Processes of Innovation in the Field of Nanotechnology

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Abstract

The globalisation of markets and knowledge-based production entails changing patterns of generating, processing and knowledge-sharing in processes of innovation. This is particularly true for the innovative application of complex technologies like nanotechnology that combine knowledge and competences from different scientific disciplines. In the wake of these developments new organisations emerge that take over the role of intermediaries between science, innovating enterprises and the market by offering various services in the innovation process. These research and development services (RDS) can be seen as a specific branch of knowledge intensive business services (KIBS). It is argued that RDS provide knowledge and competences which cause other actors in the innovation system to include them in their innovation processes, because it is economically more useful than to provide all necessary functions in-house. The paper intends to elaborate the role of RDS in knowledge sharing in innovations processes.

Key words: innovation processes, innovation biographies, nanotechnology, knowledge, research and development services

1 Introduction

It is widely recognised that innovations are the result of an increasingly interactive process consisting of complex knowledge interactions of different actors. Along with the high degree of complexity of knowledge a considerable increase in specialisation is observed. This is particularly true for the innovative application of complex technologies like nanotechnology where competences e.g. from physics, chemistry, biology, and engineering are the prerequisite for innovative activity. As a result of knowledge complexity and specialisation asymmetries of information emerge, connected with substantial uncertainties in processes of innovation and related investment. By interacting with several actors it is intended to balance such uncertainties. As one consequence large firms significantly concentrate on their core competencies, source out their former R&D departments, and buy R&D from external sources [1]. In the wake of these developments new organisations evolve that offer research and development services to other firms. Research and development services (RDS) as one subsector of knowledge intensive business services (KIBS) are of intermediate character in processes of innovation. Their intermediate attributes have resulted in complementary concepts such as facilitators, carriers, and sources of innovation [2] associated with KIBS resp. RDS. However, as Muller/Doloreux conclude in their literature analysis, in some studies KIBS are

recognised not only as contributors to innovation, rather they are considered as being innovative by themselves [3].
The aim of this paper is to shed light on the role of RDS in processes of innovation. The research is based on a case study approach by reflecting the results of several "innovation biographies" which were conducted during a pilot project of the Institute of Work and Technology at the University of Applied Sciences in Gelsenkirchen and the Center of Applied Nanotechnology in Hamburg. Of special interest is the analysis of flows of knowledge among different actors, and hence, ways and means of knowledge sharing and approaches of how actors deal with knowledge as a commodity. The sectoral background is the field of nanotechnology, a highly specialised sector crucially dependent on composite knowledge interactions. Furthermore, because of its early development stadium, actors in the field of nanotechnology constantly face a high level of uncertainty in innovative developments.

The paper starts with some theoretical considerations about processes of innovation, knowledge sharing and the role of RDS (section 1). Then the field of nanotechnology is outlined as a sector of special interest in the context discussed above (section 2). In section 3 the case studies are introduced as well as the newly developed methodology of innovation biographies. The results are discussed in section 4, followed by a conclusion (section 5).

2 Processes of innovation, knowledge sharing and RDS

At the same time with the increase in the complexity of knowledge the structure and course of innovation processes have changed notably. Rather than innovating in-house organisations tend to decentralise their innovation activities by cooperating with a diversified network of partners. Van der Duin et al. differentiate between four different generations of innovation processes that were practiced over the last decades. The first and the second generation from around 1950 until the early 1970s were characterised by linear sequential processes with the first being more science driven and the second more market oriented. The third generation (early 1970s until mid 1980s) combined at every stage technological capabilities and market needs with numerous feedback loops and both internal and external communication networks. The present generation of innovation processes is based on R&D alliances, parallel and integrated R&D and is characterised by a network of partners that needs to be coordinated through active R&D management [4].

The reason for allying with other partners to share knowledge is manyfold: a) Knowledge as a crucial resource of innovation has never been more complex and more specialised than today. Increased specialisation causes substantial asymmetries of information in innovation processes and as such a high degree of uncertainty in innovative activities. b) The costs for generating and applying knowledge are ever-growing, because knowledge generation highly depends upon talented personnel. Additionally, knowledge generation is considerably accelerating: knowledge new and valuable today is old and commonly applied tomorrow. c) As one consequence large firms significantly concentrate on their core competencies and outsource other departments for strategic reasons. As Dankbaar puts it "the message of the proponents of strategic outsourcing is that it pays off to concentrate on the activities that you are good at and that give you competitive advantages. Leave everything else to suppliers who in turn can acquire competitive excellence in those activities" [5].

The practice of using (and searching) internal and external knowledge is captured in the concept of open innovation as one key characteristic of the fourth generation of processes of innovation. "Open innovation is a paradigm that assumes that firms can and should use external

ideas as well as internal ideas, and internal and external paths to market, as firms look to advance their technology" [6].

An organisational feature of the fourth generation of processes of innovation is the emerging field of RDS, often considered as one sub-sector of KIBS. KIBS in a more general description are characterized as consultancy services providing knowledge-intensive value-added for other firms. Economically useful knowledge is their main input and main output and thus "knowledge work" is the good they sell [7]. However, to give consideration to their heterogeneity it is worthwhile to distinguish them into KIBS I and KIBS II as identified by Miles et. al. [8]. Whereas the further are characterised as advisory services (e.g. market research, bookkeeping, and management activities) the latter have an explicit orientation towards technical services, e.g. IT consultancy, engineering services, and research. Research and development services unambiguously belonging to the KIBS II category are characterised by conducting research and development activities on behalf of an external client. In this sense RDS can also be provided by public research institutions.

On account of their specialisation the raison d'être of RDS is to abbreviate processes of innovation [9]. Therefore, it is argued in the literature that KIBS resp. RDS are increasingly influential sources of economically useful knowledge, and essential providers of impulses for the development of innovations. The intermediate character and the knowledge intensive input RDS and other KIBS provide for their customers have resulted in complimentary concepts associated with their business model: For example, they are considered as facilitators, carriers, and sources of innovation. "Facilitators" because they support innovative development through consulting; "carrier" because they can transfer innovations across branch boundaries; "source" of innovation because they can be the initiator of an innovation in the client's firm [10]. Furthermore, they are labelled as bridges of innovation [11]; co-producers of innovation [12], or agents of innovation [13]. All these concepts implicate the importance of RDS in processes of innovation. However, as Muller/Doloreux conclude in their literature review KIBS are more and more considered as being *drivers* rather than contributors of innovation [14].

3 The technology in question

The birth of nanotechnology can be dated back to the year 1981 when the scanning tunnel microscope made it possible to access the atomic base of materials. There is no precise, commonly recognised definition for nanotechnology. The term "nanotechnology" is used here to denote the analysis and manipulation of structures that are 100 nanometers ($100 \text{ X } 10^{-9}$) or smaller. Today nanotechnology is regarded as a key technology in future industrial innovation. It is, however, to a great extent science driven, because nanotechnology as such is not a complete technology and still in the stage of basic research. However, its maturity for applications and manufacturing structures is rapidly evolving.

On the one hand research driven nanotechnology is a combining traditionally separated disciplines like physics, bio-organic chemistry, molecular biology, material technology or sensor technology. The critical factor is the appropriate combination of these different disciplines for applications e.g. in nanoanalytics, surface modification, manipulation or nanoelectronics. On the other hand, being market driven, nanotechnology is a cross-sectoral technology with expected future applications in optics and nanoanalytics, chemicals and other materials, energy and environment, life science, and automotive. Further examples for applications are biomedicine, specifically instruments, medical technology systems and protheses. In electronic application, nanotechnology provides a continuation of the miniaturisation process and appli-

cations could include coating on surfaces, such as panels and windows and chemical reactors such as batteries and fuel cells. Nanotechnology was chosen as the sectoral background of the case study, because of three areas of interest:

a) Its reliance upon knowledge from different backgrounds and its cross-sectoral dimension;
b) the knowledge intensity of its application as a highly specialised and creative process;
c) and the means to protect knowledge as a pre-requisite both to exploit the high market potential of the technology and to cooperate with others.

4 The case study approach

Against this background two research questions will be analysed according to the results obtained in the pilot study:

- What are the strategic elements of treating and protecting knowledge as a commodity? (It is assumed that these strategic elements are the pre-requisite of cooperative behaviour and thus, of knowledge sharing in the field of nanotechnology.)
- What is the role of the RDS as knowledge providers in the investigated processes of innovation?

In terms of the organisational context of the pilot study, three research and development enterprises, one large two of them small and medium sized, and two public research institutions were selected. All organisations were active in nanotechnology related research. As the pilot study's methodology innovation biographies were conducted. The methodology of innovation biographies was developed at the Institute for Work and Technology at the University of Applied Sciences in Gelsenkirchen. It is an instrument of qualitative research aiming at opening the "black box" of knowledge interactions in innovation processes. By considering the total life span of an innovation it is intended to analyse the knowledge dynamics and to uncover the flows and the division of knowledge that promoted the development. In this context the term "innovation" is understood in its broadest meaning including product, process, and organisational innovations.

The basic criterion of the methodology is determining in the firm of interest an innovation already introduced into the market. To grasp the interactions of the process of innovation, a set of narrative interviews with persons central to the innovation is conducted. In the interview, the interviewee is asked to narrate the course of the innovative development from the beginning until the end of its implementation phase. Subject of the narrative are knowledge interactions, the way knowledge was treated and the contribution of different actors involved [15]. Guiding questions considering the managerial and communicational process of innovation are:

- What were the milestones and barriers?
- Was external knowledge needed to promote the innovation process?
- Of what kind was the external knowledge (e.g. technical/scientific, about markets, regulations/standards)?
- How was it obtained? Where did it come from?
- Who were the central actors in the process of innovation?
- What were the ways and means to protect the knowledge generated (contractual agreements between partners, patents, other strategies)?

In order to obtain starting points for a learning curve to prepare further in-depth interviews, the narrative interview has to be thoroughly explored. When analysing the initial interviews the focus lies on the isolation of major knowledge flows and accordingly on tracing back the central actors to conduct further interviews. These can be actors inside and outside the firm. By means of detecting the specific network architecture of communication, the set of interviews allows to uncover the knowledge flows relevant for the innovation process with all its internal (firm) and external (network) links. In order to get a detailed portrait of the process of innovation the relevant knowledge is "mapped". This is also to discover the fields of knowledge interactions having taken place. In sum, the ensemble of interviews, the identification of learning curves, and the knowledge map obtained builds the innovation biography [16]. As an example of a knowledge-map two cases of the study are shortly illustrated in this paper. (For anonymity reasons the details of the innovations cannot be published.)

To analyse the examined innovations in this case study, the knowledge pattern of the analysed innovations was mapped in a matrix (figures 1 and 2). The horizontal axis of the matrix indicates knowledge areas relevant in the process of innovation and the vertical axis indicates phases of the innovation process. This axis is subdivided into four different phases of development: initial phase, acquisition and development, application and innovation, transfer and diffusion. Pavitt criticises the separation of an innovation process into different phases, because phases or stages suggest linearity in innovation processes and do not take into account the various feed back loops necessary for progressing it [17]. In spite of accepting this argument, the analytical separation provides insights into variations of character and intensity of knowledge dynamics and on getting ideas about the exposure of time in the different phases. The fields of analysis on the horizontal axis were defined according to different knowledge domains: external knowledge, firm strategic acting, and knowledge strategic acting. Additionally, the identified milestones of the innovation process make it possible to relate the different knowledge domains to development steps of the innovation. The knowledge domain "external knowledge" asks for external linkages during the innovation process. The aim is to examine the openness of an innovation process, the compositeness of the knowledge advancing it, and the need for tacit knowledge not inherent in the initialising RDS. The knowledge domain "firm strategic acting" aims at uncovering the business related operational tools in which the innovation process is embedded. The third knowledge domain "knowledge strategic acting" asks for all kinds of issues related to access, protect, and exploit knowledge. Admittedly, it is not possible in every case to clearly distinguish between firm strategic and knowledge strategic acting. For example, searching for ways to further exploit knowledge usually includes a firm strategic component since it aims at getting more returns.

The two cases illustrated in this paper underline the heterogeneity of innovation processes of RDS. The development process of the first innovation (innovation biography I) was very open with various external links, whereas in the development process of the second innovation (innovation biography II) interactions were limited to the RDS and the client.

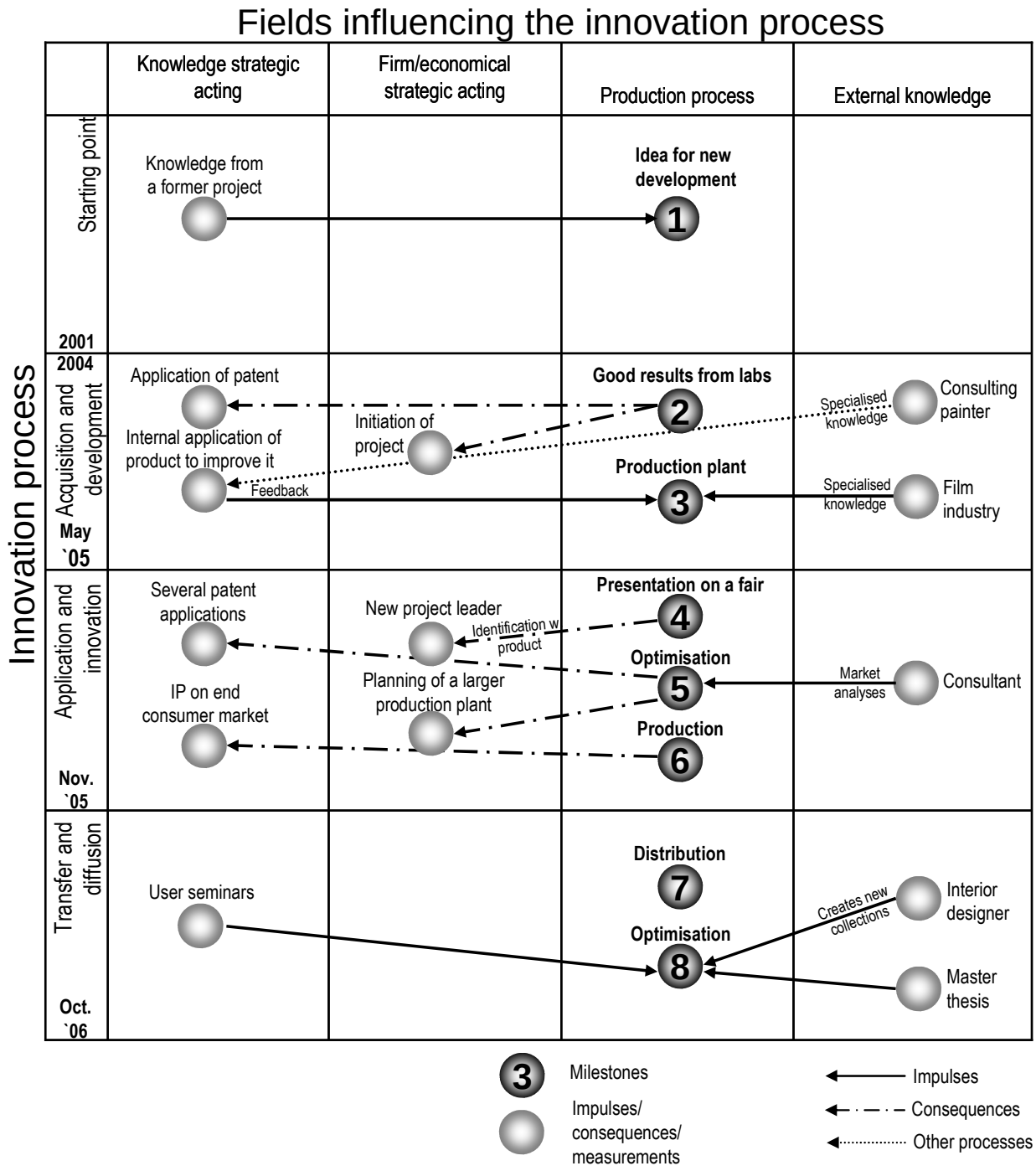
Innovation biography I 2001 – 2006 (figure 1):
The starting point of the innovation was the request to further exploit knowledge generated in another project leading to a product idea very atypical for the firm. The entire development process of innovation biography I is characterised by a comparatively high degree of openness. Apart from the relatively "normal" external interactions with consultants, a University of Applied Sciences, and plant and machine manufacturers, the development relied upon (tacit) knowledge of other disciplines. For this reason a craftsman was hired to consult the developers in the laboratories and to test the application attributes of the product. Another

problem in the innovation process was solved with the help of knowledge from the film industry, and finally an interior designer was hired to improve the product line. Additionally, to learn more about the product's attributes, performances and potentials, user seminars were conducted inside the firm to exchange experiences.

Innovation biography II 2001 – 2003 (figure 2):

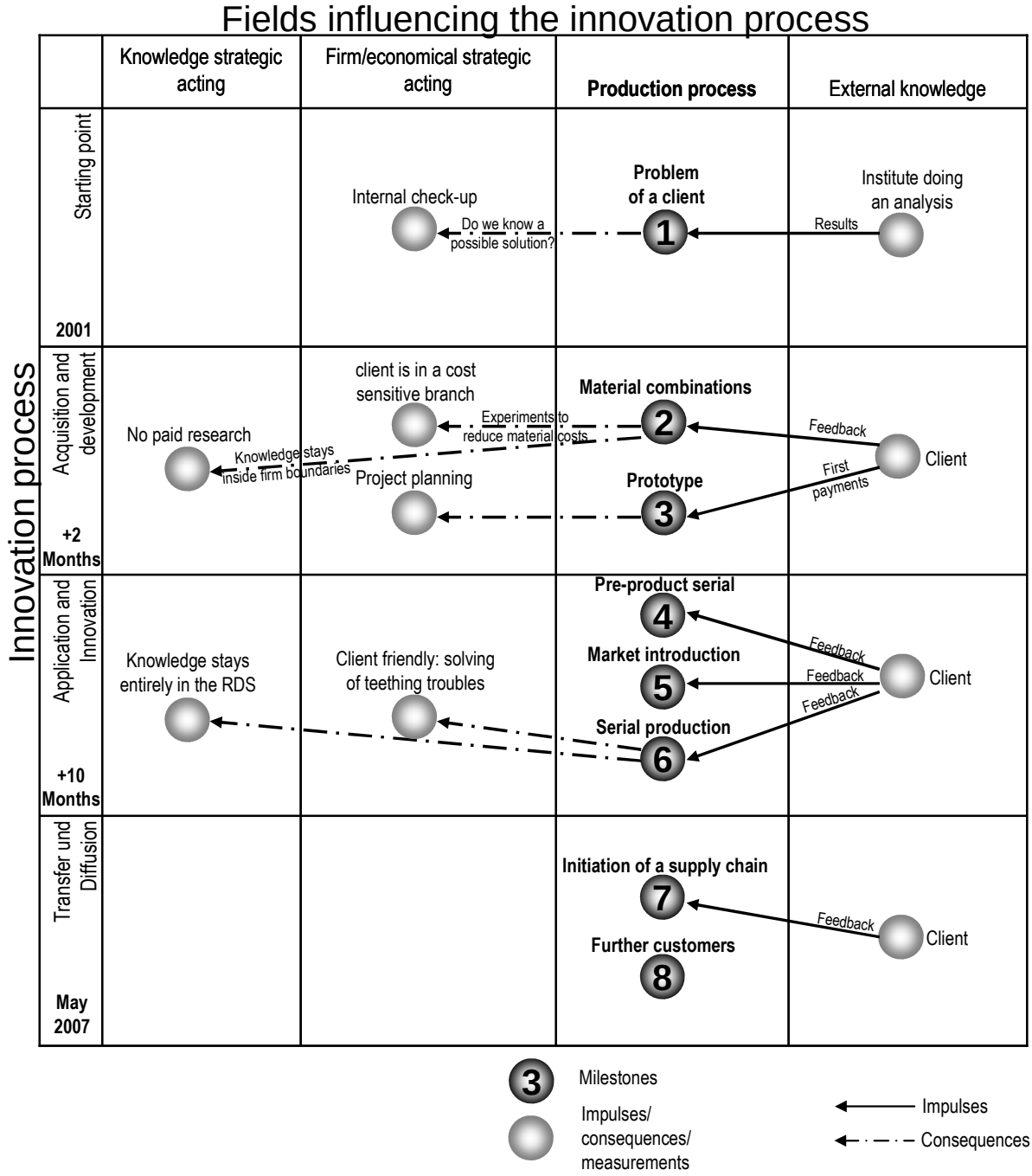
Innovation biography II is an interesting case regarding the treatment of knowledge as a commodity. The interactions of the client-led innovation process were limited exclusively to the developing RDS and the client to protect the generated knowledge. However, they were characterised through intensive and frequent feed back mechanisms. Although the initiative originated from the client, the RDS firm financed almost the entire innovation process with firm resources to keep the intellectual property rights. Even the serial production was conducted by the RDS to restrict access to the product and its technological components.

Figure 1: Knowledge map of innovation I



Source: own illustration

Figure 2: Knowledge map of innovation II



Source: own illustration

5 Results

In this section, the findings of the pilot study will be discussed according to the fields of interest outlined above: the consideration of knowledge as a commodity, and the role of RDS in innovation processes of nanotechnology as far as their knowledge input is concerned. To describe the knowledge strategy of a firm, one can distinguish between a) the ability to protect knowledge as the fundament of sharing knowledge, b) the means to profit from it, and c) the ways of how to acquire needed new and tailor-made knowledge. There are further components identified that belong to the knowledge strategic activities of firms. These are e.g. goal

oriented further training of the employees; initial research to enter new market segments; networking to get access to specialised knowledge, etc. However, since these components are of minor importance regarding knowledge strategies in concrete innovation processes, thus, they will not be discussed here.

a) In many cases the basis for protection of knowledge was established through non-disclosure agreements to facilitate knowledge exchange. However, with the exception of this very commonly applied formality, the means of protecting the flows of knowledge remarkably varied ranging from very open development processes to very narrow and restricted knowledge-sharing structures (e.g. bilateral cooperation). Patents played an important but not a superior role and if they were applied it happened mostly in the last third of the development process. In earlier phases other instruments of knowledge protection were of greater importance. The owner of one very small enterprise fabricating a product for the end consumer market underlined the fact that with a patent, knowledge is disclosed to a considerable extent. If so, lawsuits about intellectual property rights are likely, especially when large firms have an interest in the technology or the market segment. To avoid lawsuits and the risk to loose rights of production the firm's strategy is to restrict the knowledge to two persons rather than to patents. In this case knowledge was not shared at all. Restricting the access to knowledge and keeping the partner structure as small as possible was also preferred in other processes of innovation. In one case even the serial production was conducted in house and not outsourced explicitly for reasons of knowledge protection (cp. innovation biography II).

b) Apart from knowledge protection it is critical for RDS to find ways to profit in the long run from their accumulated knowledge generated on behalf of a customers. One interview partner underlined the difficulty to mediate this to clients. "Clients order our research and think they own the product and intellectual property rights, because they paid for it. What they refuse to consider is the immense amount of initial research, experiences and competences from our side advancing the development process" [18]. Another interview partner said that ways to profit from newly generated knowledge are crucial to not sell out the firm's knowledge base "if it is not possible to find such a way the company won't survive" [19]. For this reason, commonly applied instruments and means to make profit from knowledge and exploit it even after an innovation process is formally terminated are licensing, serial production and if the innovation is of intermediate character, getting shares of the value-added.

c) The first mechanism to generate new knowledge is to support the creativity of the firm's employees. A second commonly applied way to acquire external knowledge is through contacts to universities. In many of the investigated innovation processes firms hired students to write their diploma theses about a problem faced. It was also observed that some companies established user seminars to facilitate the interaction between their technicians and users of the product in order to learn more about its application and to improve it. Of course, personal contacts to other firms played an additional role. However, in the investigated innovation processes it was not very common to solve problems via informal networks. An explanation for this could be the highly sensitive market of nanotechnological applications and its dependency on non-disclosure agreements. In some cases cross-sectoral linkages were identified, which appeared to be not only cross-sectoral but also crossed "boundaries" between high- and low-tech sectors: a firm active in the field of nanotechnology relied upon knowledge of a low-tech sector when hiring an experienced painter – an example underlining the importance of tacit knowledge. Table 1 presents a summary of the knowledge strategies the RDS had chosen in the respective processes of innovation.

Table 1: Summary of knowledge strategic acting

Cases / Knowledge strategy	Case I	Case II	Case III	Case IV	Case V
Means of protection	Narrow bilateral partner structure; disclosure agreement; patents at the end of innovation process	Patent application	Relatively open innovation process; one patent right in the beginning and several patents at the end of innovation process	Disclosure agreement; patents	Patents
Means of profiting	Expenditures for innovation process were provided mainly by the RDS to fully enact about ways to profit from it; production in house	Production was outsourced	Production in house	Production in house	Product production was outsourced and profit was received via a licence
Sources of new knowledge	Knowledge generation was based on internal cross-sectoral experiences of the developers team	Linkages to several universities, member of a state-financed network, long search processes for finding people at disciplinary interfaces	Several external linkages to other sectors, user seminars, universities (theses)	User seminars, theses	Scientific network

Source: own illustration

6 Conclusions

A first result of the pilot study is the feasibility of applying innovation biographies as an adequate method to understand the variety of knowledge flows driving processes of nanotechnological innovation. Given the range of knowledge strategies discussed above sharing knowledge of RDS in innovation processes appears in various strategies reaching from the quick development of intermediate products such as the surface modification of certain components to the creation of comprehensive and highly sophisticated devices. Therefore, RDS can play both major and minor roles in innovation processes depending on the complexity and nature of innovations. However, the case studies underpin the assumption that knowledge protection is the pre-requisite of knowledge sharing in the field of nanotechnology. Being a technology in the phase of basic research, it surely contributes to the diversity of innovation processes as routines, norms, and quality standards which are not established yet.

However, there are some first generalisations that can be drawn from the findings of the innovation biographies regarding the different knowledge domains. Apart from very different starting points of the innovations (phase I), phase II was characterised by management activities such as the formal implementation of a project, first payments of the client, and increased external linkages. In phase III knowledge strategic acting was of considerable relevance and especially the protection of knowledge through patent application. The last phase was as diverse as the starting phase however, it was of great importance to establish mechanisms that allow the RDS to profit from their knowledge in the long run.

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