Une nouvelle perspective sur l'entrepreneuriat académique : une relation symbiotique entre une université mère et sa spin-off universitaire deep-tech[1]

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Résumé :

L'entrepreneuriat universitaire, c'est-à-dire la création d'une spin-off universitaire (USO) par des scientifiques universitaires, est un moyen fructueux de transférer les connaissances du monde universitaire vers l'industrie et de promouvoir l'innovation. La littérature se focalise principalement sur les antécédents et l'impact à court terme des USOs, et il y a un manque de recherche concernant leur interaction à long terme avec leurs universités mères. En nous appuyant sur l'approche processuelle dans une perspective inductive, nous avons mené une étude de cas longitudinale sur la relation de connaissance entre une USO deep-tech et son université mère. Nos résultats montrent qu'une fois créée, l'USO a développé un échange de connaissances bidirectionnel et une relation à long terme, étroite et mutuellement bénéfique avec son université mère. Cet échange de connaissances s'inscrit dans un modèle d'ambidextrie interorganisationnelle ondulatoire où l'exploration nourrit l'exploitation, l'exploitation nourrit l'exploration, et où il existe un espace partagé d'ambidextrie avec co-exploration et co-exploitation. Dans la perspective de l'écologie organisationnelle, nous proposons de conceptualiser cette relation de connaissance comme une symbiose de connaissances entre l'université mère et son USO : une relation de connaissance permanente, cyclique, proximale, socialement ancrée et mutuellement bénéfique entre une université mère et son USO.

Mots-clés : University-industry knowledge transfer, process studies, interorganizational symbiosis, academic entrepreneurship, ambidexterity

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A new perspective in academic entrepreneurship: a symbiotic relationship between a parent university and its deep-tech university spin-off

1 INTRODUCTION

Nowadays, universities have a third mission in addition to doing research and teaching students. They are expected to contribute to the economic development of their region by transferring academic knowledge to industry to support innovation (Compagnucci & Spigarelli, 2020; Etzkowitz & Leydesdorff, 2000). Indeed, in today's global knowledge economy, knowledge transfer serves to foster and develop innovation (Chesbrough et al., 2006). This knowledge transfer takes place in the context of an interorganizational ambidexterity that articulates academic exploration and industrial exploitation in their regional ecosystem. One way to transfer knowledge to industry is through academic entrepreneurship: the creation of university spin-offs (USO) by academic scientists (Fini et al., 2022). By founding a USO, academic scientists contribute to the development of their region and its economy (Caputo et al., 2022). The literature on academic entrepreneurship mostly focuses on the factors behind USOs' creation (Hossinger et al., 2020) and their short-term outputs (Treibich et al., 2013). The USO creation is understood as a linear process of knowledge transfer and innovation in which knowledge created in academia is transferred to industry for exploitation. Bolzani et al. (2021) found that USOs' success also depends on the linkage they maintain over time with their parent university. However, there is a lack of literature regarding the USOs' long-term relation with their parent universities (Prokop et al., 2019; Treibich et al., 2013) and the factors behind their long-term success (Bahuleyan et al., 2024). In this article, we conduct a case study on QuantumComp (anonymized name), a deep tech USO active in quantum physics and founded

by researchers in a renowned European University (thereafter EurUni). We use the process approach (Langley, 1999; Langley & Truax, 1994) in an inductive methodology to unveil the evolution of the relationship between EurUni and QuantumComp. Inductive research allows to investigate emergent insights and build theory (Ambos & Tatarinov, 2022). Process studies are particularly well-suited to investigate innovation and knowledge transfer evolution over time (Van Burg et al., 2014). In our process methodology, we collected data on EurUni and QuantumComp knowledge mechanisms (patent citation, publication citation, mobility) and artefacts (patents, co-patents, publications, co-publication, PhD theses) related to our case study. Through a process visualization, we represent these knowledge mechanisms and artefacts as well as their interactions through time from 1988 (the earliest recruitment by EurUni of an academic scientist in the Physics Department who was one of QuantumComp's founders) until 2022. To complement our process visualization, we also conducted semi-structured interviews with three of the QuantumComp's founders and two individuals involved in both EurUni and QuantumComp, as well as several informal discussions with the officer of EurUni technology transfer office (TTO). Finally, we gathered secondary data related to EurUni and QuantumComp. As a deep-tech USO, QuantumComp operates at the frontier of technology (Kruachottikul et al., 2023) and needs access to state-of-the-art academic knowledge to grow. Over time, the knowledge relationships between the two organizations move from an unidirectional transfer of knowledge to a bidirectional and recursive one. This resulted in an undulatory interorganizational ambidexterity characterizing a university-USO knowledge symbiosis (UUKS) between both organizations. This article has several contributions. First, it explores the long-term knowledge relationship between a successful deep-tech USO and its parent university through its evolution after the inception of the former. Such a relationship is unveiled through the interactions between different vectors of knowledge exchange that sustain the knowledge relationship between both organizations.

Second, it proposes a model of undulatory interorganizational ambidexterity. While, in the short term, the knowledge relationship between the parent university and its USO is characterized by a linear model of innovation and ambidexterity, the two organizations develop in the long term an undulatory interorganizational ambidexterity where exploration in the parent university nourishes exploitation in the USO which, in turn, nourishes exploration in the parent university. Exploration happens in an exploration space and exploitation in an exploitation space. Between exploration and exploitation, both spaces overlap to form a shared space of ambidexterity where ongoing knowledge exchange and knowledge co-creation between both organizations happen.

Third, Building on the organizational ecology approach that uses biological metaphors to describe organizational behavior (Hannan & Freeman, 1977), we transpose the concept of symbiosis from biology and ecology sciences (Egerton, 2015; Margulis, 1990; Margulis et al., 1997) and propose that a permanent, cyclical, proximal, socially embedded and mutually beneficial knowledge relationship between a university and a USO can be conceptualized as a UUKS.

2 THEORETICAL BACKGROUND

2.1 ACADEMIC ENTREPRENEURSHIP

Universities are expected to contribute to their regional economy (Compagnucci & Spigarelli, 2020) by transferring knowledge to industry. Several mechanisms exist to transfer knowledge from academia to industry such as publications, patents, joint research, consulting and mobility of academic scientists (Bekkers & Bodas Freitas, 2008). One specific way for such a transfer is academic entrepreneurship (Guerrero & Urbano, 2014), which is the creation of a USO by academic scientists to commercially exploit research results (Fini et al., 2022).

Literature on USOs mostly focuses on the factors (Hossinger et al., 2020), characteristics, antecedents and outcomes (Miranda et al., 2018) of their creation and on their short-term development (Boh et al., 2016; Treibich et al., 2013). In this context, the literature generally

takes a linear perspective. In such an approach, knowledge exploration takes place in academia and academic knowledge is transferred to industry (notably through patents) to be exploited (Ferrary & Granovetter, 2009): Academic entrepreneurs develop knowledge in their universities (exploration), and a part of this knowledge will be exploited in his or her USO (Miranda et al., 2018; Schaeffer et al., 2020). This is often done by considering the transfer of explicit knowledge from universities to USOs, although tacit knowledge transfer through academic scientist mobility to industry plays an important role in the knowledge transfer between both realms (Ferrary & Orsat, 2022). Moreover, mechanisms of tacit and explicit knowledge transfer might interact dynamically (Schaeffer et al., 2020) since published results and patents cannot be exploited per se but need the expertise of individuals (Mawdsley & Somaya, 2016) through their collaboration with the USO (consulting, partnership, or professional mobility) to transfer tacit knowledge. There is a lack of understanding of the long-term development of USOs and their interaction with their parent universities (Prokop et al., 2019; Treibich et al., 2013) as well as their long-term success factors (Bahuleyan et al., 2024). In this phase, USOs may or not continuously exchange and co-create knowledge with their parent university (Treibich et al., 2013) with a bidirectional relation of formal and informal nature (Johansson et al., 2005). Notably, in their studies about the mid and long-term development of USOs and the intensity of their interactions with their parent universities, Treibich et al. (2013) found that their interactions vary in intensity, going from short stops of the interaction to long-term interactions supporting knowledge co-production.

This would be particularly the case for USOs operating at the frontiers of technology and needing cutting-edge scientific knowledge to operate, i.e. deep tech USOs (Kruachottikul et al., 2023). Such a relationship could be a long-term success factor for deep-tech USOs. In such a setting, in addition to the exploitation of academic knowledge in the USO, industrial knowledge of the USO might also contribute to exploration in the parent university. However, while there

is extensive literature on the impact of academic research on academic entrepreneurship, literature about the opposite relationship is scarce (Fini et al., 2022). Those elements raise the following research question: What is the nature of the knowledge relationship between a parent university and its deep-tech USO after its inception? Does the technology depth affect the relationship?

2.2 INTERORGANIZATIONAL AMBIDEXTERITY

To understand the role of those two organizations and how their knowledge relationship evolves, we mobilize the concept of ambidexterity, which consists of balancing exploration and exploitation. For March (1991), "exploration includes things captured by terms such as search, variation, risk taking, experimentation, play, flexibility, discovery, innovation, [while] exploitation includes such things as refinement, choice, production, efficiency, selection, implementation, execution" (p. 71). Traditionally, ambidexterity was apprehended within an organization (Tushman & O'Reilly, 1996) but scholars, through time, investigated it at the interorganizational level (Lavie et al., 2010; O'Reilly & Tushman, 2013; Zimmermann et al., 2015). In the traditional perspective on academic entrepreneurship, the interorganizational ambidexterity between parent universities and USOs is considered in a linear model of innovation where research is conducted at universities, development is made out of such research and the process ends when there is a production or diffusion by businesses (Godin, 2006). First, parent universities conduct exploration (through discovery and experimentation), and the knowledge produced by universities is then exploited in USOs. However, how interorganizational ambidexterity is characterized in a long-term relationship between a parent university and its USO?

2.3 ORGANIZATIONAL ECOLOGY

To conceptualize the knowledge relationship between the parent university and its deep-tech USO, we build on organizational ecology (OE, Hannan & Freeman, 1977). Such a theoretical

framework has been mobilized to analyze organization and their evolution through the lens of biology and ecology sciences (Boone & Van Witteloostuijn, 1995). This theoretical lens can be used to investigate the interactions between different organization forms (Audia et al., 2006; Boone & Van Witteloostuijn, 1995) or organizational species (Betton & Dess, 1985). OE literature has focused on competition as one of its primary mechanisms, where organizational species fight for resources and, consequently, survival (Downie, 2022; Gotsopoulos & Pitsakis, 2024; Hannan & Carroll, 1992). However, cooperation plays a significant role in evolutionary biology (Sachs et al., 2004). How can OE be mobilized to conceptualize cooperative relationships between parent universities and USOs?

3 RESEARCH CONTEXT AND METHODS

3.1 CASE STUDY

By using an inductive approach, we conducted a longitudinal case study from 1988 to 2022 of the life cycle of a USO and its knowledge relationship with its parent university. 1988 corresponds to the recruitment by the university of the academic scientist who developed the basic research being the theoretical foundations of the USO and became one of its founders. This allowed us to investigate the emergence of a USO and the development of its knowledge relationship with its parent university over time. The USO on which we conducted our case study is QuantumComp, a deep tech USO born at EurUni in 2001 and active in industrial applications of quantum physics. USOs are one well-studied way of transferring knowledge from academia to industry (Landry et al., 2010). QuantumComp was founded by four individuals: Two EurUni professors (thereafter Founder1 and Founder2), one EurUni engineer (thereafter Founder3), and the former PhD student of one of the co-founder professors (thereafter Founder4). The choice of QuantumComp is based on the fact that this USO is active in deep tech and that, according to the EurUni TTO officer, is one of the success stories of EurUni. Deep technologies are technological advancements that are at the frontier of

technology and often originate from academia (Kruachottikul et al., 2023). QuantumComp proposes security solutions based on quantum physics as well as quantum sensing services. Currently, they proposed 3 categories of products: Random number generation, quantum-safe security and quantum detection system, all three categories being based on quantum physics. One of the key technologies of QuantumComp is quantum cryptography, which is part of their quantum-safe security category of products and consists of the secure exchange of keys through quantum key distribution (QKD). QKD is a cryptography protocol to exchange information based on the properties of quantum mechanics. QuantumComp was one of the first companies to propose such a technology that makes information exchange theoretically uncrackable by replacing electronic bits by photons. The launch of this technology has been recognized as world-changing by the Technology Review of the MIT.

3.2 METHODOLOGY

In this research, we use two qualitative methods: a process visualization (Langley, 1999; Langley & Truax, 1994) and semi-structured interviews. The process visualization is our primary methodology, while the semi-structured interviews allow us to gather more detailed elements regarding the process. Using these two methods allows the gathering of both synthetic data through the process visualization and finer-grained data through the interviews (Langley, 1999). We also gathered secondary data (excluded for anonymity of the case).

3.2.1 Visualization

We develop a longitudinal process visualization to represent the knowledge relationship between EurUni and QuantumComp through different vectors of knowledge exchange (patents citation, publications citations, mobility) and their interactions. We also represent specific cases of knowledge artefacts production (Founders' and QuantumComp's patents, co-patents, co-publications, USOs publications). These elements are linked to the individuals related to EurUni and QuantumComp: the 4 co-founders, the individuals who had professional mobility

from one organization to the other, as well as the supervisors of those individuals. We used the temporal bracketing strategy of Langley (1999) by identifying successive phases in the relation between EurUni and QuantumComp. The following data were integrated into the process visualization:

Mobility data: We identified the past and actual employees of QuantumComp who did a PhD at EurUni or worked at EurUni before, during, or after their activity at QuantumComp. Then, we indicated using colors the periods where individuals were involved in EurUni, QuantumComp or in both organizations at the same time. If the founders were members of the QuantumComp board, we considered them as involved in both organizations. We collected these professional mobility data between EurUni and QuantumComp through LinkedIn (Cirillo, 2019).

Supervision data: For the individuals identified in Mobility data who did a PhD at EurUni before, after or at the same time as their employment at QuantumComp, we gathered data on their supervisors through the EurUni open archive. In addition to two of the co-founders, three other professors supervised one or several of these individuals during their PhD at EurUni.

Patents data: We collected patent data through the patent database of the European Patent Office. We collected patents with QuantumComp as an applicant and either one of the founders or one of the individuals of our visualization as the inventors. Additionally, we collected patents with EurUni as an applicant and at least one of the founders as the inventors. These patents were linked in the case of citations between them. Patent data were collected at the patent family level.

Publication data: We collected the publications cited in the aforementioned patents. In addition, we also collected publications with QuantumComp individuals as (co-)authors to identify cases of production of scientific academic articles by QuantumComp or co-production by EurUni and QuantumComp.

3.2.2 Interviews

We conducted five semi-structured interviews: three with three of the co-founders of QuantumComp (two are professors at EurUni and one is the CEO of QuantumComp) who are at the source of the innovation behind QuantumComp, and the two others with individuals who are or were active in both organizations. Additionally, we had several informal discussions with the EurUni TTO officer that accompanied the creation of the USO. To conduct the interviews, we relied on an interview guide about the relationship between EurUni and QuantumComp in terms of knowledge, skills and roles. We then manually transcribe the interviews. Table 1 presents the profile of our interviewees. The names used refer to their ID in the process visualization in order to be able to locate them in it. The interviews lasted between 25 minutes and 1 hour and 11 minutes.

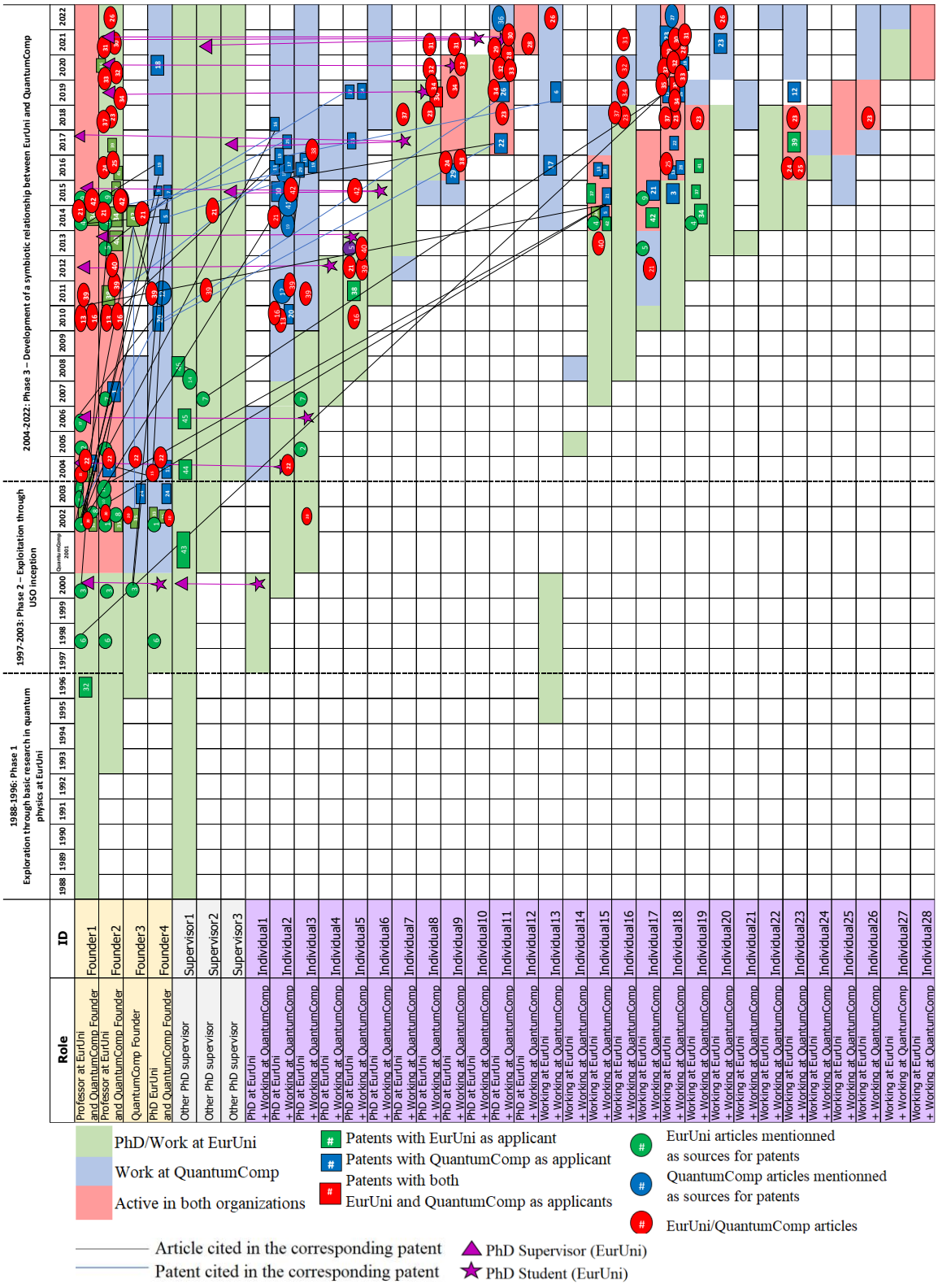
Table 1. Interviewees profile

Interviewees	Role	Interview setting
Founder1	Professor of physics and co-founder of QuantumComp	Face-to-face
Founder2	Professor of physics and co-founder of QuantumComp	Face-to-face
Founder4	CEO of QuantumComp and former PhD student of *Founder1*	Face-to-face
Individual17	Simultaneously engineer at EurUni and QuantumComp between 2014 and 2017. Engineer at EurUni since 2020	Online interview
Individual28	Simultaneously R&D Engineer at QuantumComp and Scientific Researcher at EurUni	Online Interview

4 DATA ANALYSIS

We developed a longitudinal process visualization from the earliest recruitment of one of the co-founders of QuantumComp in 1988 (Founder1) until 2022. Figure 1 shows this process visualization.

Figure 1. Visualization of the knowledge relationship between EurUni and QuantumComp



By mobilizing the temporal bracketing strategy (Langley, 1999) and the lens of our emerging concepts (Cozzolino et al., 2018), we then analyzed our interview data and connected them to the identified phases and to our emerging concepts that resulted from our analysis of the visualization. Interviews data nourished the whole analysis. A selection of verbatim is integrated into our findings. Our analysis highlighted the existence of three phases describing the relationship between EurUni and QuantumComp through time:

Phase 1 – 1988-1996: Exploration through basic research in quantum physics at EurUni. This first phase started with the recruitment by EurUni of Founder1 as an academic scientist in 1988. It constitutes the exploration period before the creation of QuantumComp. It is characterized by the exploration of quantum physics and optics, as well as by the first experimentation of quantum cryptography in 1995.

Phase 2 – 1997-2003: Exploitation through USO creation. This subsequent phase started in 1997 with the recruitment of Founder4 as a PhD student at EurUni under the supervision of Founder1, who was the impetus for the creation of QuantumComp in 2001. This phase is characterized by a linear model of innovation with the education of a PhD student, a publication related to the knowledge basis of the firm, the filling of patents by EurUni and QuantumComp, the creation of QuantumComp and the filling of patents by QuantumComp.

Phase 3 – 2003-2022: Development of a symbiotic relationship between EurUni and QuantumComp. This phase started in 2004, the year after the first patent of QuantumComp. In this period, we observed that knowledge is recursively exchanged between EurUni and QuantumComp in an undulatory interorganizational ambidexterity. This type of ambidexterity constituted the basis of a symbiosis between EurUni and QuantumComp where both organizations developed a permanent, cyclical, proximal, socially embedded and mutually beneficial knowledge relationship.

5 FINDINGS

5.1 1988-1996 – PHASE 1: EXPLORATION THROUGH BASIC RESEARCH IN QUANTUM PHYSICS AT EURUNI

This phase started with the recruitment of Founder1 by EurUni in the group of applied physics in 1988. In 1993, Founder2 was recruited by EurUni as a post-doc in the group of applied physics and led experimental activities of the group from this moment. Founder3 was recruited as an engineer by EurUni also in the group of applied physics in 1996.

In this phase, Founder1 and Founder2 were in a period of exploration where they conducted research. During this period, their research was heavily centered around quantum mechanics and optics. They were key international actors in the development of quantum cryptography. Quantum cryptography is based on the properties of quantum mechanics, and is an application of quantum optics (Bruno, 2015). In 1995, Founder1 and Founder2 notably realized the first demonstration of quantum cryptography. Founder1 highlights that his interest in photon detectors, coupled with his reading of a specific research article paved the way for him and his first PhD student to execute quantum cryptography demonstrations: *I read a paper that completely opened my eyes to what is known as quantum cryptography … I immediately understood that, well I have my photon detector, I understand optical fibers very well, so I know how to do that … And so, very quickly, with my first student here, we did the first demonstration of quantum cryptography* (*Founder1*). Founder2 explained how this experimentation was based on the knowledge of optics and quantum physics in the group of applied physics: *So, when we started QKD, we had expertise in fiber optics and quantum physics. And there weren't many groups that had both areas of expertise. So, for us, it was quite obvious to do this quantum cryptography now, using optical fibers* (*Founder2*).

5.2 1997-2003: PHASE 2: EXPLOITATION THROUGH USO CREATION

This phase started in 1997 with the recruitment of Founder4, the PhD student of Founder1 who will be later on the driving force of QuantumComp creation. Extending the research momentum on quantum cryptography, Founder4 wrote his thesis on experimental quantum cryptography under the supervision of Founder1. Besides, Founder2 was promoted in 1998 as senior lecturer and researcher at EurUni in the applied physics group and Founder1 became in 2000 the director of the group of applied physics of EurUni.

According to Founder1, Founder2 and Founder4, the first experimentation of quantum cryptography in 1995 (during the exploration phase) enhanced his status at EurUni, and there has been interest in industrial applications of quantum cryptography by external actors, notably in the US, which instilled in *Founder4* mind the idea of creating an EurUni USO. *Founder4* explained: *Historically, the reason we thought of starting the company was that there was an American company that was active in this field... They came, they contacted [Founder1 and], one day during a group session, [he] said 'Oh, next week, there are people from this company who are going to come to discuss a technology transfer. Is anyone interested? Then I raised my hand and said 'I'd be interested … And then we talked a bit with this company for a while, for a few months, and then we came to the conclusion of saying 'Well, let's try to do it without them'* (*Founder4*).

In 2000, Founder1, Founder2 and Founder3 published a paper on quantum random number generators (Publication3). This research will constitute the source of the first QuantumComp patent (QuantumComp patent 24) filled in 2003 by Founder1, Founder2 and Founder4.

Founder4 mentioned always having been interested in working in industry (he notably studied business administration during his PhD). The personal interest of Founder1 in industry as well as his previous industrial and start-up founding experience also played a role. Founder2 and Founder3 manifested interest in being part of the spinoff creation. In 2001, the company was

created under the impulsion of Founder4. The firm is located at 900 meters from the EurUni department of physics. Founder4 became the CEO of the company and Founder3 also joined QuantumComp. Founder1 remained in academia but is a member of the QuantumComp's board of directors since its foundation. Founder2 remained in academia and served on the board of directors until 2013. Founder3 left EurUni and joined QuantumComp until 2008. He was a member of the board of directors from QuantumComp creation until 2003.

Founder4 mentioned that the knowledge developed during his PhD was directly useful for QuantumComp as they needed to quickly develop products to raise revenues. The instances of knowledge transfer that we observe in this phase correspond to the linear perspective of university-industry knowledge transfer: An academic scientist wants to create a USO after his PhD, an academic article is written and serves as the basis for a patent of the USO, a USO is created, and mobility happens from the former to the latter.

5.3 2004-2022: PHASE 3: DEVELOPMENT OF A SYMBIOTIC RELATIONSHIP BETWEEN EURUNI AND QUANTUMCOMP

After QuantumComp creation and the first occurrence of linear knowledge transfer from EurUni to QuantumComp, we observe knowledge exchange between both organizations through three general settings: Knowledge transfer from EurUni to QuantumComp, knowledge transfer from QuantumComp to EurUni, as well as ongoing knowledge exchange and knowledge co-creation between EurUni and QuantumComp.

5.3.1 Knowledge transfer from EurUni to QuantumComp

Regarding knowledge transfer from EurUni to QuantumComp, Founder1 informed us that some of the research done at the department of physics at EurUni was directly useful for QuantumComp. Out of this academic work, some patents of EurUni were licensed to QuantumComp, while other patents obtained only by QuantumComp referred to academic

publications done by Founder1, Founder2 and Founder3 at the university (see, e.g., QuantumComp patents 12 and 16).

In the process visualization, we observe knowledge transfer from EurUni to QuantumComp through interaction between mobility, patents, and publications.

Several EurUni academic scientists experienced professional mobility from EurUni to QuantumComp, such as (a) PhD graduates after their PhD thesis (see, e.g., Individual1 to Individual6) or (b) senior researchers/postdocs after their contract with EurUni (such as, among others, Individual15 and Individual16). Founder1 explained that PhD students and postdocs of the department of physics at EurUni were exposed to QuantumComp, leading to professional mobility from the former to the latter.

Among these individuals who moved from EurUni to QuantumComp, there is Founder4, one of the co-founders of QuantumComp. After his PhD thesis, he left academia and moved to QuantumComp and was the inventor of several QuantumComp patents. Some of these patents cited EurUni patents and publications. Several other individuals were inventors in QuantumComp patents after their mobility from EurUni to QuantumComp, such as Individual2. He did his PhD under the supervision of Founder1 and graduated in 2006. In 2008, he joined QuantumComp. He was the co-inventor of 7 QuantumComp patents. Among these patents of Individual2, one built from a EurUni publication of Founder1, Founder2 and Founder4, one from a and another from a EurUni patent of 2011 with Founder2 and Individual15 (a former PhD student of Founder2 who received his PhD in 2013 and was recruited by QuantumComp in 2016) as inventors. Finally, another QuantumComp patent of Individual2 from 2018 mobilized a EurUni academic article from 2005 published by Founder1, Founder2 and Individual3 (a former PhD student of Founder1 who joined QuantumComp in 2010).

5.3.2 Knowledge transfer from QuantumComp to EurUni

We also observe reverse knowledge transfer from QuantumComp to EurUni. *Founder1* highlighted how practitioners at QuantumComp influenced the research avenue at EurUni. One way is from questions of practitioners at QuantumComp through constant dialogue between EurUni researchers and QuantumComp practitioners: *And that also sorted things out and triggered reflections that led to scientific papers in top scientific journals, even if the question came from an engineer at QuantumComp* (*Founder1*).

Another way is through the funding of PhD students by QuantumComp to study a specific topic motivated by QuantumComp's interests: *[QuantumComp] did not pay just to see. The "just to see" is paid by national funds, by the university, by European projects. QuantumComp had an idea "There is something we would like to do, but it is too early to say it is going to become a product"* (*Founder1*).

Additionally, specific topics were given by QuantumComp to PhD students through Marie-Curie projects, therefore leading to production of academic knowledge through topics in which QuantumComp had an interest. In these cases, individuals were employed by QuantumComp. *Founder2* explained: *So, they also received students who were working on a subject that interested them, necessarily quite technical. Since the aim is for them to do those theses, well they can't do a thesis at QuantumComp, so it's people who have done the thesis with me. And I'd tell you that a thesis is a thesis from [EurUni], but they were never employed by the Uni, in fact they were employed by QuantumComp and then it was always a bit in-between* (*Founder2*).

We also observe reverse mobility (see, e.g., individuals 7, 8 and 17). For example, Individual17 worked at QuantumComp for three weeks before being recruited by EurUni on a publicly funded joint project with QuantumComp, one polytechnical school and one university of applied sciences, because of his knowledge of a particular electronic chip: *My first job in [the city] was at QuantumComp, but only for a one-off, very short period. But during those 3 weeks,*

I was lucky enough to meet people from the university who were starting up a major project in collaboration with QuantumComp [and with other universities]. As they were looking for a specialist, they introduced me to them, and I was hired by the university. It was a project that must have lasted 3 or 4 years (*Individual17*). Moreover, during his exclusive employment at EurUni, he was co-author of an academic article. We thus have here a case of reverse mobility from QuantumComp to EurUni followed by the creation of academic knowledge.

Regarding patent citation, one EurUni patent published in 2014 (EurUni patent 42) by Founder1, Founder2 and Founder4 used a paper published by QuantumComp employees in 2011 as a source (QuantumComp publication 12). In this case, both authors were PhD students at EurUni before working at QuantumComp (Founder4 and Individual2). In this example, we can see the intertwinement and complementarity between the vectors of knowledge exchange.

5.3.3 Ongoing knowledge exchange and knowledge co-creation between EurUni and QuantumComp

In our process visualization, we also observe cases of ongoing knowledge exchange (i.e. cases where knowledge is bidirectionally exchanged within one instance of knowledge relation) and knowledge co-creation between both organizations.

Ongoing knowledge exchange and knowledge co-creation are materialized through dual employment of individuals, joint research seminars, joint research or R&D projects, co-creation of knowledge artefacts by both organizations, as well as simultaneity of exploration and exploitation through PhD students of co-founders. Ongoing knowledge exchange and knowledge co-creation are intertwined. For example, when EurUni and QuantumComp are in a joint research project or when individuals are simultaneously employed in both organizations, the co-creation of knowledge goes deeper than the mere co-patent or co-publications: both organizations daily co-create knowledge together.

With dual employment, knowledge is not first transferred from EurUni to QuantumComp and then to QuantumComp from EurUni but is rather continuously and bidirectionally exchanged between them. Individual17, after having had a reverse mobility from QuantumComp to EurUni, was simultaneously employed in both organizations. This dual involvement was linked to the project he was working on: *At the end of this project, it was something that was transferred to QuantumComp, so for me it was logical to follow and work for QuantumComp in parallel with the university to follow this project* (*Individual17*).

He highlighted that the knowledge he transferred when he took over this dual involvement was related to the skills developed in the joint project between EurUni and QuantumComp he was working on: *Pure skills, it's just that it was the same technology that was used, so I gained a lot of experience in this technology and that was important for QuantumComp* (*Individual17*). In this context, the knowledge *Individual17* had from QuantumComp was important for EurUni and vice-versa, thus leading to an ongoing knowledge exchange between both organizations.

During this dual employment, we observe well how the vectors of knowledge exchange interact: Individual17 is the co-inventor of one EurUni patent 2014 citing both EurUni publications (from 2002, 2013) and a QuantumComp publication (from 2011) and of one QuantumComp patent, as well as of one QuantumComp patent citing EurUni publications from 2013 and one EurUni/QuantumComp co-publication from 2010.

Another way for ongoing knowledge exchange to happen is through the participation of QuantumComp practitioners to seminars of the EurUni group of applied physics, leading to knowledge exchange and research ideas. Also, EurUni and QuantumComp launched research projects together, as highlighted in Table 2 which shows collaborative research projects funded by the national science foundation of the country during this phase (granted amounts are rounded to preserve anonymity).

Table 2. Role of QuantumComp in EurUni projects funded by the national science foundation of the country

Funding period	Granted amount	Applicant(s)	QuantumComp Role
2017-2019	CHF 120'000	EurUni and QuantumComp	QuantumComp is co-applicant of the project
2018-2022	CHF 500'000	EurUni	QuantumComp is project partner on this project
2019-2022	CHF 630'000	EurUni	Project in collaboration with QuantumComp

Co-creation of knowledge artefacts can take the form of joint patents (Kreiling & Paunov, 2021; Su et al., 2015) or joint publications (Kreiling & Paunov, 2021). In our process visualization, we observe cases of joint patents or joint publications. In such cases, both EurUni and QuantumComp are recognized as co-creators of artefacts of knowledge (patents or scientific articles). We observe a joint patent in 2019 with EurUni and QuantumComp as co-applicants (EurUni/QuantumComp patent 30). This patent is on single photon detection using a variety of superconducting means. One of the inventors (Individual8) is working at EurUni after a mobility from QuantumComp to EurUni in 2016 for a PhD under the supervision of Founder2, and filed the patent in 2019, the year of his PhD defense. His PhD thesis was on a superconducting nanowire single-photon detector, thus directly linked to the patent. He is a materialization of a case of knowledge transfer from the USO to the parent university. The other inventor (Individual18) is involved in both organizations since 2016, after having been employed solely by EurUni between 2010 and 2015 (mobility from the parent university to the USO as well as dual employment). He is a case of both (a) knowledge transfer from the parent university to the USO and (b) ongoing knowledge exchange and knowledge co-creation

between both organizations. We also observe several cases of joint publications. To show their interaction with other vectors, we detail one of them: EurUni/QuantumComp publication 13). This publication is about photon counting (a quantum sensing product). The EurUni authors are members of the group of applied physics and include Founder1 and Founder2. On the QuantumComp side, the author (Individual2) was first a PhD student at EurUni under the supervision of Founder1 where he worked on optical fiber metrology based on quantum physics, then worked as a post-doc at EurUni and finally got a position at QuantumComp.

Finally, while former PhD students of Founder1 and Founder2 joined QuantumComp, others started their PhD with them in the same period. This led to the simultaneity of exploration and exploitation through PhD students.

These three elements (1. Knowledge transfer from EurUni to QuantumComp, 2. Knowledge transfer from QuantumComp to EurUni and 3. Ongoing knowledge exchange and knowledge co-creation between EurUni and QuantumComp) compose a knowledge recursivity where both organizations impact one another through time. Table 3 synthetizes those three components of knowledge recursivity, their role in the exploration and exploitation of knowledge, as well as how they materialized in our case study.

Table 3. The components of knowledge recursivity and its materialization

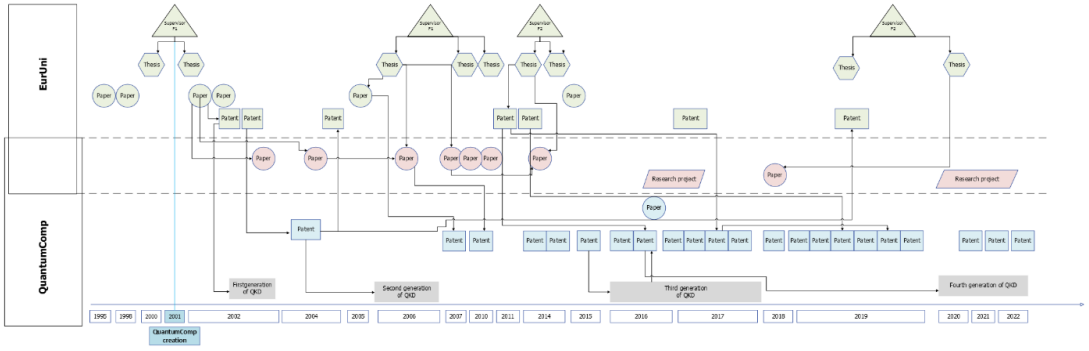
The components of knowledge recursivity	Materialization of the components of knowledge recursivity
Knowledge transfer from the parent university to the USO *Exploration in the parent university nourishes exploitation in the USO*	▪ Citation of a university patent or publication by the USO ▪ Licensing of a university patent to the USO ▪ Mobility from the parent university to the USO
Knowledge transfer from the USO to the parent university *Exploitation in the USO nourishes exploration in the parent university*	▪ Citation of a publication or patent of the USO by a patent of the university ▪ Influence of research avenues in the parent university by practitioners of the USO ▪ Mobility from the USO to the parent university ▪ Definition of specific PhD theses topics for parent university's PhD students by the USO
Ongoing knowledge exchange and knowledge co-creation between the USO and the parent university *Both the parent university and the USO co-explore and co-exploit knowledge*	▪ Dual employment of individuals in both the parent university and the USO ▪ Joint research seminars ▪ Joint research or R&D projects (leading to co-patents and co-publications) ▪ Simultaneity of exploration and exploitation through PhD students of co-founders

To illustrate the continuous exchange of knowledge between EurUni and QuantumComp, we investigate the evolution of the QKD product of QuantumComp.

Figure 2 shows the route of this product. In this visualization, we integrated the following elements when they were related to QKD: theses (and their supervisions), academic articles (including at least one of the co-founders as author) cited in patents, patents of EurUni (with at least one of the founder as inventor) and QuantumComp, generations of QKD products at QuantumComp, academic articles with QuantumComp as affiliation, co-published articles between EurUni and QuantumComp as well as research projects with the involvement of both organizations. We connected linked knowledge artefacts with arrows for a set of selected cases to visualize relatedness between elements. We see waves of knowledge artefacts between each

generation of QKD product. Periods of exploitation at QuantumComp are followed by period of exploration at EurUni and by co-production of knowledge by EurUni and QuantumComp. Here, we observe an undulatory interorganizational ambidexterity: exploration nourishes exploitation that nourishes exploration, with the repetition of this logic over time. Founder4 explained this process of knowledge going back and forth between both organizations: *[At QuantumComp,] we're on the 4th generation after 23 years, so it's in that sense. It's not so much in the first phase, there wasn't so much back and forth, but once we'd developed the first product, we had discussions with them …then they continued to do research in the field … Then, on the basis of their results, new patents were filed by the university … and licenses were granted, so this kind of exchange took place over 23 years* (*Founder4*).

Figure 2. The QKD route between EurUni and QuantumComp



This close knowledge relationship between EurUni and QuantumComp is allowed by their geographical proximity (900 meters between them) and the social embeddedness between EurUni physicists and QuantumComp employees. Founder1 highlighted these elements: *Again, it is not too far, there is a lot of interaction, they sometimes go for a beer on one of those famous Thursdays like I was telling you. So, these people know each other. And they say "Well, I would like to go and work in the industry". And then, maybe they will go and have a chat with their buddies at QuantumComp, and then submit their application and be interviewed.* (*Founder1*). He also explains that QuantumComp nurtures such social embeddedness between these individuals, and how it is related to the geographical proximity between EurUni and

QuantumComp: *Even today, I think it's the third Thursday of the month, I'm not really sure, QuantumComp offers a drink to everyone who comes. So, there are people from here who are 10 minutes away on foot or maybe a quarter of an hour, it is not very far, so there is not a huge number of people, but still today, there are people from here who, maybe not every month, but from time to time go there.* (*Founder1*)

Such a close relationship is described as having a positive impact on both organizations, leading to the growth of each of them. In addition to the impact of EurUni on QuantumComp, Founder1 emphasized the growth of its quantum physics academic group as a result of the relation between EurUni and QuantumComp:

It is not only a recipe for success for QuantumComp, but also for the group here, for the physicists here. We have grown, we have got more scholars, we have got more resources, et caetera, we are recognized by the rectorate, but also sometimes internationally. So, I think it is really one of those win-win situations. And that is not just hocus-pocus, it is really win-win. (*Founder1*)

Founder2 explained that the needed mastery of skills and technologies is common between both organizations, which naturally fosters knowledge exchange between both organizations: *What binds us together …, it's really the mastery of certain technologies or having the skills to do many things. And then of course, because we need more or less the same skills for what we do at Uni and what QuantumComp does … So that's why it's quite natural for people to exchange ideas.* (*Founder2*)

Founder2 also explained that such technologies were part of an ongoing improvement by both organizations: *And finally, together we improved the performance of these vectors. Maybe at the beginning, we did everything at Uni, then maybe later, we bought vectors from QuantumComp because it was better, easier than doing it at Uni, and so on* (*Founder2*).

Related to a joint project, *Individual28* explained that EurUni and QuantumComp both shared resources and experienced a mutually beneficial situation out of this project: *So, there is some equipment that the company can provide to the university. This is part of the money that the company is pledging in during this project. The university pledges the use of the research facilities … so some research that maybe the company didn't have the money or the equipment to do themselves can be done at the university and this can have a beneficial role for both* (*Individual28*).

The mutually beneficial relationship between EurUni and QuantumComp led, for example, to positive evaluations of grant applications from *Founder1*, leading to more funds for EurUni: *So, I think that gave us an advantage when we made proposals, but to the national fund ..., which deals with science, but which said, well, this is in collaboration, it's the same people who made QuantumComp ... The reality is also that the fact of having this success with QuantumComp, of having been able to demonstrate a form of collaboration that works, means that the evaluators see it in a much more positive light. … 80 percent of my grant requests were accepted … then still with relatively a lot of money* (*Founder1*).

In addition to funding, EurUni gained credibility through its closed relationship with QuantumComp: *It can give credibility that you're working on real application that companies are interested … it does show that the research that you do at the university has merit and it has real-world applications* (*Individual28*). Several recognitions were awarded to the founders for their work on quantum physics. Founder1 and Founder2 received several high scientific recognitions and Founder4 is recognized to be one of the most innovative people in the world. This mutually beneficial situation is recognized by each party. For example, while speaking about funding PhD students, Founder1 explains that because both parties recognized the positive impact of such a relationship, they are both ready to fund projects. The knowledge relationship between the two organizations is even formalized through contracts:

QuantumComp has a right of first refusal on the university results in the field of quantum communications … And vice versa, when QuantumComp wants to give a mandate to a university to solve a certain problem, they have to contact us first and give priority to the university for this development (*Founder1*).

The EurUni group of applied physics grew EurUni thanks to its relationship with QuantumComp.

Figure 3 shows the increase in funds for applied physics projects at EurUni by the national science foundation of the country as well as the proportion of these funds dedicated to projects related to quantum physics. Figure 4 shows the number of PhD theses supervised by professors of the group of applied physics from 1988 to 2022, including the ones from *Founder1* and *Founder2*, the ones from other professors in quantum physics as well as the ones of the remaining professors.

Figure 3. Funds for applied and quantum projects at EurUni by the national science foundation of the country

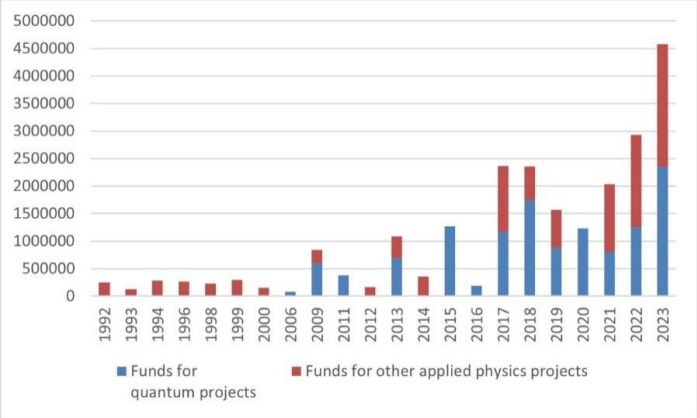
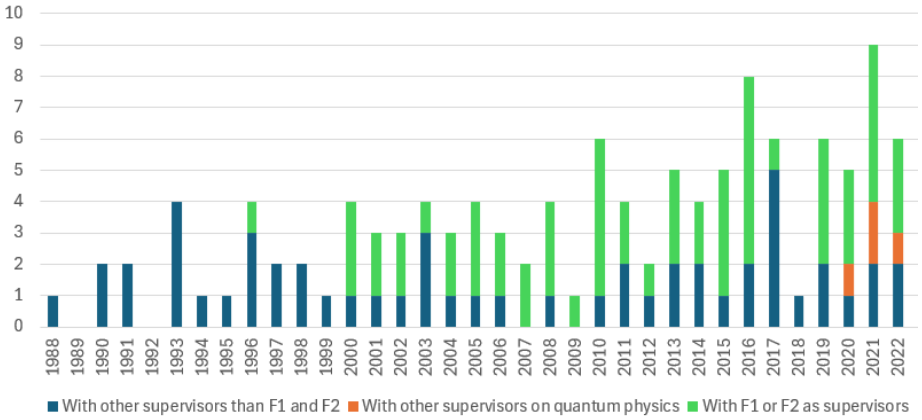
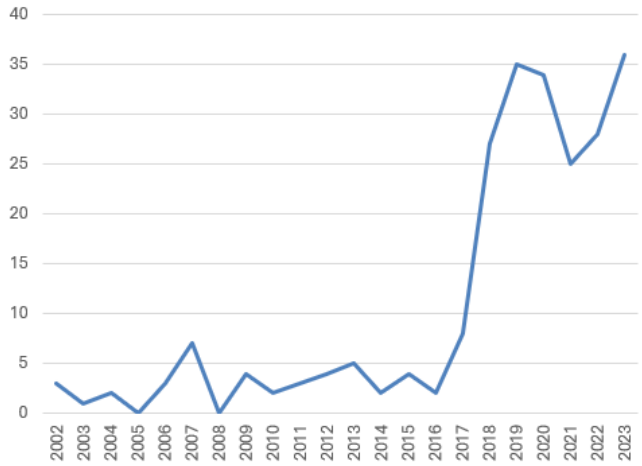


Figure 4. Number of PhD theses supervised by Professor of the group of applied physics



There are also notable cases of QuantumComp growth. In 2010, their solutions were deployed internationally for firms and governments. In 2017, they raised additional capital. In 2018, they raised USD 65 millions from the same major telecom company and another one also became an investor in QuantumComp. Parallel to this increase in products deployment and fundings, QuantumComp received increasing media attention over time (Figure 5).

Figure 5. Media articles on QuantumComp (in the title)



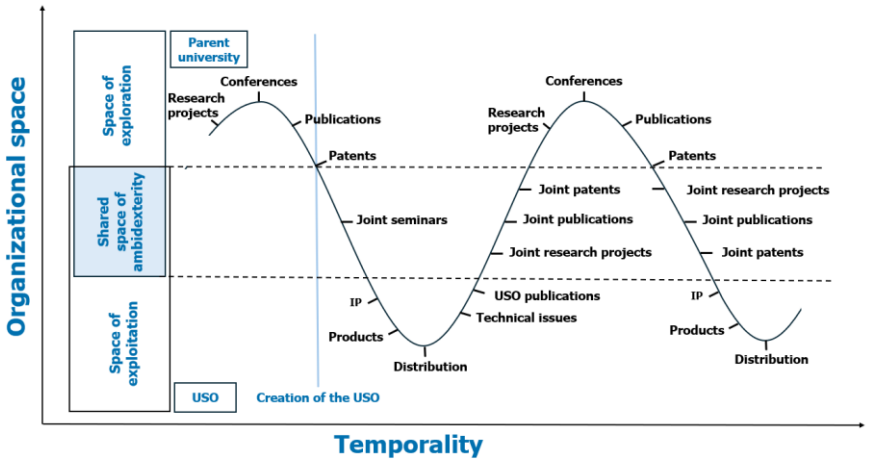
6 THEORY DEVELOPMENT

6.1 UNDULATORY INTERORGANIZATIONAL AMBIDEXTERITY

The case of EurUni and QuantumComp illustrates a knowledge relationship where interorganizational ambidexterity is not linear but undulatory. In such a model of undulatory interorganizational ambidexterity, there are: (a) a space of exploration in the parent university, which nourishes exploitation in the deep-tech USO; (b) a space of exploitation in the deep-tech USO which nourishes exploration in the parent university; and (c) a shared space of ambidexterity where a parent university and its deep-tech USO co-create knowledge. The nourishing of exploration in universities by exploitation in the USO corresponds to a case of USO catalyst for science (Plantec, 2023). Finally, the shared space constitutes a middle ground (Cohendet et al., 2021) between the parent university and the USO (Ozor et al., 2024).

Figure 6 shows our model of undulatory interorganizational ambidexterity with their corresponding knowledge elements during the process.

Figure 6. Model of undulatory interorganizational ambidexterity



In this type of ambidexterity, knowledge exchange happens bidirectionally and recursively between the parent university and the USO. Table 4 synthesizes the particularities of the traditional model of parent universities-USOs interactions compared to our model of symbiosis.

Table 4. Traditional versus symbiotic model of universities-USOs interactions

	Traditional model of parent universities-USOs interactions	**Symbiotic model of parent universities-USOs interactions**
Type of interorganizational ambidexterity	Linear model of interorganizational ambidexterity	Undulatory model of interorganizational ambidexterity
Type of knowledge transfer	Sequentiality of knowledge transfer	Recursive knowledge exchange

In such a model, knowledge is exchanged through the intertwining and complementarity (Schaeffer et al., 2020) of different vectors of recursive knowledge exchange. Table 5 shows how the different components of knowledge recursivity are related to our model of undulatory interorganizational ambidexterity.

Table 5. Undulatory interorganizational and knowledge recursivity components

Undulatory interorganizational ambidexterity components	**Knowledge recursivity components**
Space of exploration of the parent university nourishing exploitation in the USO	Knowledge transfer from the parent university to the USO
Space of exploitation of the USO nourishing exploration in the parent university	Knowledge transfer from the USO to the parent university
Common space of ambidexterity	Ongoing knowledge exchange and knowledge co-creation between the parent university and the USO

This is in line with models of bidirectional rather than linear university-industry knowledge (Ulhøi et al., 2012) as well as with the consideration of knowledge transfer mechanisms in interactions rather than in silos (Schaeffer et al., 2020). The process of knowledge exchange between the university and its USO is recursive and, additionally, runs counter to the traditional vision of the division of labor between academia and industry where knowledge transfer ends after exploitation. Rather, exploitation nourishes exploration in an undulatory interorganizational ambidexterity to support innovation. The two organizations must be in a situation where they both have an interest in pursuing a long-term relationship with each other. This might be the case for deep tech USOs:

While this kind of spinoff operates at the frontier of technology (Kruachottikul et al., 2023) and needs close links with academia to obtain state-of-the-art knowledge, the parent university can commercialize its research in and takes research avenues inspiration from its USO. Indeed, professors who become academic entrepreneurs investigate new research areas as a result of their implication in their spinoffs (Fini et al., 2022). Moreover, they tend to keep long-term links with their industrial partners, which results in the development of the ability to focus on both knowledge exploration and avenues for exploitation (Lam, 2007).

Some firms fund PhD students, leading to reverse knowledge transfer Lam (2007). In the same logic, a USO might fund PhD students to explore research avenues in which it has an interest, as we observed in the case of EurUni and QuantumComp.

As observed with QuantumComp, the USO might also transfer knowledge to its parent university through mobility, USO research or patent as well as influence of research avenues through discussions. Finally, QuantumComp and EurUni developed a shared space of ambidexterity with joint research seminars, joint research or R&D project, dual employment of individual as well as simultaneity of exploration and exploitation through PhD students. Parent universities and deep-tech USOs might develop such spaces of continuous and close interactions to develop knowledge together. These elements lead to our first proposition:

Proposition 1. After its creation, the parent university and its deep-tech USO develop an undulatory interorganizational ambidexterity to be able to support their mutual development.

6.2 ORGANIZATIONAL ECOLOGY AND SYMBIOSIS IN ACADEMIC ENTREPRENEURSHIP

The OE literature focuses on competition, based on the analogy in biology where the fittest species win the competition for resources and thus survive (Downie, 2022; Gotsopoulos & Pitsakis, 2024; Hannan & Carroll, 1992). However, cooperation between species plays a significant role in evolutionary biology (Sachs et al., 2004) and can thus be a particularly strong evolutionary force. One particular type of cooperation is symbiosis. Margulis, a prominent

biologist, defines symbiosis as the "long term, permanent, sometimes cyclical, … seasonal, physical association between members of different species" (Margulis, 1990, p. 1526) that are unlike but live together, and must be in physical contact (Margulis, 1990). We consider (but do not limit to) the case of symbiosis as mutualism, when the persistent relationship between the two species is characterized by a benefit for both of them (Egerton, 2015).

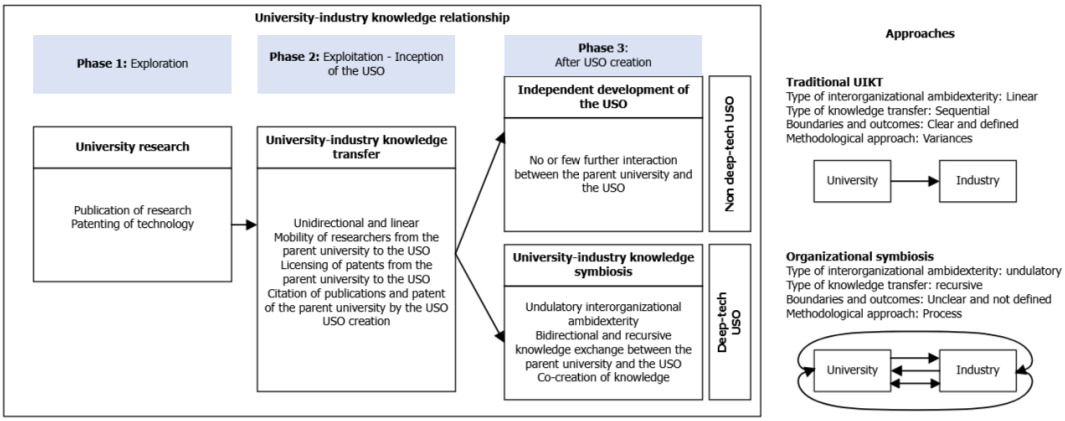
In OE, symbiosis has been lightly mobilized and often at the population level (growth and decline of populations) (Audia et al., 2006; Barnett & Carroll, 1987), with some focusing on the mutualist aspect of such relationship (see, e.g., Barnett & Carroll, 1987). The two studies cited as examples refer to the sociologist Amos H. Hawley and its definition of symbiosis between organizations – "organizations connected through their complementarity differences" (Hawley, 1992, p. 10) and not on biological definitions. The central elements of Margulis's (1990) definition of symbiosis are overlooked: the association between members of different species in a permanent, cyclical and physical way. Such members associating together are called symbionts, and "[to] be symbionts[,] individual members of at least two species must touch each other most of the time" (Margulis et al., 1997).

In the innovation literature, Schaeffer, Guerrero, & Fischer (2021) speak about mutualistic symbiosis but at the ecosystem level and without providing a definition and analogy from biology and ecology sciences. In our context, universities and USOs in an interacting and long-term knowledge relationship can be seen as two different organizational species (Betton & Dess, 1985; Hannan & Freeman, 1977) that cooperate: a university is a non-profit organization developing open basic knowledge and a USO is a for-profit organization developing industrial knowledge. Transposing the concept of symbiosis as defined by Margulis (Margulis, 1990; Margulis et al., 1997), we propose the concept of UUKS.

A UUKS means that both the parent university and its USO experience a permanent, cyclical, proximal, socially embedded and mutually beneficial knowledge relationship and live together

despite their unlikeness. This UUKS is characterized by an undulatory interorganizational ambidexterity. This corresponds to the knowledge relationship observed between EurUni and QuantumComp. We acknowledge that some USOs take an independent path from their parent university. In this context, a non-deep-tech USO working with more established and traditional knowledge can grow while being independent of its parent university. In Figure 7, we illustrate the two possible avenues in a knowledge relationship between a parent university and a USO, as well as the two concurrent related approaches.

Figure 7. Knowledge relationship between USOs and parent universities



Consequently, we propose that some universities and USOs, in particular deep tech USOs, evolve together and develop a UUKS. The aforementioned elements lead to our second proposition:

Proposition 2. The deeper the technology of the USO, the more critical it is for the USO to switch from a linear relationship to a symbiotic relationship with its parent university for its survival.

Secondly, one important element of the symbiosis between biological species is that they must be in physical contact (Margulis, 1990). For organizations, the equivalence of such a 'physical contact' is that organizations must be geographically close as well as socially embedded (Granovetter, 1985). QuantumComp is geographically close to EurUni, which allows for social

embeddedness with EurUni researchers (Heblich & Slavtchev, 2014). However, it does not automatically lead both organizations to be in contact. Rather, geographical proximity is a precondition that allows for the social embeddedness of both organizations, and it is the combination of both conditions that permits access to the parent university knowledge by its USO (Heblich & Slavtchev, 2014). Moreover, we can also argue that such conditions also permit access to the USO knowledge by its parent university. In our case study, such a UUKS is allowed by the geographical proximity between both organizations and the social embeddedness of their actors. In this context, professors who become academic entrepreneurs and are linked both to their university and to their USO might strengthen the link between them through their role of boundary spanner (Lam, 2007). In these conditions, both organizations build on and benefit from the knowledge of the other. This informs our third proposition:

Proposition 3. The knowledge relationship between a deep-tech USO and its parent university develops into an university-USO knowledge symbiosis under the conditions of geographical proximity and social embeddedness.

In our case study, we observe a strengthening of the UUKS between EurUni and QuantumComp through time: while it started with knowledge transfer from the parent university to the USO and vice versa, it ended up with occurrences of ongoing knowledge transfer, through simultaneous employment of individuals in both organizations, as well as with co-creation of knowledge through co-patents and co-publications. In such a context, the mutual benefit experienced by both organizations should lead, through time, to the self-reinforcement of the symbiotic relationship and the growth of both organizations, as both organizations have an advantage in pursuing and nurturing such a knowledge relationship. Indeed, when knowledge is recursively transferred between both organizations over time in a symbiotic relationship, these organizations might strengthen their symbiosis as a result of the mutual benefits experienced by both of them. In our case study, such strengthening indeed contributed to the

growth of both organizations. Notably, one of the founders we interviewed told us that he experienced reputational benefits (Pitsakis et al., 2015) related to his implication in the spinoff. This led, for him, to more funding as well as an enhanced social status within the university. Moreover, according to its CEO, QuantumComp also experienced reputational benefits because of its relationship with EurUni. We thus have a dual reputational benefits effect.

On the university side, in addition to purely financial rewards such as the traditional royalties that parent universities gain through the licensing of patents to their USO (Lowe, 2006), the enhancement of parent universities reputation resulting from their engagement in USO creation can lead to an increase of their research funds (Pitsakis et al., 2015) which allow to investigate new research avenues and therefore impact the production of academic knowledge. QuantumComp, on the other side, also experienced a growth in funds. We also observed that the relationship between the parent university and its deep-tech USO led to an overlapping internal labour market (Lam, 2007) for both organizations. This leads to our fourth proposition:

Proposition 4. Through time, the symbiotic relationship between a deep tech USO and its parent university is self-reinforcing and nurtures the growth of both organizations.

7 DISCUSSION

While recent literature shows that the links between a parent university and its USO is a condition of the success of the latter (Bolzani et al., 2021), we explore the case of a successful USO and the mechanisms sustaining its long-term knowledge relationship with its parent university, the forms of knowledge exchange as well as the evolution of both organizations in this knowledge relationship. We unveil the complexity of the relationship between a USO and its parent university through a processual approach that allows us to represent the intertwinement and complementarity of the vectors of knowledge exchange. Our findings contribute to the existing literature on academic entrepreneurship in several ways. First, we contribute to the academic entrepreneurship literature by investigating the life cycle of a deep-

tech USO and its long-term relationship with its parent university going from the exploration period at the source of the USO until today. We uncovered that the short-term outputs of a deep-tech USO is not the end of its relationship with its parent university, but rather the beginning of a second phase: a UUKS between both organizations. Second, we contribute to academic entrepreneurship literature through our model of undulatory interorganizational ambidexterity between parent universities and their USOs which uncovers the continuous exchange of knowledge and mutual influence between both organizations. Third, we contribute to academic entrepreneurship literature through our concept of UUKS by transposing the concept of symbiosis from Margulis's work (Margulis, 1990; Margulis et al., 1997) to characterize such a relation between those organizations. Notably, symbiosis has not been mobilized in an academic entrepreneurship context to conceptualize permanent, cyclical, proximal, socially embedded and mutually beneficial knowledge relationship between a parent university and its USOs. However, such a concept is fruitful to study and understand the lasting relationship between specific USOs and their parent university. It highlights the complex, dynamic and interactive knowledge relationship between both organizations and stresses how they are not isolated but rather in continuous interaction for their specific needs. The condition for such a UUKS to occur are the equivalences of physical association between biological species (Margulis, 1990): geographical proximity and social embeddedness, where the former is a precondition of the latter (Heblich & Slavtchev, 2014). These conditions do not only allow the access to the parent university knowledge by its USO, as shown in the literature (Heblich & Slavtchev, 2014), but also the reserve: the access to the USO knowledge by its parent universities. We also show that a UUKS strengthens over time and how this strengthening happened, complementing evidence in the literature of strengthening interactions between parent universities and USOs (Treibich et al., 2013). We found that not only the interactions increased, but also the mutual benefit experienced by the two organizations in their knowledge

relationship. Through these two elements, we also contribute to ambidexterity literature and to organization theory. We contribute to the literature on ambidexterity by proposing a model of undulatory interorganizational ambidexterity which materializes the symbiosis. This model of ambidexterity highlights the mutual influence, in terms of knowledge, between both organizations. In such a model, exploration is not anymore only an antecedent of exploitation, but exploitation is also an antecedent of exploration. Moreover, such activities are not isolated but can overlap to form a shared space of ambidexterity. Although knowledge relationships between parent universities and deep-tech USOs could be characterized in the short term by a linear interorganizational ambidexterity, their interorganizational ambidexterity might shift toward an undulatory model in the long term. We contribute to organization theory by introducing the concept of university-USO knowledge symbiosis, through the extension of biological analogies in the field of OE (Hannan & Freeman, 1977) based on a translation of the concept of symbiosis as defined by Margulis (1990), a prominent biologist who has, to the best of our knowledge, not have been considered nor in OE, neither in the academic entrepreneurship literature. In terms of practical contribution, we described the knowledge recursivity condition of a successful deep-tech USO. Such recursivity is composed of knowledge transfer from the parent university to the USO, of knowledge transfer from the USO to the parent university, as well as by ongoing knowledge exchange and knowledge co-creation between the parent university and the USO.

8 CONCLUSION AND LIMITATIONS

USOs, in particular deep-tech ones, are key organizations to foster innovation. Our study provides a longitudinal analysis of the knowledge relationship between a parent university and its deep-tech USO and shows how it develops into an undulatory interorganizational ambidexterity characterizing a UUKS. In such a relation, knowledge transfer mechanisms interact and there is co-creation of knowledge between the two organizations. There are some

limits in our study. Our process visualization integrates the elements that are related together. Therefore, it does not encapsulate all the possible knowledge transfer between both organizations (such as, e.g., patents citations not related to the individuals that are part of our visualization). Supplemental analysis at an aggregate level could be conducted to complement our data. Moreover, comparative analysis with other deep-tech and non-deep tech USOs could be done to investigate if a symbiosis happens for other deep-tech USOs and if its appearance is indeed related to the deepness of the technology of USOs.

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