The Dynamic Creation of Knowledge.
Analysing Public-Private Collaborations

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Abstract

The present paper analyses the creation of knowledge in a dynamic collaboration between private firms and public research institutions in Denmark. It is argued that the creation of new knowledge seldom happens in a vacuum, and that innovative firms often rely on external knowledge sources in the development process. The particular focus is on collaborations on innovation between private firms and public research institutions in projects that to some degree involve "new" science. The paper gives an overview of the extent of direct interactions between public research institutes and industry at the national level and analyses the dynamics of such interactions at the micro level. In particular, the role of government is discussed in facilitating public-private interactions. Other themes touched upon are the general uncertainty related to a research based innovation project; the problem of managing public-private collaboration projects; the dilemma between building long-term competencies versus creating marketable products in the short run; as well as institutional transformations. The analysis distinguishes between market-pull and technology-push cases, and proposes that there is a greater need for formal programmes for supporting public-private research collaboration projects in cases of a high degree of market uncertainty than in more narrow market-pull projects.

Key Words

Public-private interaction, innovation, industrial policy.

1. Introduction

It is widely recognised that technology and innovation are the key drivers of growth performance in the knowledge-based economy. Innovation appears to be more closely linked to scientific progress, and accordingly a more tightly knit relationship between science, technology and economic performance has been observed over the last decade (OECD, 2000). As economic growth is increasingly connected to the generation and application of new knowledge, there is a need for communication, networking and co-operation among producers and users of knowledge. This induces policy-makers to create framework policies that facilitate the production and diffusion of knowledge in the innovation system.

With an accelerating technological development and exponential growth of knowledge there is a need for developing appropriate policy measures to assure the transfer of knowledge between science and industry. Without disregarding the importance of indirect transfer of knowledge in terms of graduates and publication of research results, focus will here be on the direct relational transfer of knowledge between public research institutions and industry in product innovation and in particular the governance of these public-private interactions.

The overall aim of the present paper is to illustrate that the sole innovator is the exception rather than the rule, with a focus on the actors directly involved in research collaboration and the transfer of outcomes from public research. We will do so by analysing mechanisms for facilitating the exchange and application of knowledge in joint research or contract research projects. The paper gives an overview of the extent of direct interactions between public research institutes and industry at the national level and analyses the dynamics of such interactions at the micro level. Likewise, the role of government in the facilitation of such public-private interactions is discussed at national as well as micro level.

Section 2 below discusses the importance of interaction in the development of new knowledge from a theoretical as well as an empirical point of view. In section 3 the emphasis is on the role of industrial policy for promoting mechanisms for building a bridge between industry and public research, while section 4 presents two cases of

public-private collaboration on commercialisation of public knowledge within sensor technologies. Section 5 draws out the main lessons learned from the case studies regarding important features of public-private collaboration on knowledge development. Finally section 6 presents the main conclusions.

2. The knowledge creation process

The work of Kline and Rosenberg (1986) is seminal with regards to the understanding of the role of knowledge in the innovative process. Kline and Rosenberg, in presenting their chain-linked model of innovation, stress the importance of accumulated knowledge in the innovative process. Knowledge is defined as the stock part of science, while research is the flow part that creates new knowledge to add to the accumulated knowledge of the system. It is the use of accumulated knowledge that is essential to modern innovation, not as much in the initiating step, as in the whole process of innovation. In the traditional linear description of the innovation process science and research only appears in the beginning of the process. This is far from the complex reality of innovation processes where it is often necessary to draw on research and the science base, and thus create new knowledge, throughout all phases of the innovation process.

In the Nelson and Winter framework the creation of new knowledge through innovation is the response from a firm or industry to changes in the environment, e.g. a change in market conditions, economic growth or competition (Nelson and Winter, 1982). Nelson and Winter model the probability of a firm coming up with an innovation as proportional to the firm's R&D spending. At the same time, R&D is regarded a highly uncertain activity and institutional structures supporting innovation are complex and diverse (Nelson and Winter, 1977). This implies that the creation of new, commercially applicable knowledge is not a certain outcome of R&D activities.

While the basic idea behind the considerations of Nelson and Winter is that the firms carry out R&D - and thus innovate – alone, the model presented by Kline and Rosenberg is more open to collaboration in the knowledge creation process.

While remaining loyal to the industrial dynamics framework presented by Nelson and Winter, several recent empirically based studies have claimed that knowledge

creation at the firm level – expressed through innovative activities – happens in an interplay between the firm and its surroundings.

Based on data from the 1993 European Union Community Innovation Survey DeBresson et al. (1998) analyse the characteristics of the innovative activities in manufacturing industries in 10 OECD countries.[1] Based on the innovating firms'[2] ranking of a range of external agents[3] for their innovative activity, the importance of information networks for innovation is estimated. The analysis shows that information networks are the rule and seem to be almost universally required in the innovative process. Innovative achievements attained by isolated individual firms constitute a small minority only.[4]

Most often the important external information sources are suppliers of equipment, suppliers of components or clients. Sometimes these networks also include a competitor. And sometimes they include a government laboratory or a university. Countries vary in the scope of their organisational information networks.

Table 1 shows that public research institutes are ranked relatively low as information sources for innovation. One third of the innovative firms ranked the importance of universities for the innovative activities of the firm to be either moderately or very significant. One third of the innovative firms also found the importance of government laboratories to be either moderately or very significant.[5] At the other end of the spectrum suppliers of materials and components are assessed to be at least moderately significant information sources by 90 percent of the innovative firms. Thus although the public research institutions do play a role as an information source for the knowledge development processes in innovative firms, this role is not as dominant as the role played by e.g. supplying firms, customers and even competitors.

[1] Belgium, Denmark, France, Germany, Ireland, Greece, Italy, the Netherlands, Norway and Portugal.
[2] An innovative firm is defined as a firm that has developed or introduced technologically changed products and/or processes within the 3-year period covered by the survey (1990-1992).
[3] Suppliers of materials and components; suppliers of equipment; clients or customers; competitors in the same line of business; consultancy firms; universities; government laboratories, and technical institutes respectively.
[4] The individual innovators, i.e. innovators who did not attribute any considerable significance to external information in the innovative process, constituted between ½ percent (Denmark) and 20 percent (France) of the innovative firms in the 10 countries analysed.
[5] No firms indicated that the information from universities or government laboratories were crucial for the innovative process.

Table 1: The importance of selected information sources for the innovative process (Danish part of CIS I, 1993, N=437). [6]

	Moderately significant	Very significant	Crucial
Suppl. of mat and comp.	47%	42%	1%
Suppl. of equipment	51%	31%	3%
Clients or customers	17%	55%	1%
Competitors	51%	31%	1%
Consultancy firms	16%	1%	0%
Universities	27%	5%	0%
Government laboratories	27%	6%	0%
Technical institutes	34%	12%	0%

A recent study of the Danish innovation system supports the findings of DeBresson et al. regarding innovative activity rarely being an activity carried out in solitude (see Madsen, 1999 and Christensen et al., 1999). But in the Danish study the focus is on actual collaboration projects as opposed to the less binding information input analysed by DeBresson et al. In the Danish survey 97 percent of the product innovative firms[7] reported to have previous experiences with collaboration on innovation.

Private domestic customers and suppliers are the most frequent collaboration partners, which is very much in line with the findings of DeBresson et al. regarding the most important information sources. Universities and public research institutes appear as collaboration partners to a lesser extent: 15 percent of the innovating firms report to have collaborated with a domestic university or public research institute, while 5 percent have collaborated with foreign universities or public research institutes (see table 2).

The survey illustrates that although the process of innovation often is carried out in collaboration, collaboration is not a precondition for carrying out innovation (as opposed to relying on information networks, which seem to be the rule in innovative activity). Furthermore, collaboration with universities and other public research

[6] Own calculations based on micro-aggregated data.
[7] Defined as firms that, alone or in conjunction with others, have developed one or more new projects within the two years preceding the survey (i.e. 1996-1997).

institutions is one of the most rare types of collaboration, even though it does appear in high as well as low-tech industries.[8]

Table 2: Collaboration partners on product development (DISKO, 1999, N=283)[9]

	Domestic	Foreign
Public customers	19%	9%
Private customers	56%	37%
Suppliers of materials and components	64%	41%
Suppliers of equipment	38%	18%
Competitors	8%	5%
Institutes for certification etc.	29%	10%
Other authorised institutes	17%	4%
Consultants, legal advisors etc.	29%	6%
Universities and public research institutes	15%	5%
Other partners	35%	16%

Source: Madsen, 1999.

The fact that collaboration with research institutions is one of the most rare forms of collaboration in knowledge development processes indicates that this type of collaboration is only worthwhile in certain types of projects. Hall et al. (2000) find that universities are included in research projects that involve "new" science, based on the perception that the university can provide a research insight that is more anticipatory of future research problems that might be encountered.

The public R&D system[10] constitutes an important part of the framework conditions for carrying out innovation and creating new knowledge. Mansfield (1998) estimates[11] that 15 percent of the new products developed in the period 1986-1994 could not have been developed (without a substantial delay) in the absence of recent academic research. And 8 percent of the new products were developed with substantial aid from recent academic research. Thus the existence of a public R&D system does influence the innovative performance of an economic system.

[8] The surveys referred to only cover manufacturing industries.

[9] The 283 respondents constitute firms that have developed at least one new product within the two-year period covered by the survey, and who have participated in the extended part of the survey focussing on the most important project as well as on development projects in general.

[10] Disregarding, for analytical purposes, the role of university research as a means of providing students with research based teaching, public R&D can be perceived primarily as a means to correct market imperfections through carrying out basic research and other types of "pre-competitive" research.

Even though basic research produces public knowledge, and the results of basic research can inform and improve the productivity of applied research efforts, believing that a would-be developer can simply purchase basic research results as an input to a commercial innovation[12] represents a misconception of innovation as a linear process (Mowery and Ziedonis, 1998). A described above in relation to Kline and Rosenberg's chain-linked model of innovation, the relation to science and research is necessary throughout the entire process in the case of research based innovation. This points towards the importance of the inter-organisational relations between public research institutions and innovative firms.

An analysis of Danish firms' use of public research,[13] based on case studies of 12 R&D intensive firms, poses a critique of the Danish knowledge production system for an interaction deficit in the relation between science and industry (Valentin, 2000). Even though the analysed firms were selected on the basis on an above average R&D activity, and thus report to have a considerable interface with publicly funded research, the analysis finds that the collaboration projects generally are charged with considerable difficulties. The primary difficulty is identified to be a lack of the appropriate modes of organisation for enhancing collaboration. There seems to be a deficit in the institutional absorptive capacity in the innovation system, i.e. the ability of institutions to acquire the results of others, to respond to new problems and to communicate new knowledge across disciplinary and institutional boundaries. A call is therefore made for adjusting public policies in order to develop more adequate and differentiated incentives.

One way of analysing how government can play a role as a 'mediator' between public research institutions and industry in knowledge creation processes is presented by Etzkowitz and Leydesdorff, who launched the concept of a 'Triple Helix' between university, industry and government.[14]

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[11] Based on a sample of 77 major firms.
[12] Which Mowery and Ziedonis (1998) claim is the idea underlying the US 1980 Bayh-Dole Act.
[13] The main emphasis is on firm relations to research carried out at universities and public research institutes.
[14] While the original formulation of the Triple Helix (Triple Helix I) defined university, industry and government institutionally, Triple Helix II focuses on the three spheres as different communication

The Triple Helix as a concept might not contribute considerably to the understanding of the role of institutions in facilitating knowledge creation and innovation compared to the national system of innovation approach (see e.g. Lundvall 1992), where the institutional set-up and the interplay between different agents – both public and private – receives a considerable attention. But it does put a specific emphasis on the role of public research – and the role of government as mediator - for private innovation, which is relevant in the present case.

Etzkowitz and Leydesdorff argue that the difference between the Triple Helix approach and the national system of innovation (NSI) approach lies in the focus of analysis. In the NSI approach the main focus is claimed to be on the firm's leading role in innovation, while the Triple Helix approach focus on the "network overlay of communications and expectations that reshape the institutional arrangements among universities, industries, and government agencies" (Etzkowitz and Leydesdorff, 2000). According to this framework, the sources of innovation in a Triple Helix do not fit together in a pre-given order, but are constituted by the dynamics of the relations. What seems to matter is the way networks of relations generate reflective sub-dynamics, among actors as well as in the underlying infrastructure and institutional context.

In the present context we do not treat the Triple Helix as a distinct approach which by any means is contradictory to or substitutable with the NSI approach. Rather we apply the notion of a Triple Helix as a conceptual tool for analysing one particular – and very important - feature of a national system of innovation, i.e. the way that public policies influence the direct interactions between public research institutions and industry in knowledge creation. In our view the importance of the firm in the NSI approach is an expression of the firm being the locus for the commercial exploitation of the innovation. Thus the Triple Helix is going to be applied as a framework for the analysis of two cases studies presented in section 4 below.

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systems performing different functions. In Triple Helix III university, industry and government perform their own traditional functions as well as – at least partially - assume the roles of each other: e.g. universities market knowledge and create companies, and firms develop a new academic dimension (Etzkowitz and Leydesdorff, 1998).

Common for the two cases is that they are embedded in public-private collaboration on knowledge creation and commercialisation.

In our application of the Triple Helix the public research institution on the one side, and the firm on the other side, are the agents in focus, while the role of government can be more or less outspoken: in our view the central role of government is to promote the mechanisms which can build the bridge between industry and public research.

Contrary to the study conducted by Valentin (2000) the present analysis does not focus solely on the firm but focus on the inter-organisational relations between the key actors of the knowledge production process across institutional boundaries. This allows for exploring the divergent interests and stakes in the knowledge production process and hence identifying the carriers and barriers of the production of commercially relevant knowledge. The selection of cases is made in relation to a technology foresight project focussing on sensor technologies conducted by Risoe National Laboratory in collaboration with the Sensor Technology Centre A/S. They represent two opposite perspectives of the knowledge creation process: a market pull perspective and a technology push perspective. They do not tend to represent all problems and issues related to public-private interaction in knowledge creation, but they illustrate broad themes of problems, which are relevant internally to the involved actors of the network as well as externally to governmental policies.

The analysis of the cases will focus on five main issues:

- The uncertainty related to a research based innovation project.
- The dynamic interaction between the public research institution and the private firm where a committed interaction is the precondition for a successful outcome. At the same time the interaction in itself creates a pressure on the underlying structures in the participating organisations (knowledge becomes a tradable good, and thus there is also a pressure on the public research institutions for making money on their knowledge).

- The dilemma between building long-term competencies versus creating a marketable – and economically viable – product in the short run and hence the need for appropriate management and formal agreements.
- The institutional transformations in public-private interactions.
- The role of the government as a facilitator of public-private collaboration on knowledge creation.

Before turning to the empirical analysis, we will devote the attention to a discussion of the role of government as a facilitator for knowledge creation and diffusion.

3. Industrial policy and public-private collaboration

Until the mid 1980's, international – most notably American - industrial and trade policy had mainly considered macro and factor conditions. But Michael Porter made a considerable contribution to changing this focus by arguing that it is firms, and not countries or industries in different countries that compete. Therefore the focus of analysis should be on firms. The empirical support for the argument built on a study of several industries in several countries focussing on the upstream and downstream value chain relations of the firms, the institutional setting, the firm's surroundings and the firm itself (reported in Porter, 1990). Innovation plays a crucial role in Porter's understanding of a firm's competitive advantages, and both product and process innovations are central in creating new markets or gaining and sustaining market shares.[15]

A focus on innovation and technological capabilities is also what characterises the 'new industrial policy paradigm' introduced in Denmark in the late 1980's/early 1990's as a cure for a range of structural problems. The traditional macroeconomic thinking was supplemented with a concern for the dynamic interplay between the firm and its environment, and R&D and technology was 'rediscovered' as important production factors (Karnøe, 1999). New support schemes and activities were introduced. Contrary to Karnøe, we argue that the policy instruments introduced were mainly broadly oriented towards the dynamics of the national innovation system and in particular the inter-organisational relations among private firms and public R&D institutions rather than targeted at selective high-tech industries. Some

of the main features underlying the shift in the Danish industrial policy are described in table 3 below.

Table 3: A shift in business and industry policy

The industrial society	The knowledge based economy
• Large scale programmes applying uniform principles across sectors and firms	• Intermediary institutions serving firms according to their specific needs
• Subsidies to individual firms	• Subsidies to institutions collaboration with firms
• No incentives for institutions to collaborate	• Support to institutions collaboration across sectors (research, education, labour market)
• Supporting process and product innovation	• Also supporting organisational innovation, service innovation and marketing innovation
• Low degree of co-ordination between ministerial offices	• High degree of co-ordination between ministerial offices
• Dialogue with organisations	• Dialogue with cutting-edge enterprises contributes to identifying critical framework conditions

Adapted from Nyholm et al. (2001).

The table illustrates that collaboration is a recurring feature of the industrial policy of the knowledge-based economy. The ability of firms to compete on knowledge and competence is another cornerstone in an industrial policy targeted towards the knowledge based economy, as demonstrated in the Industrial Development Strategy launched in 2000 (Regeringen/The Danish Government, 2000). The creation of the best possible framework conditions for industry access to public research in a partnership, which is mutually benefiting to industry and academia, is an explicit aim with the strategy. It combines a summing up of recent undertakings with a presentation of new initiatives in the formulation of an overall vision of a sustainable competitive society. For example, technology foresight is introduced as a strategic tool for "wiring up" the whole innovation system and bringing technology back in the industrial development policy (Jørgensen, 2001). Figure 1 gives a brief overview of some of the recent initiatives aiming at facilitating the public-private interaction on knowledge creation.

[15] This section draws on Drejer et al. (1999).

Figure 1: Selected initiatives for supporting public-private R&D collaborations

Centre Contracts

A publicly co-funded strategic R&D collaboration between (one or more) firms, (one or more) university departments and at least one Authorised Technological Service Institute.[16] The basis of the collaboration is a commercially oriented R&D project. The initiative was launched in 1995.

Industrial Ph.D.s

An industrial Ph.D. is enrolled at a public research institution, while at the same time being employed in a firm, attached to a specific research project. The aim of the initiative, which is co-funded by public means, is to support the technological and economic development through creating networks between industry and public research institutions. The initiative was launched in 1970, but has been subject to subsequent revisions. A parallel initiative – inspired by the British Teaching Company Scheme - aimed at smaller firms with a larger emphasis on development as opposed to research is presented in the 2000 Industrial Development Strategy.

Development Contracts

The initiative was initiated in 1994. It aims at transforming public knowledge into an improved national competitiveness and increased employment in private firms. There are two main types of publicly funded development contracts: commercial contracts applied when a public institution needs the development of a product or service; and public utility contracts with a general business implication.

Government-funded incubators

The government-funded incubators, which were launched in 1998, provide financial support and guidance to innovative projects stemming from public research as well as private entrepreneurial ideas.

Act on inventions

The 1999 act on inventions at public research institutions sets out rules for payment of inventing employees as well as the public research institutions when public inventions are exploited commercially. [17] The act was effective from January 2000.

Source: Danmarks Forskningsråd/The Danish Research Council (2000).

[16] An Authorised Technological Service Institute is an independent, non-profit institution that – based on its work in technological areas which are of importance to industrial policy - has been approved by the Danish Minister for Business and Industry. The Authorised Technological Service Institutes are independent non-profit institutions, which provide services to firms on commercial terms. Through their authorisation and the public co-funding of some activities the Authorised Technological Service Institutes are considered to be part of Denmark's technological infrastructure. The mission of the Authorised Technological Service Institutes is to build bridges between the research and business communities.

[17] Concerning patenting by universities, Mowery et al. (1999), in an assessment of the effects of the American Bayh-Dole Act of 1980, find a tendency by some universities to extend the patenting and licensing activities since 1980 to cover the results of scientific research, rather than focusing their patenting on the results of applied results. Such policies might raise the costs of the use of the scientific research results in academic as well as non-academic settings, as well as limiting the diffusion of these results. Thus policies to increase university patenting might have a hampering - and not a boosting - effect on the commercial exploitation of public research results.

The actions for creating a better framework for public-private interaction are based on the recognition that a high-level knowledge production in universities and public research institutions does not necessarily benefit industry. There will always be a knowledge "spillover" from universities to industry through research based teaching of students who, after acquiring their degree, find employment in industry. But, disregarding this and other types of indirect linkages between public research and industry, constraints may exist regarding creating a private access to public research. As described in section 2 above, public research institutions and industry do collaborate on innovation and the creation of new knowledge, although it happens to a much lesser extent than firm-to-firm collaboration. One explanation for the rather limited extent of public research-industry collaboration might be the differences in inter-organisational relations between public and private organisations as compared to collaborations between two private firms. Thus there is a need for mechanisms for establishing and facilitating public-private co-operation.

4. Case studies on sensor technologies

As the interaction between science and industry, and in particular the mechanisms for the creation and diffusion of knowledge, is relatively unexplored, we have chosen to apply two case studies (see Yin, 1984 and 1988) in an investigation of the phenomenon at the micro level.

The two cases selected illustrate the creation and diffusion of knowledge in public-private direct interaction within sensor technologies. The cases are what we consider to be exemplary in terms of the ability to develop new knowledge, the ability to communicate this knowledge and the ability to use this knowledge in the industry. In the literature, considerable debate has focused on whether knowledge is technology driven or market driven (this discussion can be dated back to such works as Schmookler, 1962 and 1966 and Schumpeter, 1934). We tend to overcome this dichotomy by presenting two extreme cases:

1. A market pull case – the development of a computer input device
2. A technology push case – the development of a silicon microphone

As for the first, it is a product for the PC consumer market whereas for the latter it is a device for the industrial market of hearing instruments and telecommunication. They thus represent different stages of the value chain.

4.1. The market pull case – the development of a computer device

The birth of an idea

The development of the computer device, the so-called Free Pen, was driven by the idea that the traditional computer mouse could and should be substituted by a device adapted to the body and not the other way round. The daily use of computers in work places is nowadays creating serious physical problems to the operators. At least 25% of the Danish work force employed in positions where computers are used as the daily working tool suffer from symptoms of repetitive strain injuries[18].

Concretising the idea

In 1997, the idea-owner, an economist and marketing employee in the IT sector concretised his idea as a research and development project and became a full-time entrepreneur. The necessary financial resources were provided by private funds together with public venture capital (Vækstfonden) and in a later stage also private venture capital.

The cordless pen was the guiding idea for the search of an appropriate technology. A pencil has been known for centuries without causing pain to the body. The cordless element was inspired by optics and laser elements in CD players. The search for the available knowledge and the right technology was indeed a process of muddling through. A Danish firm producing CDs was contacted as well as a professor in Paris with expertise within the field. References from the University of Copenhagen finally led to a national research laboratory and a scientist working on optical lasers and speckles for measuring the rotation of ship propeller shafts. The technology was patented, but was not applied in a commercial product. Now the opportunity arose to apply the technology on a miniaturised scale in the computer input device.

[18] These are neck, back and lower back pain related to work position as well as shoulders, elbow, wrist and fingers pain related to the design and usage of the input device.

A research and development contract was drawn up between the firm and the research laboratory. It was based on commercial conditions and included the necessary adjustment of the technology, assistance to additional patent applications related to the product, assistance to identify production companies with expertise within VCSEL lasers and finally to specify the requirements of a production contract with a large international firm. The collaboration between the research laboratory and the firm has by both partners been characterised as an integrated R&D department based on trust, openness and enthusiasm.

The production and commercialisation of the product

The pen was brought to the market in 1999, after 1998 had been devoted to the development of the optical part, the laser detector and the processor (the ASIC[19]). Financial constraints and pressure from public and private venture capitalists to present commercial results within the agreed project time frame and budget enforced the market introduction. It was the first time that miniaturised optical sensors were commercialised in a product and minor technical problems continued to hamper the market introduction. With 40,000 pens sold, repetitive complaints and lack of resources the firm suspended its payments in summer 1999. Later the firm was re-organised with additional venture capital. The original firm fulfilled the royalty obligations whereas the development of the second generation of the pen was made in a new operation firm.

With the development of the second-generation cordless, programmable and web-optimised computer pen, the so-called Zeptor, the market potential was no longer restricted to the narrow, ergonomic-demanding welfare markets, but included new life style customer segments on the global PC market comprising more than 300 mil. potential customers.

Outcome of the public-private knowledge interaction

The firm's result of the interaction with the public research laboratory was first and foremost the development of second-generation computer input device where all technological problems were solved. Three firm patents within optics, magnetic and

[19] Applied Scientific Integrated Circuit

analog-2-digital conversion, protected the knowledge created. Two patents related to the 2nd generation pen are under their way.

Second, based on the hitherto results of the public/private collaboration, the firm succeeded in convincing the private venture capitalist that it was worthwhile to go the whole way to a commercial and reliable product and not to stop in the final difficult stage of a complex R&D project.

Lastly, the firm gained experience in the management of external stakeholders involved in the development and production of the product.

From the perspective of the national research laboratory, the interaction with the firm was an opportunity to test and develop a new technology in a commercial product. The challenge to adjust the technology to a much smaller scale than first imagined created new knowledge and competence within miniaturised optical sensors, an area that is expected to have further application in for example energy flow meters and medical devices. This made the laboratory an attractive partner in other research and development projects.

Carriers and barriers of the interaction

Important mechanisms have influenced the public-private interaction on the development of the cordless pen:

- **The imagination of market need and technology solution**

The ability of the idea-maker not only to imagine the market need but also to give direction to the technological solution based on common sense or tacit knowledge has been an important carrier.

- **Formal and informal institutions for guiding the collaboration**

In the case of the computer device the well-functioning co-operation has been founded on trust, enthusiasm, and openness, also in the difficult stage of suspended payment. Three things have contributed to this: Firstly, due to the patent regulation, the ownership of knowledge has never been an area of dispute. On the contrary, the patent owner of the basic technology has assisted the firm in applying for product

specific patents. Secondly, the formal contract of research has been fulfilled and royalty obligation has been included in the re-organisation of the firm. Thirdly, the outsourcing strategy and the ability of the firm to manage divergent economic institutions across cultural and national boundaries were tantamount to gain economies of scope in the development and realisation of the project.

- **A well-functioning venture market**

The barriers of public-private interaction are closely related to the financial situation, where it is fairly easy to get access to venture capital in the initial development stage of a project but it is much more difficult to get additional capital to meet unexpected prolongation and problems. This illustrates the importance of a well functioning venture market, which is able to appraise the technological and commercial opportunities and risks of research-based projects where a considerable degree of uncertainty is involved. Even though the Danish venture capital market has grown considerably within the last years, the market is still considered to be immature, and there is a need for upgrading and expanding competencies on the supplier side (Christensen, 2000).

4.2. The technology push case – the development of a silicon microphone

Technology push and the search for problems

The development of a silicon microphone for hearing instruments is the story about a technology searching for real life problems/applications and a private firm searching for a way to gear its R&D activities.

The realisation of a demonstration model of a silicon microphone was initiated in an industrial Ph.D. project between a private firm and a national research centre. The firm is a medium sized international operating manufacturing firm based in Denmark. Based on the strength of a highly specialised production of transducers and electromechanical components for hearing instruments, the firm has established a leading global position as a component supplier to the hearing aids industry.

The research centre was established in 1990 as an affiliation to the national technical university. It is a national research and development centre for advanced micro-

technology in semiconductor materials. Within this field, it is committed to educating scientists and engineers, conducting research on an internationally competitive level, and transferring new technologies to Danish industry through joint programmes.

The research centre presented the Ph.D. project to the firm as a favourable means for exploring alternative technologies for conventional miniature microphones. At the same time, the centre got the opportunity to push the technology into a new application and thereby gain new knowledge. The first bricks of a stable and strategic interaction of knowledge were laid between the centre and the firm.

Although the silicon microphone technology has been known in academia for more than 20 years, it was obvious to all partners that one single Ph.D. project would not fulfil the ambition to develop a silicon microphone for hearing instruments. The centre developed two scenarios: one scenario founded on an EU-research project, which rapidly would reach state of the-art of existing knowledge within the area, but at the same time be subject to the difficult task of co-ordinating the expectations of diverse international and institutional actors, often with competing agendas. The other scenario was founded on a Centre Contract, which was a recently introduced governmental support scheme for strategic R&D collaborations, in particularly the involvement of Authorised Technological Service Institutes as an institutional bridge between research and industry (see figure 1). This model would include only a few complementary partners within a Danish context and would be directed towards the exclusive problem solving regarding the silicon microphone. The latter scenario was chosen.

The co-operation model – the Centre Contract

In 1995 a Centre Contract was signed between the national research centre, the firm and an Authorised Technological Service Institute with core competencies within the fields of electronics, software technology, optics, light acoustics, vibration and noise control. As the specific Centre Contract was one of the first Centre Contracts to be drawn up, there was little guidance on how to choose the right form of co-operation and how to manage intellectual property rights, publication and secrecy of knowledge, as well as on how to solve disputes. Therefore, the involved partners

found it necessary to clarify the divergent interests and goals from the very beginning:

- *The national research centre* was interested in engaging in applied research together with the front runners of Danish industry. It was also focused on publishing research results and educating people at the level of M.Sc. and Ph.D.
- *The firm* was interested in gearing its R&D activities and developing a new, cheap and reliable component based on a new technology for hearing instruments.
- *The Authorised Technological Service Institute* was focused on adopting the technological knowledge and in particular to develop test and packaging services to industry.

The negotiation and conclusion of a legal document assisted by lawyers was a cumbersome but also necessary process.

The public financial support to the co-operation was 20 mil. DKr for 4 years that was distributed as co-financing of the activities of the Authorised Technological Service Institute and the research centre. In addition, the firm got 35% risk coverage of its project investment by a loan of approximately 4 mil. DKr from the public venture capital fund (Vækstfonden).

The application and realisation of the technology

Almost from the very beginning a certain division of work was developed, guided by the constant concern of the firm to apply the technology in a commercial product. Packaging and testing was, as mentioned above, the focus of the Authorised Technological Service Institute, whereas the ASIC component was developed jointly by the firm and the Authorised Technological Service Institute. Wafer (chip) production and application was concentrated in the clean lab facilities at the research centre in joint collaboration with the firm.

The development process was much more complicated and time consuming than foreseen. It was a challenge to identify a foundry, where the wafers could be produced. Therefore, an additional research project on “High-Performance

Interconnect and Stacking" (HISTACK) was formulated together with among others a Swiss firm/foundry and co-funded by the EU programme ESPRIT.

During the project period necessary adjustments were made and ambitions were calibrated to the reality of the problem-solving process. The firm realised that it was a long-term strategic development process driven by competitive pressures for innovation, but also by the innovation imperative itself.

Outcome of the public-private knowledge interaction

At the end of the Centre Contract period in 1999, a demonstration model of the world's smallest silicon microphone was developed. There was still a long way to go to finalise a prototype, not to mention to start up the production of a silicon microphone. The cost price in small quantities was still not competitive with the traditional microphone. This induced the firm to look for other applications than the hearing instruments, e.g. within telecommunications. Apart from the demonstration model the firm had improved its image as an innovative and strategic firm. Two product specific patents were approved (membrane and stacking) and together with the Authorised Technological Service Institute a patent was approved within packaging. The primary goal of the firm was now to develop and prepare the production of a silicon microphone in collaboration with wafer foundries. The establishment of joint clean-lab facilities at the research centre was seen as an interesting opportunity to provide a critical mass for this technology together with other industrial partners.

For the Authorised Technological Service Institute the joint project was a kick-start of its competence building within silicon technology. The open co-operation form induced partners to focus on the application from the very design phase to the final product. This was considered an important part of the service portfolio to the industry. In-house competence was increased to more than 10 full-time employees working within this area and the number was expected to increase.

The research centre presented the results of the project at conferences and published in international journals. The collaboration with the industry and the problem/oriented research had positioned it at the forefront of international research.

It had likewise filed a patent application within the technology. Most importantly, it had educated a number of M.Sc.s and Ph.D.s working with the development and application of the technology, some of whom had been employed by front runners of domestic and international industry.

Carriers and barriers of interaction

The public-private interaction on the development of the silicon microphone has been influenced by a number of formal and informal mechanisms:

- **Governmental Centre Contracts and public research programmes**

The collaboration has first and foremost been facilitated by the governmental Centre Contract programme, which was introduced at the very right time for the project. The financial eligibility rules, which excluded direct support to firms, induced the partners to constantly focus on the firm's interests in the project. On the other hand it remains a constant dilemma how to balance long-term competence building and short-term commercial output. An experience gained from the project is that adjustments of expectations are inevitable, but also that more attention should be directed to the appraisal of the technological and commercial opportunities and risks of the firm specific part of the project. It should therefore be mentioned that the 50% co-financing of costs in the EU-project were highly welcomed by the firm as the project turned out to be more strategic than initially foreseen. It should also be mentioned that the conditions under which public venture capital is invested are not competitive to a going concern with fairly easy access to bank loans.

- **The formalisation of collaboration**

Important to the smooth interaction among the three partners – the firm, the research laboratory and the Authorised Technological Service Institute - is the clarification of divergent interests and goals from the very beginning. It has been worthwhile to invest time and money in drawing up the formal contract. These initial efforts function as a model contract for other Centre Contracts.

- **Informal rules and teambuilding**

Apart form the formal direction of the co-operation, partners have experienced the need for informal co-ordination. In the initial phase individual 'fireballs' and personal relations have been a central driver of the co-operation, which in the

subsequent phases with new participants has been sustained by teambuilding. In the clean room laboratory co-operation resources have been allocated to project management and teambuilding. It has been acknowledged that the challenge in joint collaboration projects is to create a common platform and shared values, in particular in projects where people are accountable to various environments, the joint project and their hinterland.

- **The development of a critical mass**

The silicon technology is a mass production technology with high start up investment costs. New organisational forms as joint private-public project groups or firm consortia are feasible ways to share investment costs of laboratory facilities and to create the necessary critical mass of people engaged in pre-competitive R&D activities.

5. Important features of public-private collaboration on knowledge creation

The analysis illustrates that innovation is not as closely related to own firm R&D spending as assumed in Nelson & Winter's 1982 model, the relation to external knowledge networks does also play an important role. Further the two selected cases serve to illustrate that the incentive to engage in innovation can be market as well as technology driven.

Regarding the first point on the importance of own R&D efforts, we do not tend to claim, that these are not important – the absorptive capacity that they create are, as illustrated by Cohen and Levinthal (1990), a necessary precondition for being able to absorb and utilise external knowledge. We simply claim that the relation to external knowledge, and the engagement in joint efforts for creating new knowledge, is equally important and adds to the capabilities of both knowledge users and producers.

The two cases also serve to illustrate the point risen by Kline and Rosenberg, that a close connection to science throughout the entire innovation process is a precondition for research based innovation: research can not be 'delivered' as a simple input in the initial phase.

Regarding the governance of the public-private collaborations, the following lessons can be drawn:

- *Room for flexibility and adaptation in research projects*. The research based innovation processes, due to the associated uncertainty, are characterised by a considerable degree of 'muddling through' in relation to solving the technological problems encountered throughout the process. Thus there is a need for patience and flexibility in the collaboration, as well as the possibility of drawing in other knowledge sources if necessary. This is illustrated by the case of the development of the silicon microphone where technical problems called for the formulation of an additional project, which could contribute – technologically as well as financially – to the original project. Thus expectations had to be adjusted along the way. In the case of the cordless pen, a more smooth prolongation and additional funds would probably have prevented premature market introduction.
- *Dynamic creation and application of knowledge.* A successful project does not involve a one-way transfer of knowledge from the research institution to the firm. Rather the project involves a competence-enhancing element for the research institution as well as the firm, in order to sustain the intellectual motivation – and justification – of public researchers' engagement in commercially oriented collaboration projects. In both case studies analysed the public research institutions had a considerable academically relevant outcome of the project, e.g. the adjustment of technology to real-life problems, competence building in testing and technological services, as well as training of graduate students and junior researchers.
- *The management of divergent interests and perspectives.* The firm and the research institution will in most cases have opposite prioritisation of the wanted outcomes of their involvement in the project. The research institutions will often have the building of long-term competencies and testing of theoretical findings as their first priority, while the firm's primary interest is the creation of a marketable – and economically viable – product, giving long-term competence building second priority. These differences should be clear from the beginning and the contract between the firm and the research institution should take the

range of desired outcomes into account in order to minimise the risk of not meeting expectations. This calls for both formal agreements and a committed project management to make sure that potential conflicts regarding the project outcome are dealt with throughout the project.

- *Drawing up formal agreements and contracts*. Due to economic interests at the side of the firm as well as the public research institution, a clear contract regarding obligations of each project partner, intellectual property rights, royalties etc. has to be drawn up. Also the project leadership must be clear, and the firm as well as the research institution must have the proper institutional set-up for allowing a certain degree of autonomy of the project group. In both cases studied, the initial efforts used on drawing up formal agreements regarding the collaboration turned out to be a good investment. The contracts set out clear terms regarding aim of project, property rights, royalties etc. The importance of informal institutions such as teambuilding, project management, trust and openness in the collaboration should not be disregarded though.
- *Institutional transformations.* The public-private collaborations are embedded in the dynamics and complexities of the innovation system in which the participating institutions constitute new roles and thereby transcend their traditional boundaries as knowledge user or knowledge producer. Apart from producing graduates to the industry, the university research centre is actively building the technological interface between research and industry, but its constant search for real-life problems also benefits its own research. Not only does the Authorised Technological Service Institute build competencies in technological services but it also conducts forefront research within important areas of the technology and take out patents. The national research laboratory combines the role as a research institute and a technological service consultant. Just like the university centre, the application of the technology to real-life problems contributes to the excellence of the research and likewise it sells its knowledge and acts as a technological service intermediary between research and industry. The involvement of firms in public-private collaborations gives direction to the problem-solving process. Whereas the project management of the silicon microphone project is shared between the firm and the Authorised Technological Service Institute, the firm manages the cordless pen project. Both

cases give rise to new organisational forms and processes. In the microphone case joint clean room facilities are shared with other firms, all with an interest in building a critical mass in the pre-competitive stages of the silicon technology. An outsourcing strategy is used in the cord-less pen case, in which all processes are externalised except the core competencies of the firm.

- *Public support schemes and interventions.* The mechanisms created by the government to facilitate public-private collaborations on knowledge creation are important both in terms of the funding possibilities they offer, and in terms of the organisational frames they provide. Public venture capital has played an important role for the realisation of both projects. The public venture capital is not directly related to the firms' collaboration with public research institutions, although the participation of the research institutions might have made it easier for the firms to document the high-tech innovative potential in the projects to the venture capitalists. In the case of the cordless pen government induced mechanisms for facilitation the public-private research collaboration have played a minor role, while the case of the silicon microphone has relied heavily on government programmes.

The idea-holder behind the cordless pen through own search efforts eventually ended up with the right research group. Building on the enthusiasm of the entrepreneur, the clear agreements on property rights etc.; the openness of the research institution, including the willingness to engage in a de facto integrated R&D department with the firm; as well as the availability of the proper funding mechanisms, was what was needed to make the project a technological success.

In the case of the silicon microphone, the market opportunity was not as clearly envisaged, as was the case of the cordless pen, when the project was initiated. In this case the initiative came from the public research institution, and a longer trial-and-error period regarding the possibility of applying a known technology in a new context was inevitable. Therefore it was necessary with a supporting institutional set-up for carrying out the development project. The governmental Centre Contract programme, combined with an industrial Ph.D. as the initiator of the project, provided the necessary frame for the project. Apart from making sure

that the necessary formal agreements were drawn up, the Centre Contract guaranteed the inclusion of a privately oriented, but publicly research based Authorised Technological Service Institute. Further the Centre Contract provided public funds to co-fund the engagement of the Authorised Technological Service Institute and the research institution. The technological complexity and the search for the proper market for utilising the technology thus called for a much more extended 'support system' for carrying out the project, than was the case with the market driven cordless pen-project. Which one of the two projects that will prove to be the biggest commercial success still remains to be seen, but they both have a large potential.

The two cases illustrate that the need for government induced mechanisms for facilitating public-private research collaborations varies with the type of project at hand. We have chosen to present two extreme cases with regards to market-pull and technology-push mechanisms as drivers of the projects. Thus the conclusions drawn should be taken as representing extremities as well, leaving room for in-between modifications.

6. Conclusions

The present paper has analysed public-private research collaborations, focussing on mechanisms for facilitating the exchange and application of knowledge in research projects involving private firms as well as public research institutions.

The analytical starting point has been the conception of innovation as a complex process, as presented by Kline and Rosenberg in their chain-linked model. The Triple Helix way of thinking of the relation between firms, universities/public research institutions and government agencies is also applied as a framework for identifying the role of government, not as much as an active player in actual collaboration projects, but as a provider of mechanisms for facilitating public-private research collaborations.

References to previous surveys illustrated that collaborations between firms and public research institutions on product development/innovation happens much less

frequent than firm-to-firm collaborations. It is assumed that private firms primarily collaborate with public research institutions in projects that to some degree involve "new" science, including a radically new application of a previously known technology.

But another explanation for public-private research collaborations occurring much less frequent than firm-to-firm collaborations is that in public-private collaborations two very different types of organisations are confronted. Thus there is a need for mechanisms for overcoming the barriers that these differences pose.

These mechanisms are diverse but interrelated. They are simple information channels for ensuring that firms know what they can gain from getting involved with public research institutions and how these can be approached, but also guidelines for how to organise collaboration projects. They comprise formal programmes, which contain supporting structures and public co-funding as a means to drive the joint projects forwards. Programmes which aim to reduce barriers related to funding of projects with an uncertain outcome, as well as to overcome barriers related to the clash between different cultures in terms of organisation, motivation etc.

The importance of guidelines for organising collaboration projects between private firms and public research institutions cannot be ignored. A successful project requires that possible differences in intended outcome be dealt with from the initial phase and throughout the project. Conditions regarding project management, division of labour and responsibilities, intellectual property rights etc. must also be clarified in the collaboration agreement. The governmental Centre Contract programme, where a 'model contract' has been developed in relation to the silicon microphone project, is an example of a collaboration inducement project which gives high priority to the formal agreements guiding the project. The role of project management and teambuilding should not be underestimated either.

Regarding different types of projects it appears that formal programmes for supporting public-private research collaboration projects are primarily called for in cases of a high degree of market uncertainty, where the technology is driving the

projects. These projects will often be larger and more explorative than projects where the market need is the driving force and the technological search accordingly can be much more focused.

The creation of knowledge across institutional boundaries changes the way the involved actors interact. Traditional boundaries are transcended and new roles are constituted in the public-private interaction to a point where it does not matter for the knowledge creation process whether it is a university centre, a national research laboratory, an Approved Technological Service Institute or a private firm. New institutional boundaries are constituted and may in the long run challenge the way public funds are distributed among the collaborating actors.

Market-pull as well as technology-push projects are dependent on a well-functioning venture-capital market, which might include both public and private actors. Regarding market-pull projects there is a need for increasing capital providers' competencies regarding assessing the technological and economic potentials and risks. The same can be said for the technology-push projects, but in these cases it might also be appropriate to consider the interplay between the venture capital system and the public funds provided through the different collaboration support programmes.

To conclude, the analysis points towards a need for a range of collaboration promoting mechanisms. They take the different needs of different types of projects into consideration, and provide basic guidelines and information channels as well as more formalised programme structures. Key words for successful public-private research collaborations are flexibility, openness and unambiguity regarding obligations and rights.

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