The Articulation Between Formal and Informal Channels of University-Industry Knowledge Transfer: A Longitudinal Approach[1]

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Résumé :

L'objectif de la recherche est de montrer la complémentarité des mécanismes formels et informels de transfert de connaissances entre les universités et les entreprises. La littérature consacrée à ces transferts de connaissances s'attache essentiellement aux transferts formels, donnant lieu à des dépôts de brevets, des cessions de licences, des accords de royalties ou des créations de start-ups. Or, d'autres canaux de transfert de connaissances existent tels que l'assistance technique, les activités de consulting, l'enseignement, les stages d'étudiants, la formation doctorale et les thèses réalisées en collaboration entre l'université et l'industrie. Ces canaux informels sont moins étudiés, car ils sont plus difficiles à identifier et à mesurer. Les approches fondées uniquement sur les mécanismes formels conduisent à une vision réductrice des stratégies de développement de la valorisation de la recherche de l'université orientées par la recherche de la maximisation des revenus de la propriété intellectuelle.
L'étude des interactions entre les différentes formes de transfert de connaissances repose sur deux méthodologies de recherche complémentaires. La première est une analyse statistique des résultats d'une enquête conduite auprès de chercheurs académiques français. Elle montre une corrélation entre différentes formes d'implication dans la valorisation de la recherche. La seconde, mobilisée pour comprendre l'interaction entre les différentes formes de transfert de connaissances dans leur dimension dynamique, se fonde sur deux études de cas exemplaires

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de chercheurs fortement impliqués dans les activités de valorisation de la recherche, dans les domaines de la pharmacie et de la robotique. Les données qualitatives recueillies par interviews montrent que les canaux formels et informels de transmission des connaissances sont fortement interdépendants et se renforcent mutuellement dans le temps. Elles nous conduisent à mettre en avant trois résultats principaux. Premièrement, elle montre le rôle critique joué par les réseaux sociaux de chercheurs dans les transfert de connaissances. Ce résultat conduit à proposer une approche plus riche du rôle des centres de valorisation de la recherche des universités, qui ne se limite pas au management de la propriété intellectuelle, mais à un rôle plus riche d'intermédiaire d'innovation entre de nombreuses parties prenantes et d'acteur du développement des réseaux informels. Deuxièmement, elle montre le rôle central joué par les doctorants et les étudiants en études postdoctorales dans les transferts de connaissance de la recherche académique vers les entreprises ou dans la création de start-ups. Troisièmement, selon les champs scientifiques et technologiques, les interactions entre les mécanismes de transfert formels et informels sont différentes. Dans chaque cas étudié le rôle du brevet apparaît essentiel comme gage de crédibilité vis-à-vis des partenaires extérieurs. Cependant, dans un cas il a pour but de préserver la maîtrise de l'utilisation de la technologie, dans l'autre cas il apparaît comme un instrument défensif en cas d'attaque. Ainsi, il ne joue pas toujours le même rôle stratégique en matière de protection des inventions issues des résultats de la recherche.

Mots-clés : Relations université-entreprise, valorisation de la recherche, brevets, transfert de connaissance informel, transfert de technologie

INTRODUCTION

A large body of the literature on university-industry knowledge transfer (UIKT) has focused on formal aspects managed by technology transfer offices and resulting in patents, licenses, royalty agreements or start-up creations (Phan and Siegel 2006; Thursby and Thursby 2002; Lockett et al. 2005). Implicitly, these approaches are based on a linear model of innovation starting with a scientific discovery and ending with the commercialization of a technology or the creation of a start-up (Bradley et al. 2013). The linear model is not sufficient to capture the complexity of technology transfer processes. Moreover, it reduces the role of universities to the maximization of revenues through the exploitation of intellectual property rights, thus ignoring the different aspects of their contributions to the economic development, especially at the regional level (Colyvas and Powell 2004; Bozeman et al. 2015). In particular we know very little about other technology transfer channels such as, for instance, technical assistance, consulting activities, formal and informal collaborative research, transfer through teaching activities, student placements and supervision of PhD students (Link et al, 2007; Siegel et al, 2003; Perkmann et al. 2013), joint PhDs with the industry (such as the CIFRE[2] PhD in France), which represent also important channels of diffusion of scientific knowledge (Levin et al. 1987; Agrawal and Henderson 2002; Cohen et al. 2002).

We also know very little about the way different UIKT channels interact (Bradley et al. 2013; Perkmann et al. 2013). However, they are likely to interact as stated by Link et al. 2007: "Research suggests that formal and informal technology transfer may go well together (Siegel et al. 2003; Link et al. 2007) in that informal contacts improve the quality of a formal relationship or that formal contracts are accompanied by an informal relation of mutual exchange on technology-related aspects". The literature provides some static evidence based on cross section studies, which suggest that the different UIKT are correlated (D'Este and Patel 2007; Grimpe and Hussinger 2013). But no studies, to the best of our knowledge, provide a dynamic setting which allows understanding the causality between different UIKT channels and, in particular between formal and informal ones, or put forward specific patterns of interactions.

The aim of this paper is therefore to contribute to fill this gap by providing a first investigation into the dynamics of the interactions between different UIKT channels. To do so we consider a distinction between formal and informal UIKT channels, based on two

[2] CIFRE (Convention industrielle de formation par la recherché) is an industrial agreement for training through research in France.

dimensions. First, we look the contractual or non-contractual nature of the UIKT, as proposed by Link et al. (2007) and Bradley et al. (2013). Second, we look whether there exists interpersonal interactions in the occurrence of UIKT. As we know informal channels contribute to the development of social capital that enables firms to identify and meet academic partners (Grimpe and Hussinger 2013). Moreover, stable relations between partners strengthen the network effects through the development of inter-organizational routines that favor informal interactions (Giuliani et al. 2010; Dyers and Singh 1998). Therefore, to introduce this social dimension in our analysis, we distinguish UIKT based on a formal transmission of codified knowledge with very low or no interpersonal interaction and those based on interpersonal interactions which allows transferring the tacit knowledge.

Our empirical analysis contains two steps: first we conduct a cross-section analysis based on a survey of French academic researchers. This survey suggests strong correlations between different UIKT channels. However, it does not enable us to understand the dynamics of these interactions. This is why we complement it with a longitudinal and qualitative analysis of two remarkable trajectories of researchers at the University of Strasbourg. Interviews and second hand data have enabled us to reconstitute the valorization history of these two researchers and therefore to suggest some dynamic links among different UIKT channels that they have used,in particular between formal and informal ones.

The main message conveyed in this paper is that (1) not only formal UIKT channels but also informal ones matter; (2) dynamic interactions between formal and informal UIKT might be important and (3) there is not only one single pattern of interaction but many different ones. As regard to managerial and policy implications, this research suggests in particular that one should be very careful when evaluating mechanisms of research valorization at a single point in time. For instance, limiting the evaluation by counting patent licensing royalties neglects most of the interactions that patents might have with other UIKT channels such as start-up creation, formal collaborations and so on.

The first section provides a theoretical approach of formal and informal UIKT based on a literature review and an attempt to propose a unified definition of the concepts. Section 2 shows the results of a cross-section analysis based on a survey of French academic researchers. Section 3 shows the results of a qualitative and longitudinal analysis of the valorization trajectories of two remarkable French researchers at the University of Strasbourg. Section 4 discusses managerial and policy implications.

1 FORMAL VERSUS INFORMAL UIKT CHANNELS

This section first comes back to the definition of formal and informal UIKT channels. It proposes a unified classification and reviews the theoretical arguments and the empirical studies, which explain why different UIKT channels might be dynamically interrelated.

1.1 WHAT IS FORMAL? WHAT IS INFORMAL? AN ATTEMPT OF CLASSIFICATION

Obviously, a study that aims at studying the dynamic interplays between formal and informal UIKT channels must first be able to define what are formal and informal channels. No consensus about the definition emerges in the literature. Some channels are considered as formal by some authors and as informal by others. In Table 1 one sees that for Perkmann et al. (2013) collaborative research and consulting are considered as formal whereas Link et al. (2007) consider them as informal. Our view is that these divergences stem from the use of two very different approaches in order to determine whether a channel is formal or informal.

A first approach is purely contractual. It considers that a UIKT channel is formal as soon as it is structured by a formal contract. It can be, for instance, a license in order to transfer a technology, a research contract in order to frame collaborative research or consulting activity, a contract in order to organize a joint PhD and so forth. This is, for instance, the definition adopted by Grimpe and Hussinger (2013) who define informal channels as “a mechanism that does not involve any contractual relationship between the university scientist and the firm”, thus meaning that when there is a contract the transfer is formal. Perkmann et al. (2013) are on the same line.

Table 1: Different definitions of formal and informal UIKT channels in the literature

	FORMAL CHANNELS	INFORMAL CHANNELS
Link et al. 2007	"… ones that embody or directly result in a legal instrumentality such as, for example, a patent, license or royalty agreement."	"An informal technology transfer mechanism is one facilitating the flow of technological knowledge through informal communication processes, such as technical assistance, consulting, and collaborative research." "… with informal technology transfer, property rights play a secondary role, if any, and obligations are normative rather than legal."
Grimpe and Husinger. 2013		"in this paper we define informal technology transfer as a mechanism that does not involve any contractual relationship between the university scientist and the firm."
Perkmann et al. 2013	"formal activities such as collaborative research, contract research, and consulting"	"informal activities like providing ad hoc advice and networking with practitioners"

Yet, this view, even though it has the merit of coherence and simplicity, neglects to pay attention to knowledge transfer and, in particular, to the tacit dimension of knowledge. For instance, from the contractual point of view, research collaboration and a patent licensing agreement are both formal mechanisms. Yet, they can be very different since research collaboration might involve the transfer of tacit knowledge whereas a patent licensing agreement does not entail, *a priori*, such transfer of knowledge. It is just a transfer of formal rights. Put it otherwise, in UIKT channels considered as formal from a pure contractual point of view there are sometimes a lot of interactions such as personal exchanges and informal discussions.

This is, we believe, what Link et al. (2007) want to put forward when they claim that "An informal technology transfer mechanism is one facilitating the flow of technological knowledge through informal communication processes, such as technical assistance, consulting, and collaborative research". Indeed, in order to transfer knowledge one usually needs face-to-face interactions, i.e. informal communication. This view clearly adds on the contract-based view, which does not consider whether or not there are face-to-face

interactions between firms and academic researchers. It is therefore important to enrich the contractual approach by adding this distinction and separating between channels involving face-to-face interaction and transfer of knowledge and those which don't. When we cross the two approaches, the contractual one and the knowledge based one, we obtain the classification displayed in Table 2.

Table 2: A unified classification of formal versus informal UIKT channels

	CONTRACTUAL UIKT	**NON-CONTRACTUAL UIKT**
UIKT WITHOUT FACE-TO-FACE INTERACTION	Case A -Material Transfer Agreement -Licensing (patent, software)	Case B -Scientific publications
UIKT WITH FACE-TO-FACE INTERACTION	Case C - U-I research collaboration - Academic spin-off - U-I doctoral thesis - Contractual consultancy - Technical assistance	Case D - Doctoral students leaving academia - Teaching activities - Non contractual consultancy - Academic conferences and workshops - General public conferences

In Table 2 one sees therefore a first definition of a formal channel, which is when there is a contract irrespective of the existence of face-to-face interactions. Examples are contractual research collaboration, contractual consultancy, technical assistance, consulting activity or patent licensing agreement. This is what we could call a ***broad definition of formal UIKT channels***. This is in line with the contractual view put forward above. To this broad definition, which corresponds to cases A and C in Table 2, one can add a ***narrow definition of formal UIKT channels,*** which supposes that the transfer entails a contract but no face-to-face interaction. In this latter case, although there is a contract, UIKT is not considered as formal due to the "informal communication process" (Link et al. 2007). Patent or software licensing agreements and MTAs fit in with this narrow definition of UIKT. This definition corresponds to case A in Table 2.

Similarly, one can distinguish ***a broad and a narrow definition of informal UIKT channels***. The broad definition mirrors the narrow definition of a formal channel and encompasses any UIKT channels which involve face-to-face interaction, even those which contain contractual agreements. It corresponds to cases C and D in Table 2. The narrow definition mirrors the

broad formal one and encompasses any UIKT channels, which do not have formal agreement and involve face-to-face interactions. It corresponds to case D in Table 2. Finally a last case, case B in Table 2, accounts for standard knowledge externalities, i.e. when "knowledge flows in the air" and is not transferred via any contractual or face-to-face mechanism.

1.2 WHY ARE FORMAL AND INFORMAL UIKT CHANNELS NOT INDEPENDENT?

Transaction cost theory (Coase 1937; Williamson 1975) provides justifications to the organization of transactions between distinct entities through formal contractual arrangements. Following the work of Simon (1957; 1961), this theoretical approach is based on two fundamental hypotheses about human behavior. The first is limited rationality, resulting not only from the limitation of cognitive capabilities, but also from the optimization in the use of the cognitive resources of the firm. The second is opportunism, which leads to adverse selection (Akerlof 1970) and moral hazard (Hôlmstrom 1979). Limited rationality and opportunism lead to low level of trust between the actors involved in transaction within a firm or between two organizations.

When the object of the transaction is technological knowledge, risk of opportunism is particularly important (Teece 1980). In the literature on UIKT, technology is considered as a set of artefact, knowledge and skills (Metcalfe 1995; Sahal 1981, Bozeman 2000). Then technology transfer relies on the transmission of both codified and tacit knowledge. The non-exclusive and non-rival properties of knowledge provide some characteristics of public good to technology. Therefore, to preserve the economic potential of the results of R&D activities, technologies are often protected by secrecy. When a transaction consists of technology transfer, the owner of the technology faces a disclosure dilemma (Arrow 1971). He has to reveal *a priori* enough information about the technology to make the transaction possible, but at the same time has to preserve a part of secrecy otherwise the transaction would become useless since all the information would have been transferred to the potential partner before the transaction. Secrecy generates an important asymmetry of information between the parties, and creates conditions for opportunistic behaviors. Another consequence of secrecy is the non-availability of information about the location of technological knowledge, which makes difficult the meeting between the owner of the technology and the potential external buyers. The last factor that makes knowledge transaction very specific is the tacitness of technological knowledge. A part of technological and scientific knowledge is embodied in

human resources and cannot be completely described in a contract. This contributes to the increase in risk of opportunism and also implies that technology transfer relies on human interactions. The transmission of tacit knowledge is time consuming, costly and makes technological knowledge not easily transferable (Zander and Kogut 1995).

Patent is a tool that contributes to facilitate the transfer of knowledge. It resolves some problems resulting from the protection of knowledge by secrecy and its elaboration is based on codification of knowledge that facilitates the transfer. However, this codification of knowledge is not perfect, because it is difficult to describe R&D activities and even when a technology is patented, it relies on tacit knowledge. To exploit a technology, codified knowledge contained in patents must often be complemented with tacit knowledge and the granting of a license may lead to academic consulting to transfer this tacit knowledge (Zucker et al. 2002; Perkmann and Walsh 2008). Moreover, the protection offered by patents is never complete, because it would be too costly to establish complete contracts (Bessy and Brousseau 1997; Agrawal 2006) and even if they would be complete, actors could develop strategies to bypass patents. Therefore, even in transactions of patented technologies, there is a place for opportunism which can obstruct the transaction. As a consequence, trust between different parties makes the transaction more fluid, because it functions as a self-enforcement governance mechanism, which reduces the risk of opportunism (Sako 1991). Trust is developed through personal interactions and is an asset specific to a relation, developed over time through repeated interactions (Powell 1990; Gulati 1995).

In technology transfer activities based on cooperation, there are additional sources of risk that increase the risk of opportunism. Cooperation agreements and alliances are hybrid forms of coordination between hierarchy and markets (Williamson, 1979; 1991), in which the two parts remain autonomous but are mutually interdependent in long-term relations as they follow a common objective. A strong specificity of these relations leads in the uncertainty about the result of the transaction, which is not known before the transaction. As a consequence, cooperation agreements are based on incomplete contracts. They do not anticipate all possible contingencies and preserve the adaptability of the relations to unpredictable events. The counterpart of this incompleteness is the importance of governance mechanisms in the viability of collaboration. Contractual arrangement is a tool used to resolve some conflicts (Williamson 1975), but in UIKT based on research collaboration, trust is fundamental. The

stability of relations over time contributes to the increase in trust which constitutes a relational asset, specific to each inter-organization relation (Dyer and Singh 1998).

1.3 COMPLEMENTARITY OF UIKT ACTIVITIES: EMPIRICAL EVIDENCES

Through a longitudinal study of Georgia Tech, Youtie and Shapira (2008) show how a university can participate to the development of an innovation-driven region, by behaving as a knowledge hub. In their approach, the complementarity of technology transfer activities is an implicit element of the transformation of a university from a knowledge factory to a knowledge hub model. In the knowledge hub model, university promotes the diffusion of technologies through multidirectional interactions among the different actors of the system of innovation. These interactions participate to the circulation of tacit knowledge in the system and then favor the transformation of academic knowledge into business projects, which relies on both codified and tacit knowledge (Amin and Cohendet 2000). All activities that favor the diffusion of tacit knowledge in the system contribute to develop an environment conducive to transfer of knowledge from university to its environment (Youtie and Shapira 2008).

Bercovitz and Feldman (2007) in a research focused on the strategic determinants of firm and university research alliances, characterize the university-industry relationship, in opposition to the university-industry transaction, as a set of activities in which the firm is engaged in, such as funding several sponsored research, hiring graduate students, participating in research centers or providing endowment funding. They conclude from a survey of executives at R&D intensive firms in Canada, that firms engaged in exploratory activities develop these multifaceted relationships. Thus, strong ties between universities and innovative firms are not the repetition of the same kind of relation, but a set of diverse relations.

Cohen et al. (2002) show that different channels such as consultancy, conferences, collaborative research are used in conjunction. They stress that the influence of public research on industrial R&D does not correspond to a linear model of transfer of knowledge but to an interactive process. The informal channels of transfer of knowledge appear to be more important than IP licensing or collaborative research (Levin et al. 1987; Agrawal and Henderson 2002). The most important channels for firms to access public research are public channels such as publications and conferences, and personal channels based on informal relations, that can be informal advices given occasionally, with no formal consultancy contracts (Faulkner and Senker 1994).

Grimpe and Hussinger (2013) emphasize the complementarity between formal and informal transfer channels from academia to industry, by focusing on the firm side. Based on a survey of more than 2000 German manufacturing firms, their findings suggest that the use of informal channels, which are defined as mechanisms that do not include any contractual relationships, increase the marginal return of formal technology transfer and the firm's innovative performance. Therefore to achieve the full potential of a formal technology transfer, firms need to establish close informal ties with universities.

Link et al. (2007), present empirical evidences on the determinants of informal technology transfer activities through a survey of university scientists and engineers in US. Their findings suggest that faculty characteristics are important determinants. Male, tenured and research-grant active faculty members are more likely to be engaged in consulting, joint publications with firms and transfer of commercial technology, which are considered as informal channels in their study. The work of Grimpe and Fier (2010), which is a replication and extension of Link et al. (2007), compare US and Germany in terms of informal technology transfer activities. Similarly, faculty characteristics are found to be an important determinant. In particular, faculty quality, which is rather based on patent records of university scientist than publications, is effective in terms of attracting industrial partners in joint informal transfer activities.

Based on a survey of UK university researchers, D'Este and Patel (2010) also stress that university researchers interact with industry using wide variety of channels. In compare to patenting or start-up creation, other channels such as joint research, training, consultancy and contract research are frequently used. Further, their findings suggest that individual characteristics have stronger impact than the institutional characteristics in explaining variety and frequency of the interactions with industry. In particular previous experience of collaborative research increases the variety and frequency of interactions. They conclude that supporting variety of interaction channels build an enduring relation between science and technology by contributing university researchers to acquire individual skills.

In sum, technology transfer relations appear to be strongly socially embedded (Brown and Duguid 1991). Social networks that include academic and industrial scientists, actors of the technology transfer management inside universities, actors of the regional and national systems of innovation play an important role in university-industry technology transfer process (Link et al. 2007).

2 A CROSS-SECTION APPROACH: RESULTS OF A SURVEY ON RESEARCHERS IN TWO LEADING FRENCH UNIVERSITIES

We have collected information about the valorization activity of researchers in two large French universities. An online survey has been sent to all the researchers of these two universities in 2015. The objective of this survey was to explore the engagement of university researchers towards valorization activities and interactions with industrial partners. This questionnaire enabled us to collect information on four different UIKT channels used by researchers: formal collaborations, consulting, licenses and involvement in start-up creation (see Table 3), thus improving our understanding as regard to how these different channels correlate with each other. It also contains information related to researchers' characteristics thus enabling us to understand how these characteristics affect the number of distinct valorization channels (breadth/range of valorization activity) that the individual researcher is involved in, as in D'Este and Patel (2007).

Table 3: Distinct forms of research valorization channels

UIKT CHANNEL	DEFINITION
Formal collaboration	The research programs carried out in partnership with companies within the framework of bilateral collaboration contracts, CIFRE (Industrial contracts for training through research) contracts or multi-partner projects (European projects, ANR, etc.) involving companies.
Consulting	Service provider contracts, study and research for a company.
Licensing	The commercial exploitation of research results through the granting of licenses (of patents, know-how, software, etc.) to companies or the cessions (of patents, know-how, software, etc.).
Start-up creation	The involvement of researchers in a company (creation, management, participation in bodies of governance and scientific council) in relation with their research.

We have received 315 exploitable answers from researchers in all scientific disciplines. A limitation of this survey is that we cannot calculate exactly the response rate because we do not exactly know to whom the questionnaire has been sent since, for confidentiality reason we did not have access to the researchers' email addresses but only to the one of their department director who has been asked to forward the questionnaire. We are not certain that whether all department directors did forward it.

First information deals with the involvement of researchers as regard to valorization activities. As displayed in Table 4, 53% of the respondents reported having been involved at least once in an industrial contract which involved an industrial partner, 42% reported having performed at least once a consulting job for an industrial partner, about 14% reported having been involved in the creation of a start-up and 15% reported having one of the patent they have invented been licensed to an industrial partner.

Table 4: Researchers' involvement in four valorization activities

	NBER OF RESEARCHERS (N=315)	%
FORMAL COLLABORATIONS	168	53,33
LICENSING	48	15,24
CONSULTING	133	42,22
START-UP CREATION	44	13,97

A second result deals with the intensity of researchers' involvement towards valorization. As displayed in Table 5, about 62% of the respondents report having used at least one channel. 26% of them report having used two channels; 10% report having used three and 5% having used all of them.

Table 5: Number of distinct UIKT channels used by the respondents

	NBER OF RESEARCHERS (N=315)	%
0 (none of the 4 channels are used)	119	37,78
1 (1 out of the 4 channels is used)	66	20,95
2 (2 out of the 4 channels are used)	81	25,71
3 (3 out of the 4 channels are used)	32	10,16
4 (all the 4 channels are used)	17	5,40

An important question we are interested in deals with the interaction between the different UIKT channels. To explore this question we have calculated the correlation between them (Table 6). As expected all the channels are positively and significantly correlated suggesting that they eventually reinforce each other as discussed in the theoretical section. Interestingly we observe a strong correlation between formal collaboration and consulting suggesting that the two might feed each other, a successful collaboration, which demonstrates the expertise of

the researchers, possibly opening the door to future consulting activities or, conversely, a successful consultancy leading to a formal collaboration.

Table 6: Correlation matrix between the four UIKT channels

	Formal Collaboration	Consulting	Start-up creation	Licensing
Formal Collaboration	1			
Consulting	0.5677***	1		
Start-up creation	0.2117***	0.2118***	1	
Licensing	0.2904***	0.3350***	0.3388***	1

Note: *** means that the coefficient is significant at the 1% level

The causality between the different channels cannot be analyzed here. More insights as regard to these questions will be offered in the next section with a qualitative study.

3 A LONGITUDINAL APPROACH: LESSONS FROM TWO RESEARCHERS' REMARKABLE TRAJECTORIES

In order to have a dynamic and longitudinal picture of the UIKT activity we have tracked the full career of what we believe are two remarkable (as regard to their involvement in UIKT) researchers. Before interviewing the two researchers, they send us their curriculum vitae (35 pages and 38 pages), describing their entire academic and UIKT activities. We also collected information about their PhD students, the career of their PhD students, the start-ups created, patents and licenses, formal and informal collaborations with scientists and firms, consultancy activities, etc. The first researcher is Professor Pharma specialist in organic chemistry and the second one is Professor Rob specialist in robotics[3]. Both are researchers at the University of Strasbourg.

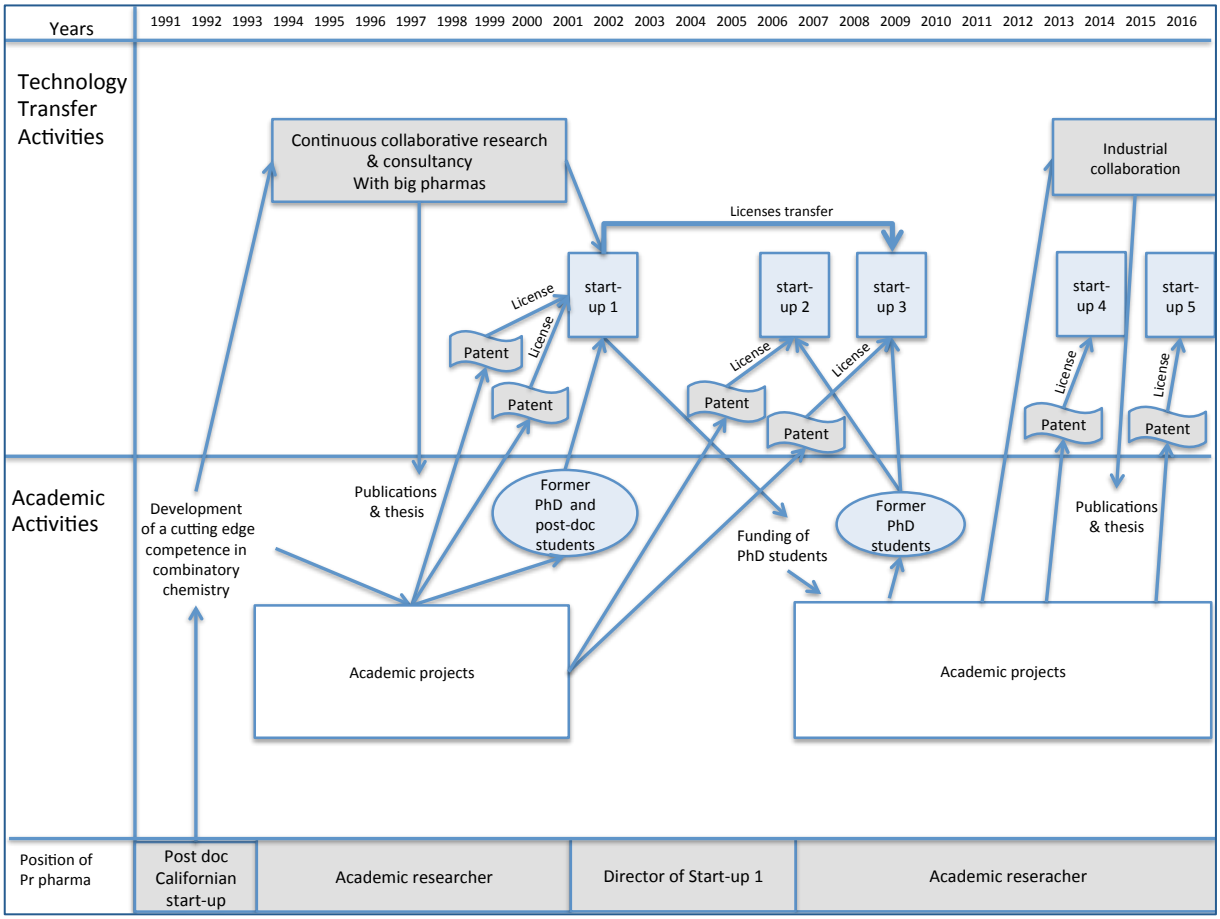
3.1 A STORY OF UIKT IN PHARMACEUTICALS

Prof. Pharma is specialized in organic chemistry. He is 52 years old. His involvement in technology transfer activities is described in Figure 1. After a PhD thesis in Strasbourg he spent three years in California as a post-doctoral student in a start-up in San-Francisco. He was working with a scientist having a very high level of international scientific reputation. Prof. Pharma developed a specific competence, which was a cutting edge, in combinatorial chemistry. When he came back in France as a researcher in a public research organization, the CNRS, this competence constituted a strong asset to create his own research team, with the

[3] For the sake of anonymity, all names in this section have been changed.

industrial support of big pharmaceutical firms which were interested in his competence. This industrial support took the form of funding of PhD projects, consultancy activities and contractual research. Beside these contractual activities, Prof. Pharma developed his own research thematic and filed two patents.

Figure 1: Technology transfer activities of Prof. Pharma



He decided to create the first start-up around the year 2000 (start-up 1). The aim was to generate benefits to fund research and to be free to choose his research problematic. He left temporarily his position in the academic laboratory to work full time in the start-up. The two patents that he had previously filed were exclusively licensed to the start-up. The PhD student who had worked on the development of the proof of concept for the patents was hired by the start-up and is still working in the firm today. Furthermore, Prof. Pharma was in touch with a former colleague (who became of a friend) he met in California during his post-doctoral studies. This friend had created a start-up in Germany and introduced him to investors. He also introduced him to the future manager of the start-up, who was working in his own start-up, and had the desire to come back in France. This manager still manages start-up 1 today.

The first difficulty to create the firm was to raise funds. No investor was really interested at this stage in 2001. Then, Prof. Pharma and the manager decided to start with an activity based on contractual research for firms. They hired a former post-doctoral student. They obtained contracts thanks to the network Prof. Pharma had developed before with big-pharmaceutical firms. This contractual research activity was successful and after a short period the start-up reached 40 employees. However, the business model was not as the one established in the first step, which was the exploitation of a patented product. So Prof. Pharma decided to create another start-up (start-up 3) to pursue his first objective. To do so he transferred one employee (who historically helped to develop the technology) and licensed two patents from start-up 1 to this new start-up.

After 5 years spent in the first start-up, Prof. Pharma decided go back to full time academic work, to develop new fields of research and to develop a potential to make new inventions and create new start-ups which would be more profitable than the first one. To do so, it is interesting to note, Prof. Pharma did set-up a strategy of systematic patenting and start-up creation in order to valorize its research. He develops academic research activities in fields having a technology transfer potential, he builds teams around this competence, manage the team, patents, create a start-up and transfer the technology through a license. This strategy is also a way to place PhD students and post-docs formed in the laboratory. Furthermore, in order to develop specific skills and competences, and to have full and exclusive rights over its research results, he decided to stop collaborative research with big firms. To help begin these new research activities, start-up 1 funded two PhD students.

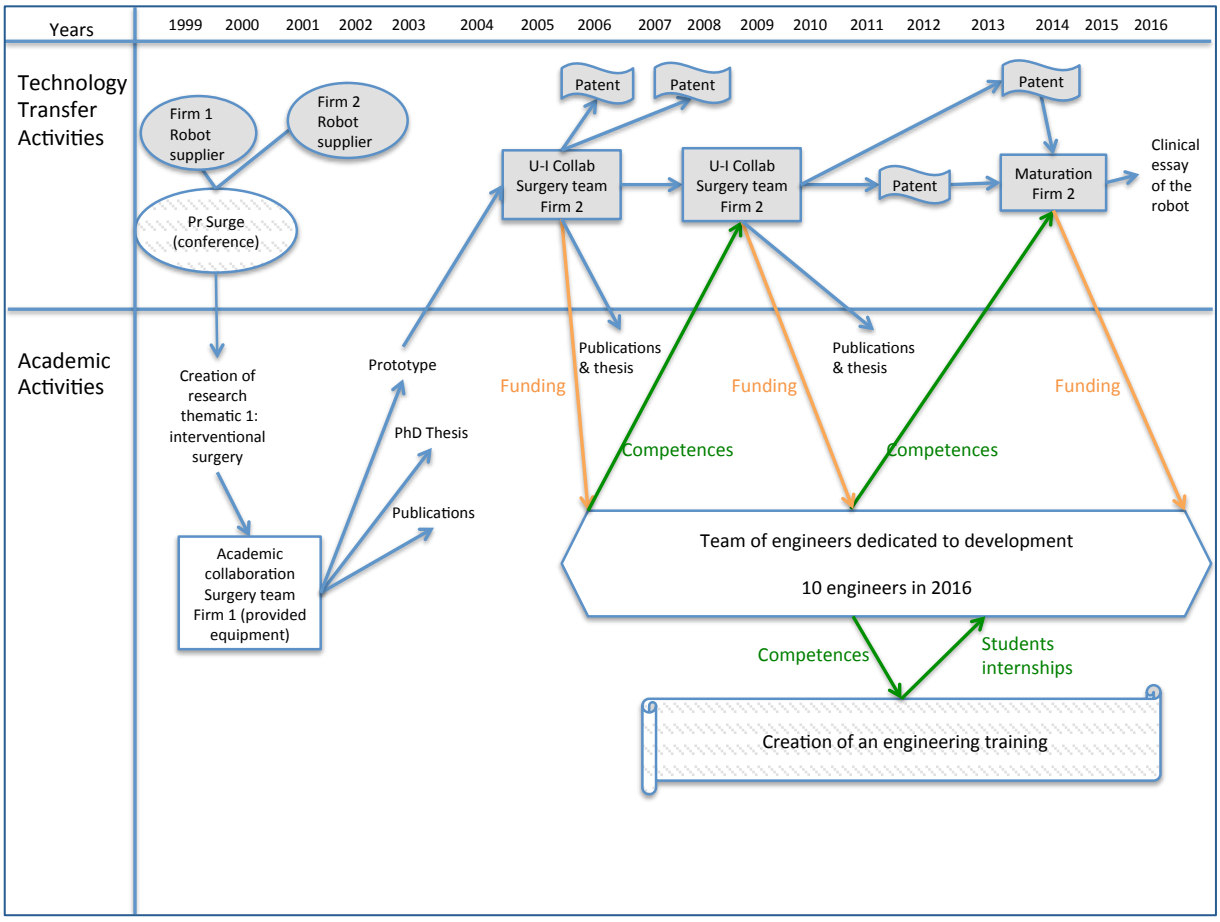
Today, Prof. Pharma has developed specific scientific skills and is recognized for his competence, so he works again with industrials on collaborative research or consultancy contracts. Thanks to its research specificity he is now in a better bargaining position to deal with firms. Also, the strategy of systematic patenting and start-up creation led to many patents which helped to create three new start-ups. Start-up 2 created in 2007 is the exploitation of a patent developed in the public laboratory to produce and sell nutritional complements. The manager of this start-up is the same as the one of start-up 1 and the firm also hired a former PhD student coming from Prof. Pharma's academic lab. In 2014 and 2016 Prof. Pharma created two more start-ups to which he exclusively licensed patents developed within the university and he is working on the creation of another start-up for next year. And it is unlikely to be the last one.

3.2 A STORY OF UIKT IN ROBOTICS

After a PhD in Carnegie Melon University Prof. Rob became associate professor at the University of Strasbourg in 1993. He worked on purely theoretical subjects related to robotics, until he became a full professor. Then he elaborated a long-term research strategy based on the development of application of robotics to the medical field. The international reputation of the academic team results from this strategic choice and from the synergy between academic research and technology transfer activities. The technology transfer strategy of Prof. Rob is based on partnerships with highly recognized firmsin the medical field, considered a key opinion leader, and on the development of deep expertise in the academic team. In 1999 they were three researchers in the team (Prof. Rob and 2 associate professor), in 2016 there are 26 researchers. Prof. Rob developed the expertise of his laboratory in three main fields of application of the academic knowledge and skills in robotics: surgery by visual control (Figure 2), interventional MRI (Figure 3) and transcranial magnetic stimulation (Figure 4). These three fields have led to technology transfer activities which are largely interdependent (even though, for more visibility, we present them separately in three figures).

The starting point of the technology transfer activities of Prof. Rob was a meeting with Prof. Surge (figure 2), who is a surgeon internationally recognized for his skills and his involvement in the development of minimally invasive surgery. They met at a conference given by Prof. Surge, in an informal way, in 2000 and they decided to collaborate. They first engaged in an academic project in order to study the development of new tools based on robot guided by visual control. From 2000 to 2005 the academic team is engaged in academic collaboration, and has no technology transfer activities. The team engages in collaborations with industrial partners after 2005. In the first phase, the team accumulates competences through academic projects involving PhD students. Some of them were hired in the laboratory. The team grew progressively. During this phase, the relation between the industrial partner and the academic team presents a reverse logic compared to the linear model: in an informal way, the industrial partner (Firm 1) contributes to the academic research project, by providing a robot necessary for the researchers' experimentation.

Figure 2: Technology transfer activities of Prof. Rob - First research thematic

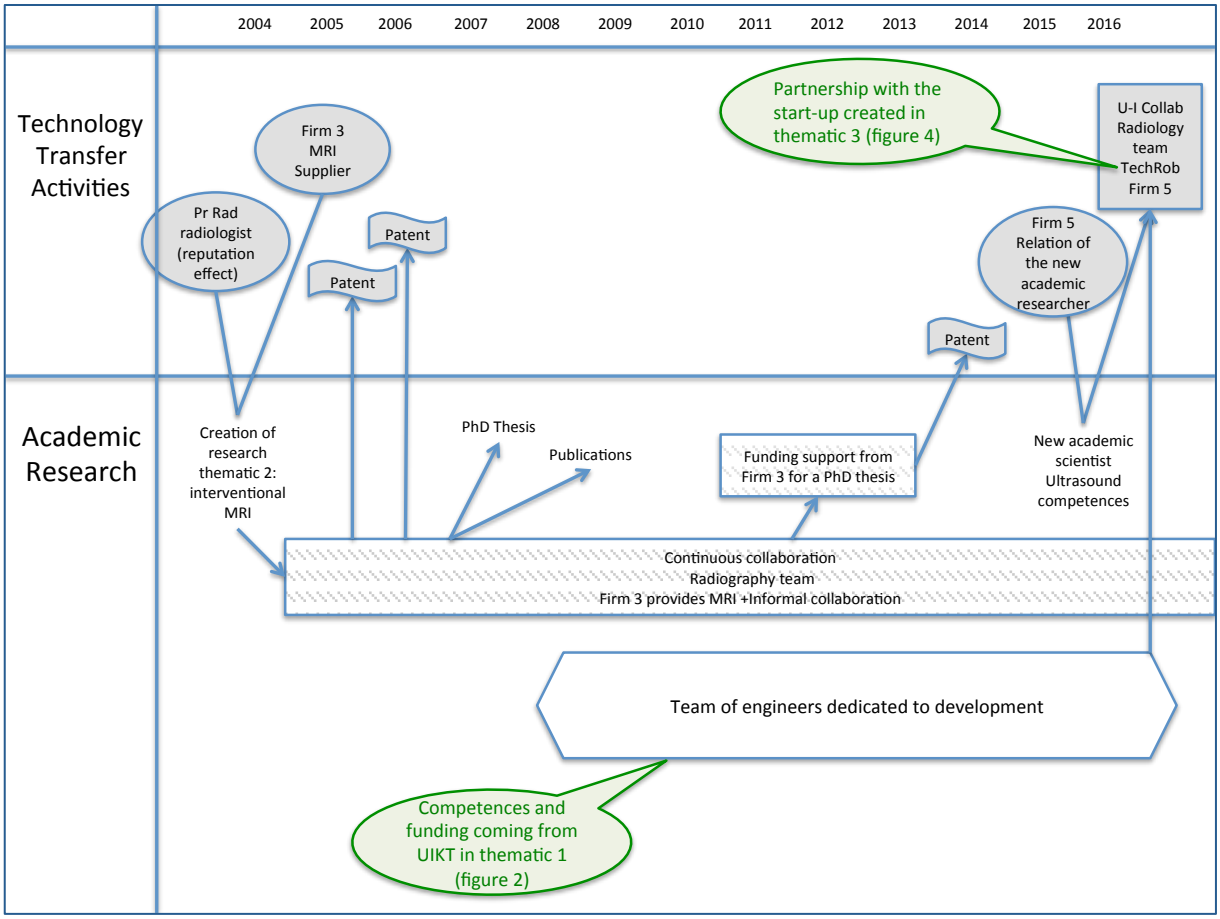


In 2005, the academic team reaches a critical mass in terms of human resources and competences, and began technology transfer activities. The case shows a permanent interplay between research and technology transfer activities (collaborative contractual research, joint PhD supervision, patenting and licensing). In this field the delay to develop a robot is around 10 years. The different collaboration projects we can observe in Figure 2 are successive steps of the development of a product (a medical robot). They belong to the same technology transfer story and involve a stable set of partners interested in the technology. This interplay results from the technological complexity of robots, which require competences in several fields such as robotics, mechanics, computational sciences and electronics. The constitution of multidisciplinary team is a progressive and long process. Several patents appear over the process of development of the technologies.

The second research thematic leading to technology transfer activities presented in Figure 3 also begins with the meeting of a leading actor in the medical field, Prof. Rad, having a status of key opinion leader. This meeting is a consequence of the increasing local scientific

reputation of the team in the early 2000s, and the need for Prof. Rob to develop new tools to increase the possibilities related to interventional MRI.

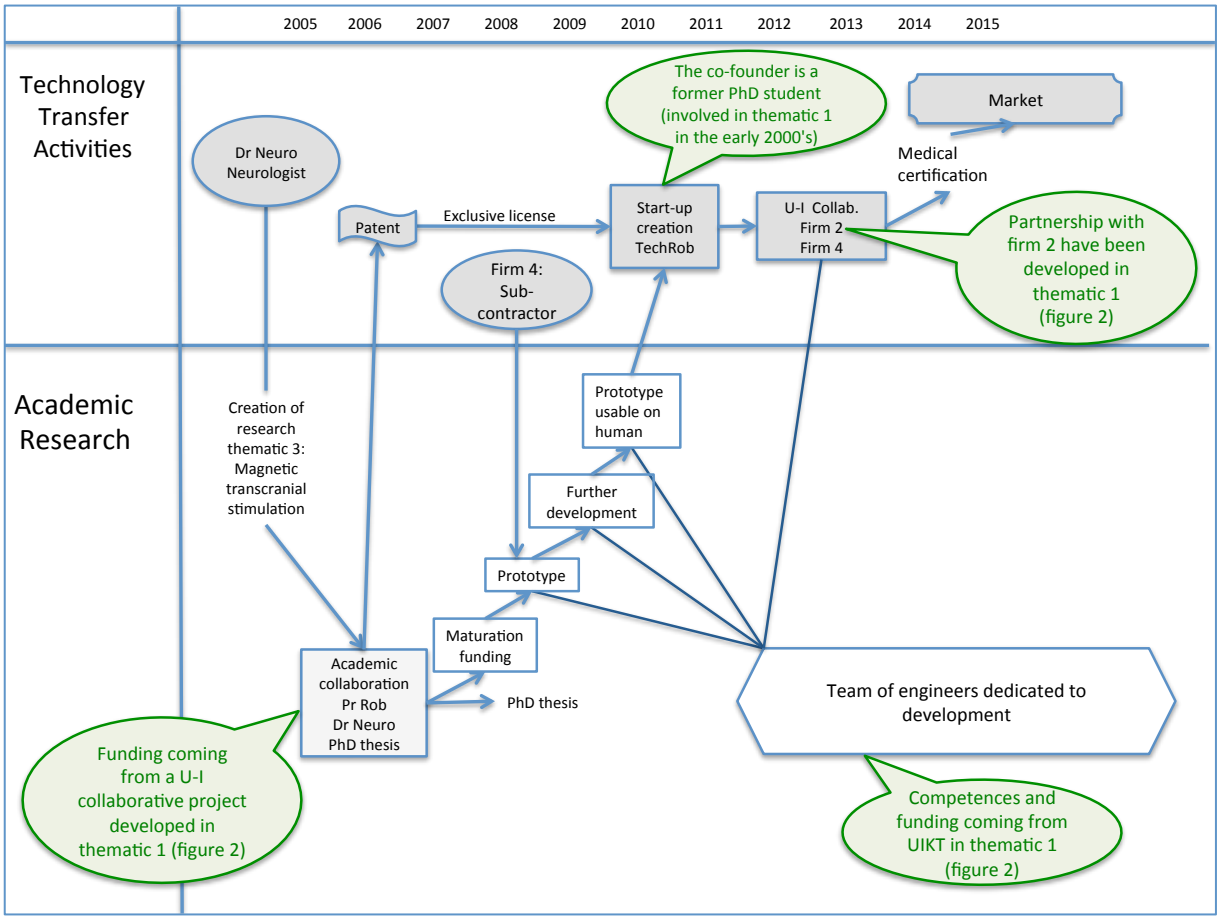
Figure 3: Technology transfer activities of Prof. Rob - Second research thematic



The collaboration between Prof. Rob and Prof. Rad leads to three patents obtained in 2005, 2006 and 2014. They constitute formal outputs of the academic collaboration but they result from continuous informal relation between the industrial partner, the medical team and the academic team. Interestingly, the industrial partner is not very interested in patents. In this field only clusters of patents have value for big firms.

The third thematic of research also begins with a new medical problematic and the meeting with a new medical academic partner, Dr. Neuro, a neurologist (Figure 4). Neurologist practitioners have a need for new robotized tools, to practice transcranial magnetic stimulation. The collaboration begins in the academic world by a common PhD thesis project, during the 3 years.

Figure 4: Technology transfer activities of Prof. Rob - Third research thematic



If we look at only the technology transfer activities, we can see that the patent obtained in 2006 leads to a project of start-up creation around 2009 and the effective creation in 2011. But between 2006 and 2011 there is a continuous support of the academic team, with the involvement of the engineers of the laboratory to maturate the technology during 5 years, to obtain a prototype enabling it to be used on humans.

It is important to note that the three episodes of valorization presented here display important connections. The development of the third research thematic, the technology transfer activities and the maturation of the technology, has been possible due to the technology transfer activities developed in the first thematic. Indeed the first collaborative project presented in Figure 2 provides the funding for the PhD project, leads to the development of a team of engineers in the laboratory that were involved all along the maturation of the technology mainly realized in the laboratory as shown in Figure 4, and leads to the partnerships with firm 2 which was involved in the maturation process. Similarly, in figure 2, we can see that the start-up whose creation is presented in figure 3, is involved in a

collaborative project related to transcranial magnetic stimulation. The firm 2, which was a partner of Pr. Surge, is involved 12 years after in the maturation of the prototype resulting from the initial collaboration with Dr. Neuro. The multiplication of technology transfer activities and the capitalization of knowledge in the academic team lead therefore to new combinations of knowledge across different research thematic and open the door to further possible valorization activities.

3.3 SYNTHESIS AND DISCUSSION ABOUT THE TWO CASES

As regard to UIKT channels and their interactions these two stories present many similarities and some differences. Main insights shaping the patterns of these interactions are discussed below.

3.3.1 Importance of informal and interpersonal contacts

The theoretical framework based on the justification of contracts through a transaction cost approach leads to advance two majors arguments to justify the complementarity between informal and formal UIKT: the development of a relational capital resulting from both formal and informal links to reduce the risk of opportunism, and the constant renewal of informal ties with the environment to locate dispersed knowledge (Powell et al. 1996).

Our cases obviously confirm the critical role played by social networks in the success of a technology transfer project. Both cases show the role of personal and professional ties: the manager of the first start-up created by Prof. Pharma was the manager of a German start-up created by a friend met in San-Francisco during his Post-doctoral studies. In each start-up created by Prof. Pharma, the co-founder is a former PhD student or a post-doctoral student. The co-founder of the first start-up of Prof. Rob was a former PhD student with a carrier in the industry. When Pr. Pharma created his first start-up, the research contracts he obtained resulted from his professional relations with industrial scientists of big pharmaceutical firms. Prof. Rob has been able to maturate the robot he developed for the neurologist, thanks to the involvement of the firm 2, which he met several years before he began to work on robot for minimally invasive surgery. This role of interpersonal contacts explains most of the interactions among the different UIKT channels. A first valorization experience is often made possible by prior personal contact and, at the same time, contributes to enrich the social network of the scientist, thus increasing his ability to develop further valorization activities.

However, even when they are highly involved in technology transfer activities, academic scientists don't have a networking strategy to develop their openness to the industrial world, which would lead to a multiplication of new ties constituting informal UIKT. This commercial approach is too far from their academic activities. This role is played by the university's technology transfer office, which maps competences and tries to license patents to external firms. The academic scientists we met have technology transfer strategies based on the development of cutting edge knowledge for which they identify potential applications. These teams are very open to the academic world and develop their network in the academic world, to identify promising fields of research and to be able to renew the competences leading to informal and formal technology transfer activities.

3.3.2 The central role of PhD students or post-docs in start-up creations

An element which appears regularly in both cases is the placement of PhD students or post-docs in firms in order to accompany the technology transfer. In both cases, former PhD students of the laboratory were involved in the creation of start-ups, because they possess the skills necessary to exploit the technology. This means that the complementarity between formal and informal channels does not rely only on social aspects and on the ability to locate potential partners and knowledge, but also on the deep interdependence of explicit and tacit knowledge constituting technological knowledge. Indeed, technology transfer rarely involve only codified knowledge. As defined by Metcalfe (1995) technology is made of a set of artefacts, knowledge and skills. Even when technologies are formalized in patents, their exploitation relies on the transfer of tacit knowledge that is not completely formalized. In the case of robotics Prof. Rob indicated that “if you transfer a patent to a big firm having an important R&D department, they have the internal competences to develop the skills necessary to use the technology. However, when you transfer it to a small firm, highly specialized on a technology as in the case of robotics, the patent will be useful only if the formal transfer is accompanied by the lab.” Prof. Rob further explained that "the firm will be interested to hire the researcher who has patented, to have the know-how. But generally the senior researcher will not be interested to spend one or two years to transfer the knowledge". Therefore, placing in the firm the PhD students or the Post-docs who had formerly worked in the lab, facilitates the transfer of the tacit knowledge associated with the transferred technology.

3.3.3 Cumulative effect of valorization

Despite these differences, it appears clearly in the trajectories of both researchers that past experiences of valorization matter. Past valorization activities tend to boost future ones. They increase the resources of the researcher, his network, his experience, his credibility, etc., thus putting him in a better position to develop other projects. For instance, Prof. Pharma acknowledged explicitly that "the first start-up gave credibility, contact with investors, and an experience as regard to intellectual property". It is the same in the case of Prof. Rob. The first UIKT, in 2005, had many effects on the next UIKT. It created ties with new industrial partners, involved in several projects over time. The financial effect of the first collaborative project allows the development of internal technical competences and the funding of a purely academic PhD thesis in the early collaboration with Dr. Neuro. In addition to these networks and financial effects, the cases also show the flow of knowledge from a project to another. Each project contributes to the development of the competences of the academic research team, in which the latter is used in other UIKT.

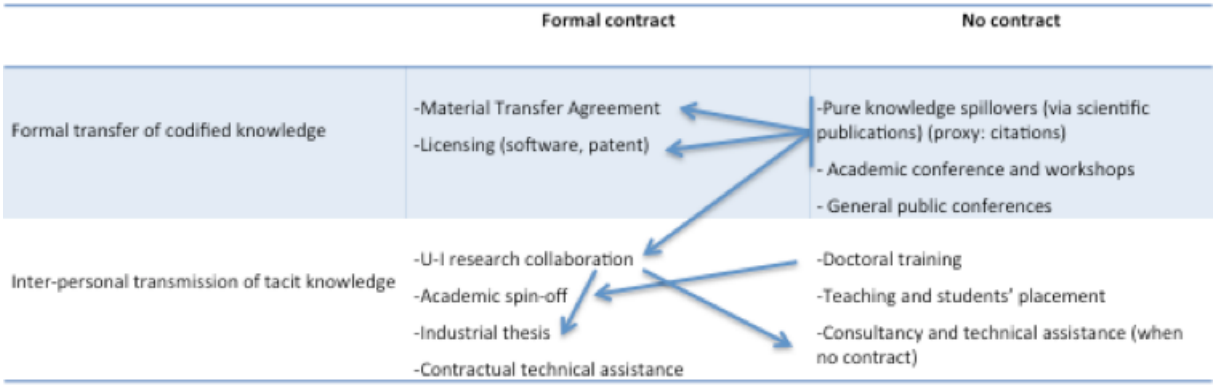
3.3.4 Domain specificity matters

The two cases also show differences about the articulation of the technology transfer activities. In pharmaceuticals the transfer relies on a limited number of patents that are exclusively licensed. In the development of robots, the transfer looks more complex, takes more time and involves more channels. These differences are strongly linked to the nature of the technologies. In the field of pharmacy, there is a kind of homogeneity of the knowledge embedded in the technology. All the academic and industrial scientists involved have a background in chemistry, even if each develops their own skills along their research trajectory. As a consequence, the transfer of a technology can be based on a limited number of patents which are licensed to a start-up or a big pharmaceutical firm. For the development of robots, the technological artefact is complex and the technological knowledge embodied in belongs to different fields such as mechanics, electronics, software, etc. This technological complexity increases the complexity of the development process, which consists of many trial and error cycles and long-term relations between the partners. The notions of team and inter-organizational partnerships are then very important during the process of development of a product, which takes around 8 to 10 years for a robot usable on humans. The time of development is not the time of research collaboration, and this lead to a succession of technology transfer activities all along the development process, with a lot of interactions to

develop common knowledge, new combination of knowledge and creation of technological knowledge. In this process where trial and error are central, informal interactions are obviously important.

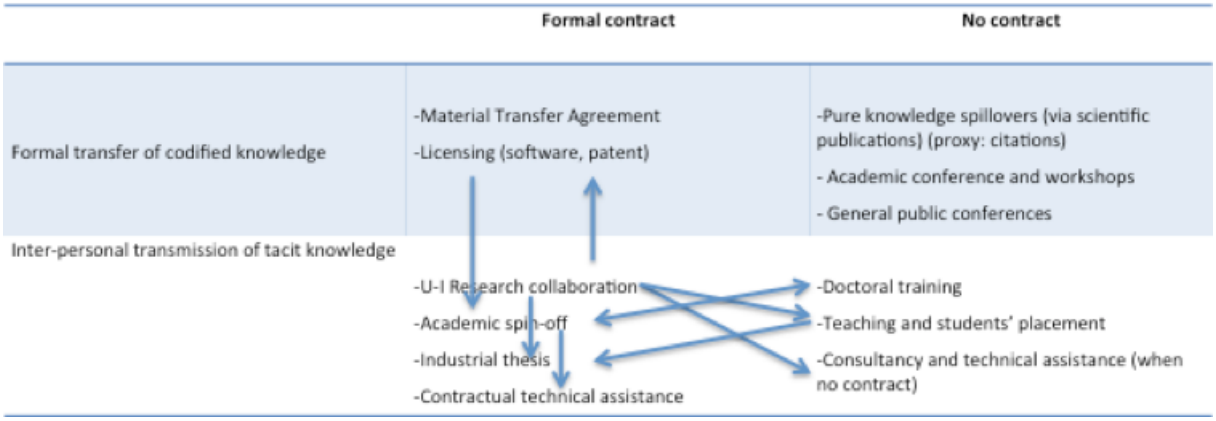
The role of informal UIKT and their complementarity are different in the field of robotics and pharmacy. In the latter, the signaling of academic competences through publications is an important informal UIKT.

Figure 5: Interactions between formal and informal channels in the pharmaceutical field



Big pharmaceutical firms are very open to the academic world. They have R&D departments open to the academic world and attentive to their publications and the knowledge they diffuse through conferences. The role of the academic scientist is upstream in the process of development of a drug. The cycle is closer to the logic of the linear model than in the case of robotics. It is based on a scientific discovery, leading to a patent and to the creation of a start-up, with the grant of a license, and the story appears to be repeated in a same way regularly. The role of the codification of knowledge is important in this field, however we show the importance of tacit knowledge embedded in the skills necessary to exploit the technology, and which lead to a fundamental role of former PhD or post-doctoral students in the creation of start-up. In the robotics field, interpersonal and non-contractual relations are central in the development of UIKT. The product development relies a lot on tacit knowledge, in trial and error logic, far from the linear model (Figure 6).

Figure 6: Interactions between formal and informal channels in the robotics field



The complexity of the robot leads to the progressive development of a set of diversified competences in the academic laboratory. The academic team possesses tacit knowledge about the development of robots, and is involved in a succession of projects, all along the development process, that lasts over 8 or 10 years after the beginning of the project.

3.3.5 The role of patents to promote technology transfer and start-up creation

In both cases patents play a critical role. They protect the invention and constitute tangible proofs of credibility for potential partners or funders. But the role of the patent in each case is not the same. The differences in the nature of the technology lead to different protection strategies. They are omnipresent in the case of Prof. Pharma where each start-up creation is preceded by one or more patents which are then exclusively licensed to the start-up. This is a well-known model in pharmaceuticals where it is necessary to protect a molecule to preserve its commercial value. Without a patent it would be very difficult, if not impossible, to create a start-up. In the case of Prof. Rob the role of patents is more strategic. A robot is made of many components and a single robot relies on several patents. Then a solo patent has a little value. Firms have to constitute patent portfolios. The value of patents in the field of robotics is therefore most of all defensive. Patents contribute to increase firms' bargaining power and to preserve their freedom to operate. Prof. Rob also insists on the role of patents as important signaling tools, necessary to apply in funding programs or to develop new collaborations. They constitute elements of credibility. In the two cases studied here patents seem therefore central. Yet, this might not always be the case in other contexts and other domains.

CONCLUSION

Despite differences resulting from the specificities of the links between scientific and technological knowledge in different fields, our research shows some similar patterns in the interplay between formal and informal UIKT channels. The first is the link between patents and start-up creations, in coherence with the linear model of technology transfer, in which the university can be seen as a knowledge factory. The second regularity is the central role of PhD students and post-doctoral researchers in academic entrepreneurship. Even in the pharmaceutical field, where the role of codified knowledge is important in UIKT, start-up creation relies on the transmission of tacit knowledge from the academic world to the industrial world. Young researchers are involved in the creation of start-ups, and appear as central vectors in the transfer of knowledge.

We showed through a survey of academic scientists a strong correlation between the different UIKT channels. The identification of the antecedents of the involvement of researchers in multiple UIKT channels shows that senior researchers and researchers who co-publish with industrial researchers, are more likely to be involved in several UIKT activities. These results can be explained by the cumulative effect of UIKT activities, showed through two case studies. The cases show that researchers develop over time a tacit knowledge on patenting, spin-off creation, a network of partners and benefit from an increasing scientific reputation.

The case studies confirm the importance of formal transmission of codified knowledge in the UIKT in pharmaceutical field. The diffusion of scientific knowledge through publications and conferences, what we call pure science spill-overs, is an important informal channel, which leads to contractual UIKT, such as licenses and research collaborations. In the field of robotics, where tacit knowledge is central, direct scientific spill-overs play a lesser role while non-contractual UIKT based on inter-personal interactions, such as teaching or informal interactions play an important role in the development of formal UIKT.

The confirmation of these results coming out of two cases would require further interviews in different scientific fields. This would also allow us to see whether there exist a similar pattern in a persistent way. It would be interesting then, to complete our survey with a more complete approach of the different UIKT channels, to identify through a quantitative analysis different patterns of interaction between formal and informal channels.

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