***
UK (Wales)	-0.908	-1.629	0.052	*
Portugal (Aveiro)	-1.716	-2.375	0.009	***
Industry:				
Food, beverages	-0.260	-0.412	0.340	
Textiles, clothes, leather	-0.791	-1.121	0.131	
Wood (products), paper	0.579	0.874	0.191	
Chemicals, rubber, plastic	-0.277	-0.567	0.285	
Metal, metal products	0.122	0.255	0.399	
Machinery	-0.414	-0.831	0.203	
Other industries	-0.265	-0.401	0.344	
Transport equipment	-0.167	-0.283	0.389	
Producer services	0.018	0.035	0.486	
Alternative-specific constant	1.501	3.493	0.000	***
Model significance:				
Number of cases		318		
Log-likelihood				
Start		-220.421		
End		-184.224		
lr-test		72.393		
ρ^2		0.164		
ρ^2 corr.		0.060		

(1) Direction and strength of a variable's influence on the level of innovativeness
(2) Significance: * probability < 0.1, ** probability < 0.05, *** probability < 0.01
Source: REGIS-survey (1996).

Only three types of innovation partners have a significantly positive influence on the probability of having introduced products which are new to the market - suppliers, consultants, and universities. Referring to firm characteristics only the region is important whereas size and industry are not significantly distinguishing between incremental and more advanced innovators. Referring to the region the investigated firms in Baden-Württemberg surpass the firms of the other regions clearly. The differences between the other regions are far smaller. This extraordinary position of Baden-Württemberg can be partly explained by the rich institutional setting as far as technology, innovation, and research are concerned which obviously stimulates the innovative performance of the firms. Overall, however, the significance of the model (ρ^2) is rather low. External relations have some influence on the innovativeness of firms, but they are not decisive for enabling firms to introduce more advanced innovations. The statistical analysis leads to the following conclusions:

(1) According to the survey-data, universities stimulate or enable firms to introduce more advanced innovations whereas contract research organizations have no positive effects in this respect. “Pure” science seems to be more effective in stimulating advanced innovations than applied research focusing on commercialization.

(2) The generally most frequent innovation partners - the customers - have neither a positive nor significant influence on the frequency of advanced innovations. However, other partners from the business system - suppliers and consultants - do have a positive influence. They frequently have a bridging function to knowledge suppliers and transfer important technology and know-how to innovating firms, enabling them to introduce more advanced innovations.

(3) On the contrary, institutions particularly designed to act as intermediaries between science and industry like technology transfer organizations do not seem to be effective in stimulating advanced innovations.

(4) Internal capabilities are more important factors than external relations in stimulating or enabling a firm to go beyond incremental innovation activities and to introduce more far-reaching innovations.

The importance of science for firms’ innovation activities is due to providing new knowledge, creating knowledge interactively with firms, and stimulating innovation projects. The provision of scientific knowledge is the most widely recognized contribution of universities to innovating companies. New knowledge is transferred to the industry in several ways. Most important are personal contacts and publications. But science often provides also new instruments, techniques, and methods which can be used in applied research and development by firms (Meyer-Krahmer 1997). Technological developments are more likely to be far-reaching in universities than in company- and contract-R&D, because universities focus primarily on the production of new knowledge independent of economic considerations. Therefore new technologies based on scientific knowledge are often generic offering the potential for further product innovations and new related markets. Scientific knowledge is often transformable to a wide range of commercial applications. The fact that contract research is less independent of economic considerations, focusing more on rapidly commercializable R&D, might explain the insignificant role of this type of institution in stimulating advanced innovations.

The direct influence of science results primarily from joint R&D-projects. In such collaborative cases scientific knowledge is not only transferred, but new knowledge interactively created. This might be the actually most important role of science in stimulating more advanced innovation. Fritsch and Schwirten (1998) conclude that the main contribution of research organizations to firms' innovation activities affects the early phases of the innovation process, i.e., creating and developing new ideas, but that they are less important regarding the realization of already existing ideas. According to an investigation of three German regions (Fritsch and Lukas 1997), slightly more than a quarter of the innovating firms (27%) have joint R&D-projects with research institutions. Research contracts are placed only by 19% and thesis collaboration is done only by 23% of innovative firms. In spite of the fact that the most frequent type of relations between firms and science (30%) is still the use of equipment and laboratories, the results confirm the importance of "real" cooperation (i.e., actual collaboration) in order to stimulate innovation. And it is not only the business partner who benefits from such a cooperation. Academic researchers, too, rank collaborative research very high, more important than contract research and consultancy. Obviously, innovation cooperations often consist of bi-directional knowledge exchange, including also the transfer of knowledge from industry to science (Gibbons et al. 1994; Meyer-Krahmer and Schmoch 1998).

The stimulation of innovation projects results from the “clash between different modes of behaviour and habits of thought” (Johnson 1992, p. 36) - routines, heuristics, decision-making methods, values, incentive systems - implicit to the interaction between science and business organizations. Communication and interaction among “people with different information, skill, knowledge, competence, incentives and values ... increases the probability for unforeseen new combinations and for discoveries to occur, i.e., it may generate unexpected novelty. It may also increase the capacity to utilise such unexpected novelty, which is fundamental in the innovation process” (Johnson 1992, p. 36). Modes of behaviour and habits of thought differ more between the business community and university scientists than contract researchers, again a potential reason why contract research is not able to significantly stimulate advanced innovations.

The negligible role of customers concerning the stimulation of products which are new to the market is a surprising result of the REGIS-project. This seems to be a contradiction to the fact that customers are the most frequent innovation partners (see Table 1). But obviously, the contribution of customers is rarely stimulating more advanced innovations of firms. A likely reason why customers have no significant positive influence on firms in this respect is that users or consumers tend to stick to already known solutions and applications. They are usually not willing or ready to assess unfamiliar product or process innovations or to formulate an explicit need for them (von Hippel 1988). They usually are not the originators of ideas too far from what they are accustomed to. If a firm innovates in close interaction with such clients, it is unlikely that it will engage in more advanced innovation projects or develop radical solutions.

Furthermore, risk averse firms tend to link their innovation activities to their customers, because the exact knowledge of the clients’ demands reduces the risk for the innovating firm to end up with a commercial failure. At the same time, however, this strategy impedes the recognition of more remote opportunities for product development. Demand-pull strategies of innovation are more widespread than those exploiting technological capabilities due to better chances of commercial success (Nelson and Winter 1977). A survey on R&D-cooperation in three German regions (Baden, Hanover, Saxony) confirmes the close involvement of customers in many firms’ innovation activities. Nearly half of the innovating firms include customers in the planning and operation of their innovation projects. This close form of interaction is only slightly less frequent than casual contacts for information purposes (Fritsch and Lukas 1997). The feedback by users of the products about quality improvements leads to modification activities within the existing product concept. It is very likely that close interaction with the client restricts a firm to incremental innovation and keeps it from developing radically new products. User-producer relationships “communicate information about both technological opportunities and user needs” shaping and restricting product innovation activities. It is costly to leave such well-established relationships and it “involves a loss of information capital”. Therefore “user-producer relationships tend to be durable and selective” (Lundvall 1992, p. 51).

According to the REGIS-survey, other types of innovation partners from the business sector - suppliers and consultants - are, on the contrary, significant contributors to advanced innovation. Therefore it cannot be argued that the business system is generally of little relevance for developing innovations which are new to the market. Suppliers, especially providers of equipment, and specialized producer services are important for technology and knowledge transfer. In some cases they also transfer scientific knowledge or supply technology in which such knowledge is embodied to firms.

If direct influences of the science sector are impossible, stimulating innovation is taken over by mediating institutions. Such intermediaries are either specialized institutions like technology transfer organizations, particularly designed for this purpose, or organizations which perform this function in addition to other activities like suppliers and consultants. In contrast to the significant influence of suppliers and consultants on innovativeness, technology transfer does not seem to be successful in this respect. Contract research organizations might be able to combine applied research and science intermediation, but they, too, are insignificant partners for advanced innovation. Many firms able to introduce advanced product innovations do not seem to need mediation, but cooperate directly with scientific knowledge providers.

The empirical results - showing a tendency that relations within the business system lose importance while relations to science gain importance with increasing innovativeness - support our hypothesis that border-crossing between science and industry stimulates more advanced innovations. We also have to recognize, however, that the relative importance of external partners regarding advanced innovation is small compared to firm-specific capabilities. The model shows a low overall level of explanation which means that external relations in the innovation process are certainly not the most important factors stimulating or enabling a firm to go beyond incremental innovation activities and to introduce more far-reaching innovations. Firms obviously rely more on their internal capabilities and ideas for innovation projects than on external sources (see also Koschatzky 1998).

6. Conclusion: the importance of systemic diversity for innovation

The arguments and empirical results presented in this article lead to the general conclusion that the interaction with science stimulates firms' innovativeness, because it makes a far more diversified range of knowledge sources accessible to firms than in the case of intra-business interaction. As a consequence, firms cooperating with science increase their ability to realize more radical innovations and to introduce products which are new to the market. Science-business relations can occur between separate organizations (e.g., universities and firms) as well as within certain organizations (e.g, profit-oriented contract research institutions). Both forms are basically viable, important is the well working inter-systemic exchange.

It is therefore a reasonable target of technology and innovation policy to find ways to increase the interaction between industry and science. It is of crucial importance, however, that the systemic diversity is maintained in order to improve the innovative performance of the involved firms. As a consequence, reducing the barriers blocking cooperation between institutions belonging to the two systems should not try to make all the operating principles of science-linked organizations similar to those of the business sector. This is often part of strategies to reorientate universities more towards short-term applied R&D and an increased share of industrial funds. Adjusting the science system's modes of interpretation, decision rules, objectives, and specific communicative standards to those of the business sector eliminates exactly the factor which stimulates innovation - diversity.

The results presented above suggest that the effort to strengthen the collaboration among firms should not be overemphasized in the context of network-oriented policy strategies aiming at improving innovativeness. The importance of inter-firm collaboration, as the prominent example of Silicon Valley (Saxenian 1996) shows, is beyond doubt. But in addition, interaction with innovation-related non-business organizations, universities in particular, must not be neglected.

The first problem to be solved in order to increase science-industry interaction is the reduction of barriers which are due to systemic differences. Institutions which are part of the science system have become more important for firms' innovation activities in the recent past (Fritsch and Schwirten 1998; Meyer-Krahmer and Schmoch 1998), nevertheless, science-industry collaboration is still rare compared to intra-business partnerships. As argued above, the "assimilation-strategy" of making the operational principles of universities more similar to those of firms is counter-productive, because innovation-stimulating diversity is reduced as well. Therefore instruments are required which are able to "bridge" between industry and science maintaining the different nature of the systems. Bridging - making one system's operation understandable and, thus, its output usable for another system - is required. This is certainly going far beyond traditional science-industry mediation as in the case of technology transfer institutions. It has to translate system-specific rules and ways to communicate, and furthermore, it has to contribute to make the different operational principles compatible.

Unfortunately, a well-working science-industry interaction is no guarantee for the successful stimulation of innovativeness. If only few sources are used repeatedly, the interaction will likely lead to lock-ins like sticking to long established technological trajectories and strictly intra-disciplinary cooperation. To avoid such problems it is important to pay attention to a well-developed absorptive capacity of companies regarding external research results and to maintain or enable weak ties and flexible interaction between a wide range of innovation partners (Granovetter 1973; Grabher 1993; Meyer-Krahmer and Schmoch 1998).

To perform the bridging-function and to increase the flexibility within industry-science networks both intermediary and training institutions are necessary. Such support organizations should actively help to establish cooperative relations as well as offer training programmes how to manage the linking between science and industry by the firms themselves. At present, institutions like technology centres are not very successful as far as the stimulation of collaboration between science and industry is concerned. To improve their performance in this respect, it will be necessary to shift the focus from mediation to translation and active linking and to target more explicitly R&D-cooperation involving science. The traditional uni-directional technology transfer-function is certainly insufficient, the bi-directional exchange of knowledge should become the main objective (Meyer-Krahmer and Schmoch 1998). However, it is difficult to initiate interaction between industry and science because of the broad range of potential barriers: lack of available science institutions, mismatch of information, knowledge, or services needed by industry and offered by research, little willingness to cooperate or involve external partners, communication barriers and incompatible rules and routines. Contradictory objectives and interests cannot be simply removed by translation. Many firms are hardly willing to cooperate with external partners regarding their innovation activities, not only with science but also with other firms.

Systems need to remain specific social entities, based on different modes of interpretation, decision rules, objectives, and specific communicative standards. But this does not necessarily require separate organizations, each linked to a single system only. There is a role for hybrid organizations (Etzkowitz et al. 2000) integrating science and business systems. Such organizations, however, will always be very demanding as far as their smooth operation is concerned. Nevertheless, especially regarding the crucial task of translation between the systems the importance of this type of organization will probably increase in the future.

Communication and collaboration between actors embedded in different systemic contexts is costly. But we think that there is enough evidence that the benefit in terms of increased innovativeness on the side of business as well as stimulated research activities on the side of science makes it worthwile for science and technology policy to target these difficulties and to stimulate collaborative relations between industry and science more intensively than in the past.

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