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WORKING PAPER

How does Tacit Knowledge Transfer Influence Innovation Speed? The Case of Science Based Entrepreneurial Firms

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HOW DOES TACIT KNOWLEDGE TRANSFER INFLUENCE INNOVATION SPEED? THE CASE OF SCIENCE BASED ENTREPRENEURIAL FIRMS

ABSTRACT

The increased pressure put on public research institutes to commercialize their research results has given rise to an increased academic interest in technology transfer in general and science based entrepreneurial firms specifically. By building on innovation speed and knowledge literatures, this paper aims to improve understanding of how tacit knowledge can be effectively transferred from the research institute to the science based entrepreneurial firm. More specifically, we assess under which conditions tacit knowledge contributes to the generation of innovation speed, which is a crucial success parameter for technology based ventures. Using an inductive case study approach, we show that tacit knowledge can only be transferred effectively when a substantial part of the original research team joins the new venture as founders. Our analysis also reveals that the mere transfer of tacit knowledge is insufficient to ensure the successful commercialization of technology. Commercial expertise is also required on the condition that the cognitive distance between the scientific researchers and the person responsible for market interaction is not too large. Our findings have implications for science based entrepreneurs, technology transfer officers, venture capitalists, policy makers and the academic community.

Key words: science based entrepreneurial firms; tacit knowledge; technology transfer; innovation speed; cognitive distance

INTRODUCTION

Over the past decade, there has been a substantial increase in the creation of academic spin-offs or more generally termed Science Based Entrepreneurial Firms (SBEFs) (Wright et al., 2007; Clarysse and Moray, 2004). This rise stems from the pressure faced by public research institutes (PRIs), including universities, to commercialize at least part of their research results through licensing and/or new ventures. Not surprisingly, a stream of research has followed identifying the drivers of technology transfer and commercialization including intellectual property (Siegel et al., 2003; Di Gregorio and Shane, 2003; Thursby and Thursby, 2002), contract research (Poyago Theotoky et al., 2002), graduate and researcher mobility (Argote and Ingram, 2000), the role of the technology transfer office (Debackere and Veugelers, 2005; Wright et al., 2008), and science parks and incubators (Phan et al., 2005).

What is less clear from this growing body of literature is what drives *successful* technology transfer and commercialization particularly from the perspective of SBEFs. While success from the perspective of the PRI has been studied by examining the drivers of licensing revenues and new venture creation rates (Bray and Lee, 2000; Lawton Smith and Ho, 2006; Markman et al., 2005; Lockett and Wright, 2005), understanding the performance of SBEFs that emerge from these PRIs has been largely neglected (Colombo and Grilli, 2005). Addressing this gap remains a major policy issue since the performance of many SBEFs has been limited, not to say disappointing (Wright, et al., 2007; Siegel and Wright, 2007). Understanding the processes underpinning performance is important since the development of SBEFs emerging from PRIs faces distinctive challenges.

First, SBEFs are characterized by high levels of innovation in new and rapidly changing markets (Ittner and Larcker, 1997). Such innovation is subject to rapid depreciation and hence speed of innovation may be important to obtain a competitive advantage (Markman et al., 2005; Eisenhardt and Martin, 2000). Innovation speed is the time elapsed between an initial discovery and its commercialization (Kesser and Chakrabarti, 1996). Yet there is insufficient understanding of the factors that explain and predict differences in innovation speed. For example, while Markman et al. (2005) examine the role of innovation speed in determining the number of new ventures at the University Technology Transfer Office (UTTO) level, they do not examine the factors influencing innovation speed and the performance of SBEFs at the firm level.

Second, SBEFs are characterized by shortcomings in the knowledge required for commercialization (Lockett et al., 2005). SBEFs are usually formed around the technology transferred from the research institute and the very specific knowledge that is inextricably linked to that technology which is typically embodied in the academic scientists and entrepreneurs (Wright et al., 2006; Clarysse et al., 2007). As the technology is rarely market ready, knowledge surrounding the technology is needed to modify or tailor associated products / services to meet customer requirements (Di Gregorio and Shane, 2003; Zucker et al., 1998b). Despite recognition of knowledge gaps both in the routines of UTTOs (Lockett et al., 2005) and in the skills of academic entrepreneurs (Franklin, Wright and Lockett, 2001; Mosey and Wright, 2007), understanding remains limited concerning how knowledge might best be transferred and effectively utilized in the context of SBEFs. Markman et al. (2008) point to the fact that as a part of the evolutionary path of spin-off firms there is often a need to reorient the business and to reconfigure the technology. They indicate that research on research and technology commercialization has so far neglected identifying the most effective configurations of entrepreneurial teams for the commercialization of research. Apart from the limited understanding on factors influencing innovation speed and effective configuration of entrepreneurial teams, little understanding exists on the link between knowledge, innovation speed and venture success at the SBEF level.

This study presents a first attempt to bring together insights relating to innovation speed and the knowledge of founding entrepreneurs required to develop SBEFs. Specifically, we address the following broad research question: What is the nature of the relationship between the knowledge of team founders, innovation speed and SBEF performance?

In order to address this research question, we conduct a longitudinal inductive study by drawing on innovation speed theory and the knowledge based view of the firm, as well as nine case studies of SBEFs that originated from IMEC, a top research institute in the area of micro-electronics situated in Belgium (Moray and Clarysse, 2005). IMEC provides an important context for our purpose since in each of the SBEFs, the research institute held equity positions which were either sold or lost their value. As such we are able to use an objective measure of SBEF performance by measuring the valuation of the SBEFs at the moment the PRI's shares are sold to investors or industrial parties or at the moment of liquidation. Interviews were carried out with founders of the SBEFs at multiple points in time. Their views were corroborated with evidence from the IMEC TTO and other documentary evidence.

The paper is structured as follows. The following section situates our study within the innovation speed and knowledge literatures. We then present the research design and methodology, followed by a description of the cases. Next, we present the results of an iterative process of analyzing our data and comparing it with extant literature and theories of innovation speed and knowledge. Finally, we reflect on our findings and discuss their implications for scientist entrepreneurs, technology transfer officers in PRIs as well as wider policy issues.

THEORETICAL PERSPECTIVES: INNOVATION SPEED THEORY AND THE KNOWLEDGE BASED VIEW OF THE FIRM

We draw on two separate theoretical perspectives, innovation speed theory and the knowledge-based view of the firm. In this section we explain how these perspectives can be used to understand SBEF performance. More importantly, we highlight how using these two theories together may be more informative than using them in isolation.

Innovation speed is likely particularly important for SBEFs. SBEFs tend to operate in environments where innovation is valued and is often the basis of competition. In such circumstances accelerated innovation speed becomes essential since any given window for exploiting technological discoveries is constantly shrinking due to knowledge spillovers, imitation by competition and technological obsolescence (Markman et al., 2005). Further, greater innovation speed may allow the organization to experiment with a greater number of new technologies and / or product features, thus spreading the costs of errors over several efforts whilst increasing the likelihood of successful innovations (Eisenhardt, 1989b; Ittner and Larcker, 1997; Schoonhoven et al.,1990; Langerak and Hultink, 2005; Lieberman and Montgomery, 1988).

Although the concept of innovation speed is not new, it has mostly been applied in the context of established organizations. Kesser and Chakrabati (1996) propose that the antecedents of innovation speed include factors such as firms' strategic orientations and organizational capabilities that can either facilitate or retard the pace of development. While these factors may be relevant to established businesses, they may be less applicable to newer ventures whose strategic orientation is not fully established and where organizational capabilities are yet to be developed. Indeed, Allocca and Kessler (2006) suggest that the antecedents of innovation speed vary between smaller ventures and large firms. Extant literature emphasizing institutional (Markman et al., 2005) and organizational (Kessler and Chakrabarti, 1996) antecedents of innovation speed may not be as applicable to new SBEFs

To commercialize technology successfully, SBEFs need external information and feedback from the market, and to revisit and refine the product / service which is based on the technology (Leonard and Sensiper, 1998). The speed at which the venture goes through these processes will be crucial for successful commercialization. Innovation speed is likely to be advanced by an ability to access and utilize information and knowledge accessed externally. This suggests that a key antecedent of innovation speed in SBEFs will relate to their capacity to access and manage knowledge.

The knowledge based view of the firm sees access to, and the development, protection and transfer of knowledge as a means of creating and preserving competitive advantage (cf. Grant, 1996; Henderson and Cockburn, 1994; Liebenskind, 1996). Knowledge-based theories of the firm suggest that a firm's success will depend on how well it can a) enhance its own knowledge base (i.e. access to new knowledge); b) integrate knowledge; and c) apply knowledge to either successfully develop new products / services or improve current products and processes (Grant, 1996; Spender, 1996; Nonaka and Takeuchi, 1995; Kessler et al., 2000).

Kessler et al. (2000) link knowledge-based theory to innovation speed and argue that external sourcing of knowledge may slow down the new product development process. They indicate that externally-generated knowledge usually takes longer to integrate with the firm's existing knowledge base because it is harder to richly understand and interpret (Bierly and Chakrabarti, 1996). Moreover, they point to the fact that the problems with integrating external knowledge will be exacerbated if the knowledge is mostly tacit and complex in nature and the firm lacks absorptive capacity in the area (Cohen and Levinthal, 1990).

Knowledge theorists often distinguish between explicit and tacit knowledge. Explicit knowledge has the qualities of being relatively easier to codify and communicate in a formal, systematic language (Polanyi, 1966; Nonaka and Takeuchi, 1995; Simonin, 1999). Knowledge that is codified (i.e. explicit) is generally easier and quicker to access and transfer, assuming that it is being transferred to a party who can read the "codes" (Cowen and Foray, 1997; Chen, 2004; Zander and Kogut, 1995; Teece, 1998). In the research institute context, explicit knowledge typically takes the form of publications and patents (Hong, 2008) and can be transferred through arms-length contracting such as licensing. However, there is often a considerable body of knowledge not captured in patents and licenses; that is, the tacit component. Polanyi (1966: 7) claims that all knowledge is "*either tacit* or *rooted in tacit knowledge*. Tacit knowledge is acquired by and stored within individuals and is embedded in a social and cultural context (Nonaka and Takeuchi, 1995; Osterloh and Frey, 2000). A *wholly* explicit knowledge is unthinkable" (original emphasis).

In a technology transfer context, therefore, the transfer of explicit knowledge alone may not result in the successful transfer of knowledge. Tacit knowledge is embodied in the inventor / researchers (Lowe, 2006). Its transfer requires inter-personal communication (Ounjian and Carne, 1987) involving what Roberts (2000: 439) calls "show-how". However, due to its very nature, tacit knowledge is difficult to communicate. Considerable interaction is required between parties to ensure that new codes and formula to describe the technology are developed so that knowledge can be transferred from one party to the other (Zucker et al., 2002). The level of interaction needed calls for the co-presence and co-location of the transmitter and receiver of knowledge (Roberts, 2000). This suggests that it is of crucial importance for the discoverer of the technology to work closely with whoever is commercializing it. Continued collaboration between the new venture and the original researchers has been linked to venture success (Zucker et al., 1998b; Zucker et al., 2002) suggesting that collaboration may be key to the efficient transfer of tacit knowledge.

Leonard and Sensiper (1998) liken the innovation process to one of problem solving to which tacit knowledge is particularly pertinent. They indicate that the reason why experts can solve a problem more efficiently than novices is that the experts have in mind a pattern born of experience (i.e., tacit knowledge), which they can overlay on a particular problem and use to quickly detect a solution. Given the iterative process that innovation requires, tacit knowledge has an important role in both stimulating the requisite variety of ideas and then in the convergence that permits focus on actionable next steps. Hence access to tacit knowledge in the technology transfer will not only facilitate the innovation process, it will also accelerate it.

METHODOLOGY

Inductive case study approach

Our study employed an inductive case study approach to understand under which conditions tacit knowledge was effectively transferred from the RI to the SBEF to ensure sufficient innovation speed and lead to SBEF success. With a few exceptions, much of the extant literature on technology transfer from public institutions has been quantitative. Qualitative case studies, however, may be highly complementary by shedding light on how and why questions (Yin, 2003). Further, they are well suited to research that involves observations over time. Our case studies were designed to allow investigation into the way each of the individual enterprises was created and developed, how they reached sufficient innovation speed, and how tacit knowledge was transferred and eventually turned into a financial success or failure from the point of view of the research institute. Our approach of examining the ventures from gestation to exit by the research institute allows us to explain how a sequence of events unfolded over-time to produce a given outcome (Van de Ven, 2007).

Within the typology of case study approaches, the design adopted here is multi-case, embedded research. The term embedded here refers to the duality of the units of analysis, namely the research institute and the spin-off (see also Pettigrew's 1973 triangulation methodology using multiple respondents). Given that we only study ventures that originated from a research institute that specializes in one field, namely the field of micro-electronics, we avoid the impact of sectoral differences on knowledge transfer and innovation speed (Kessler and Chakrabarti, 1996).

While our approach is inductive in nature, this should not be seen to imply that we ignored extant literature / theories. On the contrary, we followed an iterative process involving a back-and-forth journey between the data collected and existing literature and theories (Van Maanen et al., 2007). This approach was complemented by our multiple case analysis. Cases can be treated as a series of independent experiments (Brown and Eisenhardt, 1997), allowing for the adoption of "replication"

/ “comparative” logic (Yin, 2003 and Eisenhardt, 1989a, respectively). This refers to the way in which evidence is accumulated through comparing cases where similar aspects exist, a process yielding theoretical replication (Yin, 2003).

Identification of cases and data collection

The cases used in this study all originated from one research institute in Belgium, the Inter University Micro Electronics Centre (IMEC). IMEC originated in 1982 and is based in Leuven, Belgium. IMEC was set up following a program of the Flemish government in the field of microelectronics. The program targeted at strengthening the microelectronics industry in the Flanders district. This program included the establishment of a laboratory for advanced research in microelectronics (IMEC), the establishment of a semiconductor foundry and the organisation of a training program (now INVOMEC & MTC). Today, IMEC is Europe's leading independent research centre in the field of microelectronics, nanotechnology, enabling design methods and technologies for ICT systems. The research organization has evolved significantly in its technology transfer policies over the years (Moray and Clarysse, 2005). IMEC has set up 25 new ventures and because of its long-established nature has a track record of realizations. As such, IMEC provides an important context to address the research question addressed in this paper.

We draw on nine cases where the phenomenon of interest (i.e. SBEF performance) is “transparently observable” (Eisenhardt, 1989a: 537). Using a finite number of cases, usually between four and ten, allows the researcher to balance the need to generate rich theory with large amounts of data (Brown and Eisenhardt, 1997). Data were collected from a variety of sources but primarily using in-depth face-to-face or telephone interviews with the founder and/or CEO of each of the nine companies. Each interview lasted between one and two hours. The data was verified and supplemented with that obtained from the TTO of IMEC and for some cases co-founders, members of the current management team and / or the leading professor of the research group at the PRI from which the venture’s technology originated. This process allowed for triangulation (Yin, 2003) and helped minimize the effects of retrospection. The interview transcripts and documentary evidence were read and reread as data were collected and emerging themes were refined as this process progressed. To avoid confirmation biases, two of the authors were kept at a distance from the data collection process.

There is limited consensus surrounding how spin-off performance should be measured. Although the use of financial and non-financial yardsticks to measure spin-off performance is consistent with the entrepreneurship literature (Chandler and Hanks, 1993; Ensley et al., 2006) some measures may not be appropriate for high-tech spin-offs. For example, technology-based ventures often make strategic choices that result in employment growth before sales growth occurs (Delmar et al., 2003; Brush et al., 2001) questioning the use of sales based performance measures. In this study we are able to use an objective measure of SBEF performance by measuring the valuation of the SBEFs at the moment the PRI's shares are sold to investors or industrial parties or at the moment of liquidation. We only selected those cases where the investments had been exited by IMEC. We avoid the problem of success bias as we include SBEFs that had either experienced a trade sale, were sold to a financial investor or had been liquidated or went bankrupt. Focusing on the exit value realized by IMEC allows us to focus on the early stage performance of spin-offs. Our approach has the added advantage that the exit value of the investments by the PRI can be objectively measured, in comparison to IRR estimations before exit which tend to be overvalued (Dittman et al., 2004). Among our cases, four interests had been sold, either through trade sale, or through sales to another investor at values that were above historic cost (or the price at which IMEC's TTO acquired shares in the company). We call these the success cases since they allowed the investor to realize positive return on investment. In three of these cases, the exit route was through trade sale and in one case the TTO's interest was sold to a venture capital fund. In the remaining five cases, IMEC's interest was sold below historic cost. We call these failed cases, since they did not allow the TTO to recoup the initial investment. Four of these ventures went bankrupt, while another was sold below historic cost to a venture capital fund. Knowing the venture outcomes from the PRI's perspective allows us to identify patterns that may explain the processes underpinning the successful commercialization of technology. An important and unusual feature of our study is that we were able to obtain access to the founders of failed ventures as well as those who founded successful enterprises. The fifth column in Table 1 indicates the venture outcome for each of our cases.

TABLE 1 NEAR HERE

The cases

Table 1 provides an insight into the companies, their core technology, founding date, and whether the companies were product or service companies at the moment of start-up. The table also provides an insight into the innovation speed obtained by each of the SBEFs, taking into account the stage of product development at the moment of founding. For confidentiality reasons, we replaced the company names by SBEF1 up to SBEF9.

SBEF1 originated from a research project that IMEC carried out on behalf of the EU Space Agency (ESA). During this project, a chip for satellite communication was developed. The company was founded in 1996, six years after the start of the ESA project. SBEF2 develops software tools for the exploration of hardware/software partitioning, co-simulation and the synthesis of software drivers and interface logic between a CPU’s core and supporting hardware. Both SBEF3 and SBEF9 originated from the same technology, and commercialized technology on image sensors. SBEF4 is the only company that started off as a service company, and offers System-on-Chip design services. SBEF5 is a company specialized in design technologies for embedded software in electronic systems. SBEF6 was founded in 1992 in order to exploit the measurement technology for reliability of electronic components. The technology was developed based on research at LUC, a Belgian university and IMEC. SBEF7 is a company in fixed wireless access, established in 2002. SBEF8 originated from research at the UIA, a Belgian University, and IMEC. The company was based on research on electronically conducting polymers. The company was set up to develop sensor modules for commercial electronic noses, based on new sensor materials.

RESULTS

Our results provide insights that inform our primary research questions. The following discussion of results is organized to present our findings in relation to a) the relationship between innovation speed and venture performance; b) the role of researchers and founders in facilitating tacit knowledge transfer and their impact on innovation speed and venture performance; and c) the importance of the knowledge composition of the team and the role of cognitive distance among team members.

Innovation Speed and SBEF Performance

The cases (Table 1) show differences at the level of product development at the moment of founding and innovation speed obtained. Whereas two companies started up with a product or service that was market-ready, four started up with an Alpha-prototype, and three companies were founded without a functioning prototype. For those companies that did not have a market-ready product at the time of founding, we find substantial differences in the time to product or service. Two companies that started with an Alpha prototype had developed a marketable product after half a year. The two other companies that had a similar technological starting position both required 3 years in order to develop a product out of the technology. In the cases where the technology was still in a pre-prototype phase, it took one of the companies 7 years to finalize the product. In the two other cases, the technology never reached a product phase. Naturally, the closer the product is to being market ready, the greater the innovation speed. The cases are in line with the expected relationship between innovation speed and successful commercialization and subsequently SBEF success. It shows that those SBEFS that realized great innovation speed, irrespective of the stage of development at time of founding, were more successful than those who did not generate sufficient innovation speed.

The importance of innovation speed for successful commercialization is supported by the cases. Three companies (SBEF6, SBEF7 and SBEF8) were founded when the technological development was still at an early stage. Both SBEF7 and SBEF8 went bankrupt before a marketable product was developed. In the case of SBEF7, both the TTO and CEO attributed the failure to similar causes that relate to innovation speed. The TTO comments:

> *"The technology that SBEF7 had developed was outstanding. Besides, at the moment that they started up, it was clear that there was a window of opportunity. This window however closed very fast, with many parties entering the market and speed to market was crucial. SBEF7 did not have the resources to generate the speed it needed to valorize the opportunity. It is painful to see how technologies that were inferior to that of SBEF7 are currently dominating the market".*

Similarly, SBEF6 had a proof of concept that was far from a working prototype at founding. Two years after start-up, the first measurement equipment was ready, but there was little interest from the market, which required not one tool but a full set of measurement equipment. It took the company 7 years from start-up to develop a full set of equipment of 3 measurement products that were ready for sales. The CEO comments:

> *"In 1994, the first measurement equipment was ready. With this product it was possible to measure one component with high resolution but the customers were not interested in this equipment, since they needed equipment that could measure a full set of components. Besides, the standards had changed and we did not have the resources to be present on standardisation meetings and to lobby. It took us till 2000 to develop the set that was required by the market".*

Researchers, Founders and Innovation Speed

Having established the importance of innovation speed to the survival and performance of SBEFs, we sought to understand the drivers of innovation speed. Our data reveals three interesting patterns concerning the effective transfer of tacit knowledge and its impact on innovation speed.

First, it shows that, in cases where no tacit knowledge is transferred, innovation speed is affected negatively, resulting in products or services being introduced on the market too late, or never finalizing the process from technology to product, thus resulting in the failure of the SBEF. Successful knowledge transfer is more likely if the original scientists who worked on developing the technology on which the venture is based, are also involved in the venture (See Table 2). Even if the knowledge surrounding the technology is codified (e.g. in the form of a patent or license), there is likely a tacit component to the knowledge too. Close interaction with the original scientists will make the transfer of the tacit knowledge more likely.

SBEF1, SBEF2, SBEF5 and SBEF9 all started at the same level of technological development; they all had an Alpha prototype. In the case of SBEF1, the company started up with an Alpha prototype of a chip. Six months after founding, the company sold the first chip to two large industrial companies. In the case of SBEF2, a similar innovation speed was realized: it took the company half a year after founding to reach the product phase. In both cases, a significant portion of the founding team comprised the original researchers. In the case of SBEF2, the entire research group stepped into the new venture. The CEO of SBEF2 comments:

> *"At the time of spin-off creation, it was crucial to have the people who developed the technology within the team because the technology was in their heads. Even more important was to ensure that they remained with the company throughout time. Therefore it was important to let those people grow with the company".*

In contrast, none of the researchers joined SBEF9. Despite having an Alpha prototype, SBEF9 struggled to develop a market ready product but gave up after three years and went bankrupt. It is interesting to compare SBEF9 with SBEF3 as they were both based on the same technology. Although SBEF3 was slightly more advanced in terms of technological development in that it had a market ready product / service, in contrast to SBEF9, it had the added advantage of having the entire research group in its founding team.

In stark contrast, despite the "technology being fantastic and promising", the CEO of SBEF9 attributed their failure to the absence of original researchers within the founding team:

> "*The fact that the original developers did not join was problematic for the new venture, since the technology proved to be still in a laboratory phase and needed a lot more development… The existing software of potential customers needed to be adapted in order to read the signal of the image sensors and also the hardware needed some adaptations…It was hard to find good technical people with this specific knowledge on the labour market".*

Having learnt from the mistakes made in SBEF9, IMEC opted for a different strategy with SBEF3 by ensuring that the original researchers joined. This strategy had also proved successful with SBEF4 several years earlier.

It is interesting that while SBEF9 and SBEF3 shared the same technology, the main difference between the two companies was that in the latter the original researchers joined the venture but did not in the former. This may explain why SBEF9 failed in reaching sufficient innovation speed and SBEF3 succeeded.

TABLE 2 NEAR HERE

Second, our data suggests that a critical mass of tacit knowledge is needed. We find that only in cases where the majority of the initial researchers joined the SBEF as founders, was tacit knowledge transferred effectively, and resulted in reaching sufficient innovation speed. SBEFs in which only the minority of the initial researchers joined, or which relied on research contracts with the initial researchers to access tacit knowledge, failed to generate sufficient innovation speed. As many of the technologies in question were developed with teams where team members were inter-dependent and complementary to one another, being able to draw on some team members and not others appeared to result in incomplete tacit knowledge transfer.

The (former) CEO of SBEF7 states*:*

> *"At the time of start-up, only one of the researchers stepped into the new venture. We definitely lacked R&D capacity to develop the technology into a product. Besides, standards were set in the sector, and we missed the people who could engage in the discussion on the standards".*

In this case, the lack of tacit knowledge and hence R&D capacity caused innovation speed to be too low, especially in a market where speed was crucial for success. Similar problems occurred in SBEF6, which was set up without any involvement from the original researchers. In one of the cases (SBEF7), only one of the researchers was willing to join the new venture. In order to secure access to valuable knowledge, 8 researchers from the original research team were employed by the venture. The SBEF7 case however shows that research contracts between original researchers and the new venture are ineffective in reaching sufficient innovation speed. This brings us to our third finding.

It is not just *access* to tacit knowledge through close interaction with the original scientists that is important for innovation speed. Beyond close interaction, other conditions may facilitate effective knowledge transfer. The *manner in which* tacit knowledge is transferred from the PRI to the SBEF appears to be particularly important. Osterloh and Frey (2000) argue that intrinsic motivation is particularly important in the transfer of tacit knowledge. If individuals are solely motivated by extrinsic rewards (or penalties), they will only focus on aspects of knowledge transfer that are rewarded, which will favor explicit knowledge transfer (because this is more readily observable). This suggests that accessing the knowledge held by the original scientists through arms-length employment contracts may help transfer explicit knowledge but to a lesser extent tacit knowledge. In contrast, scientists that are intrinsically motivated are likely to be more engaged with the venture. Joining the founding team will involve greater participation in the venture and suggest greater emotional commitment. Emotional commitment and personal involvement are important drivers of tacit knowledge transfer (Glynn, 1996). Participation signals an agreement on common goals and leads to greater perceived self-determination which strengthens intrinsic motivation (Osterloh and Frey, 2000). The CEO of SBEF3 comments*:*

> *"One of the key success drivers for our company is certainly the founding team and the technical knowledge we developed within the company. Even though we had a product ready at the time of spin-off, the product often needed customization for clients and required the developers to exert their knowledge."*

It follows therefore, that those original scientists who display greater participation in the venture (e.g. by joining the founding team) will facilitate the transfer of both explicit and tacit knowledge. In several of the successful cases (SBEF2, SBEF3 and SBEF4) all of the researchers from the research institute joined the spin-off as founders.

The above discussion leads to the following propositions:

> **Proposition 1:** *The greater the proportion of the original research team joining the SBEF as founders, the greater will be the transfer of tacit knowledge and hence the greater the chances of reaching sufficient innovation speed that will lead to enhanced SBEF performance*

Knowledge composition of the founding team and innovation speed

Our data reveals that alongside the *extent* of tacit knowledge about the technology embodied in the number of original researchers transferring to the founding team, it is important for the SBEF team also to include a commercial mindset for requisite innovation speed to be achieved. A common concern with entrepreneurs from a research background (e.g. academic entrepreneurs) is that they often lack commercial experience, which may result in a tendency to focus on the technical aspects of innovation to the detriment of commercial aspects (Franklin et al., 2001). Commercial knowledge is needed in the venture to ensure that the founding team is alert to external market cues. Information from outside the venture needs to be received, processed and then responded to, to ensure that the product / service meets market requirements. Without some commercial knowledge in the founding team, team members may not be alert to valuable market information. Indeed, numerous studies highlight the importance of interaction between technical (R&D, manufacturing) and more commercial roles (e.g. marketing and sales) for both the commercialization of technology and innovation speed (Atuahene-Gima and Evagelista, 2000; Cooper and Kleinschmidt, 1987; Schoonhoven et al., 1990; Song and Parry, 1992). By establishing a forum for interactive learning, including overlapping of problem solving, Kessler and Chakrabarti (1996) and Meyer (1993) propose that a multifunctional team will be indispensable for rapid innovation speed.

Table 3 shows that in most cases, the founding team had someone with commercial experience. The exceptions were SBEF4 (successful) and SBEF8 (failed). SBEF4 was an unusual case because it was a service company. Although the four founders did not possess considerable commercial experience, two of the founders worked for large microelectronics companies (Philips and Acatel) while the other two founders worked for IMEC and a university. Further, as the TTO commented, they rapidly developed both a commercial function and a commercial attitude:

> "*The speed at which the researchers that joined SBEF4 developed a commercial attitude was exceptional. This probably had to do with the fact that they had done quite some contract research at the research institute. Actually, the start-up had a similar business model in the first years: the researchers carried out projects at the customer's site, where they used their*

technical knowledge, and were at the same time in close contact with the customer".

All founders were able to access customers relatively quickly through their contacts from prior employers. Further, the board of directors included a number of members who were brought in to provide further access to customers.

In the case of SBEF8 one of the founders, on paper, had some commercial experience as he already owned another business. However, the TTO at the time commented that:

"*He did not show any industrial spirit or reflection… It was impossible to convince him that the technology he worked on and developed was not sufficient to build a company around. He was convinced that his work was done, the sensor was tested and ready. The economic reality proved that it wasn't. Up to this moment he was convinced that SBEF8 had a product that could be brought to the market in a profitable way*".

The SBEF8 case illustrates the importance of not just having commercial experience but also making sure that a commercial mindset develops alongside the experience gained.

This discussion leads to the following proposition:

Proposition 2: The more that the SBEF team incorporates both tacit knowledge about the technology and a commercial mindset, the greater the chances of reaching sufficient innovation speed that will lead to enhanced SBEF performance.

The presence of both tacit knowledge of the technology and commercial experience in the founding team, however, does not necessarily mean that these two aspects will be integrated. Nooteboom (2002), examining general issues related to trust, suggested that to the extent that people have developed along different life paths and in different environments (e.g. technical versus commercial), they will interpret, understand and evaluate the world differently. This, he argued, leads to the concept of cognitive distance, that is the extent to which there is overlap of, and mappings between, different sets of cognitive constructs. Cognitive distance yields both an opportunity and a problem. Opportunities arise as contact with others provides the possibility to profit from the insights that arise from their different experience. Problems arise because, as cognitive distance increases, it becomes more difficult to understand the actions and expressions of a partner (Nooteboom, 2002). In the context examined here, this suggests that high levels of cognitive distance between technical and commercial founding team members may be expected to interfere with effective knowledge sharing and combination which is needed to commercialize technology rapidly. As intimated earlier, for codified knowledge to be diffused, the recipient must be able to ‘read’ the codes (Cowan and Foray, 1993). If the knowledge is tacit, new codes and formulae are needed to enable knowledge to be shared and combined; a process which takes time (Zucker et al., 2002). If cognitive distance is too high, team members may be unable to ‘read’ the codes and / or develop new codes quickly enough to respond to market change. Common to our successful cases (with the exception of SBEF4 as explained above) was the observation that those team members who possessed commercial experience also tended to have technical expertise as well as experience of working with IMEC (see Table 3). This might thus be seen as a means of reducing cognitive distance among team members. For instance, the following quote from an SBEF 3 founder was representative of the views of other SBEF 3 founding members and the TTO:

> *“Although the founding team consisted of 8 people, the core team consisted of 3 people. These three people had worked together at IMEC since 1987. One of them was not planning on joining. However, the lead investor wondered why he would not join, given the technical experience he had had for 14 years within the research team and given his IMEC experience. At founding, he became Sales and Marketing manager and collaborated extensively with the other two core people, who became CEO and CTO.”*

Experience working with IMEC suggests that the founders’ technical expertise is particularly well suited to microelectronics (the area in which IMEC operates) and therefore represents a source of common language among team members. We argue that these aspects of technical knowledge are important because they can help reduce cognitive distance between the “commercial people” and the “technology people”.

This suggests that while heterogeneity in the team is important (Ensley and Hmieleski, 2005), without a technical background it may be difficult for the commercial person, who is alert to external market information, to 'translate' this so the researchers can understand the implications for the design of the technology / product. Similarly, it is likely to help if the commercial person, who has dealings with customers, can know what is feasible and the extent to which the product can or cannot be tailored to meet customer requirements. For instance, the CEO of SBEF9 comments:

> *" Soon after the creation of SBEF9, I realized that the product was in a much earlier stage of development than I had expected. However, none of the original researchers were willing to support the further development, which made me turn to a recruitment agency that could help me hiring a salesperson and a technical person. In the end, we recruited both profiles. Looking back at the recruitment, one could have predicted that the team was not going to work: the salesman had sufficient sales experience, but lacked any experience or affinity with the technology. On the other hand, the technical person was an engineer 'pur sang'[*i.e. pure blood*] who only engaged in the technical part of his job."*

Based on the above discussion we propose the following:

Proposition 3: *The lower the cognitive distance between the SBEF team members with tacit knowledge about the technology and those with a commercial mindset, the greater the chances of reaching sufficient innovation speed that will lead to enhanced SBEF performance*

TABLE 3 NEAR HERE

DISCUSSION

This study aimed at understanding the nature of the relationship between the knowledge of team founders, innovation speed and SBEF performance. Using an inductive case study methodology, our research reveals the importance of transferring both tacit knowledge about the technology and commercial knowledge. Our research also identifies important modes by which this knowledge might be best transferred and leveraged in order to contribute to innovation speed and commercialization success. A diagrammatic representation of the model that arises from our analyses is presented in Fig. 1. We elaborate below.

FIGURE 1 NEAR HERE

First, our analysis suggests that in order to successfully transfer tacit knowledge about the technology, a high proportion of the original researchers who worked on developing the technology should join the new venture, preferably as founders (P1). Co-location and co-presence allow for greater interaction which improves access to tacit knowledge transfer which is in the heads of the researchers. Participation in the new venture by becoming part of the founding team can also increase intrinsic motivation, which further promotes tacit knowledge transfer. Our results show that where none or only a limited number of the original researchers join the founding team, or when tacit knowledge transfer is attempted through research contracts, innovation speed is too slow, not allowing the new ventures to go through the process from technology to product or service on the market at sufficient high speed, and therefore preventing successful commercialization of research results. This can be explained by the nature of the innovation process involving problem solving. Because the product is rarely market ready, it needs to be fine-tuned to meet customer requirements. Tacit knowledge has an important role in problem solving by stimulating the requisite variety of ideas and then in the convergence of ideas that lead to clearly actionable next steps (Leonard and Sensiper, 1996). The lack of access to tacit knowledge prevented a number of the cases from further developing the technology at a sufficient pace and hence reduced innovation speed. In some of our cases, it was clear that overconfidence by the TTO on the market readiness of the new technology caused ventures to be set up in an early stage without the involvement of the original researchers. In other words, the founding team did not possess the necessary tacit knowledge to further develop the technology into a marketable entity, which subsequently led to the failure of the venture.

Second, our research shows that the transfer of tacit knowledge will lead to successful commercialization of the technology if the founding team also includes member(s) with commercial experience (P2). Commercial knowledge is needed to access and interpret market information that is crucial for developing a market-ready product / service. However, thirdly and crucially, we obtain the novel insight that it is important to reduce the cognitive distance between members of the team with commercial and technical expertise (P3). If cognitive distance is too great, the commercial team member may be unable to explain the relevance or implications of market information to the technical members. This likely reduces innovation speed and makes the new venture less responsive to market change / information. Being in possession of technical knowledge (e.g. having some technical experience and preferably experience of working in the same technology sector) may also help the commercial team members' interactions with customers because they understand if and how the product / service can be tailored to suit customer demands. This insight is important given the emphasis in recent literature on the need for commercial expertise in research-based spin-out ventures.

Implications

This research has a number of implications for TTOs, science based entrepreneurs, the venture capital community, policy makers and the academic community.

For TTOs our results show that when innovation speed is important (which is often the case for high tech ventures (Eisenhardt, 1989b)), the transfer of the researchers who developed the technology will be crucial. Our research also confirms the importance of assembling a founding team whose members have complementary skills. In particular, consistent with prior research we find that a commercial mindset is also needed in the new venture. However, our research goes beyond previous research by revealing that the benefits of this commercial mindset will be maximized if the team member with commercial experience also has some technical expertise, preferably in a domain related to the technology on which the new venture is based. Crucially, we propose that it is essential for team members to be able to transfer their tacit commercial and technical experience to other team members for innovation speed to be achieved.

Our results lead to a number of new challenges for technology transfer offices since they emphasize the importance of commitment by the original researchers to the new SBEF. We suggest that it will be hard to achieve successful commercialization by "pushing" the technology into the market without the commitment of the scientists who discovered / invented the technology. An important role for the technology transfer officer will lie in the stimulation of researchers to commercialize their technology and the creation of awareness of entrepreneurship as a potential career move within research communities. A bigger challenge facing technology transfer officers, however, is how to balance the need to transfer scientists to new ventures on the one hand, whilst considering the implications of losing teams of researchers from the PRI. The TTO at IMEC reveals why there may at times be reluctance to transfer researchers from the original research team to the founding team:

"The transfer of the researchers to the new venture was not an easy decision. Even though we knew that it was crucial for the future success of the company, for IMEC it meant losing top researchers, who had been with the organization for many years, losing knowledge and technology and loosing potential contract research budgets."

The loss of valuable scientists might therefore affect the critical mass of researchers needed to achieve research goals and other commercialization alternatives (licensing, contract research) of the research institute (Wright et al., 2008).

TTOs should also be aware of the importance of assessing the stage of development of the technology at the time of founding, and the challenges that new ventures face when the venture is launched at an early stage of technological development. Our cases show that the researchers who work on developing the technology are probably in the best position to assess the market readiness of the technology. Researchers who refused to join founding teams often indicated that this was because they felt that the technology was not yet ready for the start-up. At the same time, researchers that have a market ready product may be reluctant to commercialize the technology, wanting to continually develop and refine the technology. Here again, the TTO can play a role in raising awareness of the potential advantages of an entrepreneurial career. This role is particularly important in "general universities", where there are commercialisation opportunities based on a wide range of technological domains (Wright et al., 2008). It is unlikely the TTO will have knowledge about all technological domains, which will be necessary to assess the technological development stage. Therefore, we believe the role of the TTO to be mainly one of awareness creation, and guidance of the researchers through the commercialization process upon their initiative, which is an intensive process and requires TTO capacity. The research institute under study in this paper has evolved in the way that it handles commercialization through new venture establishment. An Incubation and Industrialization department was established in 1997 and currently consists of a team of 8 people of which 3 persons are directly engaged in evaluating and supporting specific spin out projects. Nowadays at IMEC, no spin-offs are created without prototype. This requires the availability of sufficient resources to finance the development of the prototypes. In the case of IMEC, this stage is funded through the surplus value realized on the sales of the "first" generation spin-offs that are discussed in this paper. More specifically, IMEC realized an annual return on investment of 22.69% on the sales of participations we examined. This figure compares very favourably to returns on investment in early stage ventures reported elsewhere. Many researchers have shown that in this stage of investment it is hard to realize positive returns on investment, and that there is an imbalance between the risk that is involved with these investments and the return (Murray and Marriott, 1998; Lockett, Murray and Wright, 2002). Murray and Marriott (1998) report, based on a study of Venture Economics and Bannock Consulting (1997), a pooled IRR for early stage investments of 5.7% per year. A similar study by Thomson Venture Economics and EVCA (2004) report a pooled IRR of 1.9% for early stage investments.

For science based entrepreneurs, our study suggests that they should be aware that their involvement and commitment will be crucial for the successful commercialization of the technology they developed. They should also be aware of the need to add commercially minded people to the founding team. Science-based entrepreneurs may be wary of team members with a commercial background, fearing that they will not understand the technology and will try to "push" the product to market prematurely. Our cases suggest that a compromise route is an option and indeed a desirable one. Science-based entrepreneurs may be able to alleviate their concerns by introducing team members who have a technical background but who have also been able to acquire commercial expertise. Having said this, commercial experience on paper does not necessarily mean that the team member has a commercial mindset. TTOs may have an important role to play in coaching team members to develop more of a commercial orientation in approaching problems and opportunities relating to the technology.

Third, for the venture capital community, our findings have implications for the screening of investments. The composition of the team is among the main features of a proposal venture capitalists look at when screening and evaluating an investment opportunity, yet this is particularly a problematical area in spin-outs from PRIs (Wright, et al., 2006). Managerial and entrepreneurial experience of the team members is often given much greater credence than technical experience (Shepherd and Zacharakis, 1998; Tyebjee and Bruno, 1984). While the former types of experience are clearly important, the importance of technical knowledge (in particular tacit knowledge) should not be underestimated, especially in SBEFs. Our research shows that it is not sufficient for an investor to check the strength of the appropriation regime of the technology, which refers to the codified knowledge in the new venture, but also to look at the tacit knowledge which will be crucial for translating the technology into a marketable product or service. Our research therefore calls for an increased attention by investors to the founding team as a whole, and for an increased attention to assessing the commitment of the initial developers of the technology and their cognitive distance to the person exerting the commercial role.

Our research also has a number of implications for policy makers who have to a large extent directed their efforts on policy towards technology transfer. Much of the policy work on commercialization through spin-offs has been oriented towards the transfer of codified knowledge (Siegel, Veugelers and Wright, 2007). Our research calls for greater attention by policy-makers to the design of initiatives that may promote and support greater tacit knowledge transfer. We believe that governments have an important role to play in awareness creation towards commercialization in the research community, for instance by setting up educational programmes that specifically focus on commercialization of research results.

Finally, this research is of interest to academia. By providing a model for when knowledge in SBEFs in important and how it can be transferred effectively from the research institute to the SBEF, this research contributes to Lockett et al. (2005)'s call for adopting a knowledge based view (KBV) when studying SBEFs. The KBV of SBEFs suggests that a broader of view of technology transfer needs to be assumed; one that includes the transfer of knowledge surrounding the technology. Apart from joining Lockett et al. (2005)'s concerns for an increase interest in knowledge and knowledge transfer, it indicates what type of knowledge and knowledge transfer matter under which conditions (cognitive distance) for successful commercialization.

Limitation and directions for further research

This research has a number of limitations that lead to different directions for further research. First, given that we studied the ventures created at a research institute that is specifically focussing on one technology, namely micro-electronics, one concern may be the generalization of our results. Indeed, innovation speed was found to be especially important for high tech businesses and radical innovation (Kessler and Chakrabarti, 1996). However, we do believe that our results can be generalized towards all science based entrepreneurial ventures, since universities and research institutes are seen to mainly work on radical technologies (Nelson, 1991). Further research should indicate the extent to which these results hold in other technology transfer cases, for instance in the case of corporate spin-offs, or in the case of other types of commercialization, for instance through licensing.

Second, given that we measured success and failure using data on exit of the investment by the research institute, our findings do not allow us to draw conclusions on the long term viability of the science based entrepreneurial ventures. This is however only the case for two of the ventures studied, which are still in the VC portfolio. Yet, given that these two were in a commercialization phase at the moment that IMEC exited the investments, and given that we studied the impact of tacit knowledge transfer on innovation speed, studying these cases in relation to their later performance probably would not change the conclusions of this research.

Third, this research allowed us to assess the effectiveness of the tacit transfer mechanisms that IMEC used, but does not assess any other transfer mechanisms. For instance, in Israel, at the Weiszman Institute in Tel Aviv, an incentive system exists that requires that the original researchers remain at the research institute, but do receive part of the proceeds of the venture that originates from the research activities. In this way, intrinsic motivation for tacit knowledge transfer is in place, without physically moving the original researchers to the new venture. Further research should assess the extent to which these new and specific types of tacit knowledge transfer are effective in generating innovation speed.

CONCLUSIONS

This study has presented a first attempt to bring together insights relating to innovation speed and the knowledge of founding entrepreneurs required to examine the nature of the relationship between the knowledge of team founders, innovation speed and SBEF performance. We used a novel longitudinal inductive study comprising nine case studies of SBEFs that originated from IMEC, a top research institute in the area of micro-electronics situated in Belgium. Our analysis shows that a higher proportion of inventors in the founding team and a knowledge composition in the team that involved both technical and a commercial mindset was associated with the transfer of the tacit knowledge required for higher innovation speed. However, we also show that the cognitive distance between the possessors of tacit knowledge surrounding the technology and the commercial people cannot be too large. Those SBEFs in which the people who had commercial experience also had prior technical expertise and working experience within the PRI were the most successful in achieving requisite innovation speed. As such, have extended prior research that has focused on the UTTO level to identify the most effective configurations of entrepreneurial teams for the commercialization of research, and in particular to understanding the link between knowledge, innovation speed and venture success, at the SBEF level.

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Table 1: Characteristics of cases

Name of spin-off	*Founding date*	*Technology*	*Product or service company at start-up*	*Venture outcome (Success/Failure)*	*Time till exit for IMEC*	*Innovation speed*	
						Product development stage at founding	Time to product/service
SBEF1	1996	Chips for satellite communication	Product	S (acquired)	5 years	Alpha prototype	0.5 years
SBEF2	1996	Software tools for system level designs	Product	S (sold to VC)	7 years	Alpha prototype	0.5 years
SBEF3	1999	Image sensors	Product	S (acquired)	4 years	Product/service ready	0 years
SBEF4	1991	System-on-Chip design services	Service	S (acquired)	9 years	Product/service ready	0 years
SBEF5	1996	Design technologies for embedded software in electronic systems	Product	F (sold to VC)	7 years	Alpha prototype	3 years
SBEF6	1992	Measurement technology for reliability of electronic components	Product	F (bankrupt)	8 years	Pre-prototype	7 years
SBEF7	2002	Fixed wireless access	Product	F (bankrupt)	1 year	Pre-prototype	Never finalized
SBEF8	1998	Electronic nose manufacturer	Product	F (bankrupt)	3 years	Pre-prototype	Never finalized
SBEF9	1996	Image sensors	Product	F (bankrupt)	3 years	Alpha prototype	3 years

Table 2: Tacit knowledge and Innovation speed

Company name	***Tacit knowledge***			*Innovation Speed*	
	Team Size	Number of researchers joining spin-off	Proportion of founding team that were original researchers	Product development stage at founding	Time to product/service
SBEF1	4	3 out of 10	75%	Alpha prototype	0.5 years
SBEF2	7	6 out of 6	86%	Alpha prototype	0.5 years
SBEF3	11	8 out of 8	73%	Product/service ready	0 years
SBEF4	4	4 out of 4	100%	Product/service ready	0 years
SBEF5	4	4 out of 10	100%	Alpha prototype	3 years
SBEF6	1	0	0%	Pre-prototype	7 years
SBEF7	3	1 out of 20 (8 IMEC employees contracted)	33%	Pre-prototype	Never finalized
SBEF8	3	2 out of 3 (but left the company early)	67% down to 0%	Pre-prototype	Never finalized
SBEF9	1	0	0%	Alpha prototype	3 years

Table 3: Commercial knowledge and indicators of cognitive distance

Company name	***Market interface***	***Cognitive distance***	
	Number of people with commercial experience	Commercial and technical experience?	Prior working experience with IMEC?
SBEF1	1	Y	Y
SBEF2	2	Y	Y
SBEF3	1	Y	Y
SBEF4	0	Na	Na
SBEF5	1	Y	Y
SBEF6	1	Y	Y (10 years earlier)
SBEF7	1	N	N
SBEF8	0	Na	Na
SBEF9	1	1	N

Figure 1: Model of Relationship between Tacit Knowledge, Innovation Speed and SBEF Performance