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ABSTRACT: *University – Industry (U-I) collaborative Ph.D. is one particular channel amongst a wide range of methods for firms to access academic knowledge. While often presented as a mean for firms to hire Ph.D. candidates or to address problem-solving issues, U-I collaborative Ph.D. could constitute an interesting proxy to deeper explore U-I collaborations goals and principles. We focus here on (1) what could be the different archetypes of U-I collaborative Ph.D. in terms of R&D strategies and collaboration forms? (2) In what extent firms and universities contribute to new knowledge co-development and unknown exploration through those collaborations? This exploratory study was based on an original date set of 90 collaboration agreements between laboratories and companies through the French "CIFRE" programme. First, we developed a coding scheme to classify each project between three collaboration forms (outsourcing of knowledge development / knowledge transfer & absorptive capacity / knowledge co-development) and three R&D strategies (process or product improvement / new competences enhancement / new innovation area exploration). Second, we computed descriptive statistical analyses to define four main archetypes of U-I collaborative Ph.D. As a result, the archetypes definition provided a more comprehensive vision of the literature on U-I collaborative Ph.D. projects that were appearing fragmented. We also highlighted that there was a high share of projects aiming at co-developing new knowledge for unknown exploration in our limited sample. We finally discussed (1) institutional factors that could favour this orientation and (2) possibilities to extend the scope of the study.*

KEY WORDS: *University – Industry ecosystems, R&D strategies, R&D collaborations, University – Industry Ph.D student, doctoral programmes.*

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1. INTRODUCTION

University – Industry (U-I) collaborations have been a topic of major academic research for decades (Bruneel et al., 2010; Lee, 1996). In particular, the benefits of new knowledge developed by universities have been recognized as a major source of industrial innovation (Cohen et al., 2002; Mansfield, 1991; Siegel et al., 2003). Indeed, U-I collaborations multiple forms and goals and their associated contributions to industrial innovation processes have been documented as co-evolving alongside the development of firm's R&D divisions (Stokes, 1997). It is particularly relevant in today's modern economies as accessing scientific knowledge rather than internally developing it has received more attention within firm's innovation strategy (Arora et al., 2018) and following the open-innovation paradigm (Chesbrough and Rosenbloom, 2002; Miller et al., 2018; West et al., 2014).

In order to describe the plurality of exchanges and relationships between universities and industries, scholars have notably developed either theoretical models to analyse knowledge flows within the ecosystem (Carayannis and Campbell, 2012; Etzkowitz and Leydesdorff, 2000; Gibbons et al., 1994) nor taxonomies to investigate their forms (Cohen et al., 2002; Perkmann and Walsh, 2007; Schartinger et al., 2006; Siegel et al., 2003). Those relationships may encompass for example: "*research partnerships, research services, academic entrepreneurship, human resources transfer, informal interaction, commercialization of property rights, scientific publications*" (Perkmann and Walsh, 2007, p. 262). Whereas U-I interactions forms such as academic entrepreneurship (cf. for litterature review: O'Shea et al., 2005) or commercialization of IP (cf. for litterature review: Miller et al., 2016) have been under lots of scrutiny by scholars and policy-makers, U-I collaborative Ph.D. is a particular form for which academic literature remain scarce. Often presented only as a

mean for firms to hire Ph.D. candidates, U-I collaborative Ph.D. is nevertheless a quite common form of U-I interaction (Borrel-Damian et al., 2015). U-I collaborative Ph.D. schemes are existing in several European countries (France, Denmark, Germany, UK, Sweden, etc.) but represent a topic of little systematic research (Salminen-Karlsson and Wallgren, 2008; Thune, 2009; de Wit-de Vries et al., 2018), in particular regarding firm's innovation strategy.

Following our literature review, first we showed that apart from few exceptions (Assbring and Nuur, 2017; Grimm, 2018; Harryson et al., 2007; Thune and Børing, 2015), previous studies were mainly focusing on (1) higher education research field, (2) in-depth description of the knowledge transfer process (mainly from academia to industry) and (3) the success factors regarding academic publications and patents. Second, we also noted that there is a wide range of U-I collaborative Ph.D. projects goals and contexts which were described by colleagues in the literature, from very exploitative or applied projects (eg. Grimm, 2018) to very exploratory and collaborative ones (eg. Harryson et al., 2007). As a result, we proposed here first, to focus our investigations on firm's R&D motives to be involved in U-I collaborative Ph.D. projects. Second, due to the multiple forms and goals of reported U-I collaborative Ph.D. projects, we acknowledged that those programmes could constitute an interesting proxy to explore U-I collaboration forms and strategies. Our research topic is then the following: **in what extent firms and universities contribute to new knowledge development and scientific exploration through U-I collaborative Ph.D. programmes?**

In this exploratory study, our methodology is both conceptual and quantitative. Based on the literature review we built a new framework to classify U-I collaborative Ph.D. projects in terms of collaboration modalities and research strategies. Based on this framework, we developed a method to classify an original dataset of collaborative Ph.D. projects in France.

We performed statistical descriptive analyses to discuss project archetypes identification and magnitude, in particular with the distinction between large company and SMEs. We contributed to the literature on U-I collaborative Ph.D. by developing an original framework to better understand firms and academics motives in terms of R&D contribution. Archetypes definition also provided a comprehensive vision of the literature on U-I collaborative Ph.D. projects that were appearing fragmented. Finally, we also showed through our analysis on a limited sample that many projects were including both high level of engagement through knowledge co-development and were focusing on exploratory projects which may contrast with traditional views on U-I knowledge transfers, in particular for U-I collaborative Ph.D.

2. LITERATURE REVIEW:

2.1. U-I collaborative Ph.D., a definition:

Scholars have used different terminologies to deal with Ph.D. students collaborating with industrial partners. The latter encompassed mainly: "*joint supervision of Ph.D.*" (Harryson et al., 2007; Schartinger et al., 2006), "*Industrial Ph.D.*" (Salminen-Karlsson and Wallgren, 2008), "*Collaborative Ph.D.*" (Borrel-Damian et al., 2015; Grimm, 2018; Salimi et al., 2016). Furthermore, some studies may also referred to those types of Ph.D. directly through the programme's names such as CIFRE Ph.D. in France of CASE Ph.D. in the United-Kingdom (Gertner et al., 2011). In our contribution, we called those projects "*U-I collaborative Ph.D*." and defined them as the following definitions based on previous literature:

- "*a project with a typical duration of 3-4 years and which involves a university, a firm and a Ph.D. candidate, all working together to meet common or individual exceptions*." (Salimi et al., 2016, p. 2) ;

- "*The industry experts take part in the supervisory committee, officially and informally*" (Borrel-Damian et al., 2015, p. 17) ;
- "[From an academic perspective], *they entail the same high standards for scientific quality of research as that required of a doctorate in a traditional doctoral programme*" (Borrel-Damian et al., 2015, p. 8).

U-I collaborative Ph.D. schemes are mainly supported by government for funding and/or regulatory schemes. For example, in France and Denmark, the programme is supported by public funding (through the Danish Agency for Science, Technology and Innovation[1] for Denmark and the National Association for Research and Technology in France[2]) and regulated by law. Similar programmes are also existing in Sweden (through industrial research schools), the United-Kingdom (EngD, Knowledge Transfer Programme (KTP) or CASE programmes), Italy or Germany with different levels of State engagement and national or regional regulatory formalisation efforts.

2.2. Issues of U-I collaborative Ph.D. integration in firms' R&D strategy:

Scholars acknowledged that U-I collaborative Ph.D. projects represents a topic of little systematic research (Thune, 2009; de Wit-de Vries et al., 2018). We listed in table 1 below main contributions relative to the topic.

[1] https://ufm.dk/en/the-ministry/organisation/danish-agency-for-science-and-higher-education/danish-agency-for-science-and-higher-education-1
[2] www.anrt.asso.fr/fr

MAIN TOPICS	LITERATURE
Higher Education Research - Impacts analysis of having completed U-I collaborative Ph.D. training on students career comparatively to those having complete classical Ph.D. training	Granata and Dochy, 2016; Malfroy, 2011; Neumann, 2005
Knowledge Transfer Processes - In-depth analysis of knowledge transfer mechanisms embedded in the U-I collaborative Ph.D.	Gertner et al., 2011; Kihlander et al., 2011; Salminen-Karlsson and Wallgren, 2008; Slaughter and Campbell, 2002
U-I collaborative Ph.D. Management – Analysis of factors favouring academic publications, patents and performances of student in the job market such as: project management, communication, etc.	Butcher and Jeffrey, 2007; Gustavsson et al., 2016; Roolaht, 2015; Salimi et al., 2016

Table 1 - Main topics of U-I collaborative Ph.D. literature

As highlighted by Wit-de-Vries & al. (2018) and Thune (2009) there was a need for further research on firm's motives to engage in U-I collaborative Ph.D.[3] Accordingly, we focused here on how much those research projects undertook through U-I collaborative Ph.D. schemes were part of broader firm's R&D strategies. Furthermore, research projects of U-I collaborative Ph.D. that we found in the literature referred to very distinct situations. In some cases, they were relative to very exploitative situations or problem solving for firms (eg. Grimm, 2018 in the automotive industry in Germany) while other projects were focusing on very innovative and exploratory projects (eg. Harryson et al., 2007 in the audio industry in the Netherlands). Then, we supposed that U-I collaborative Ph.D. could be an interesting proxy to investigate firm's R&D strategies. Our research questions are then: **(1) What would be the different archetypes of U-I collaborative Ph.D. in terms of R&D contribution? (2) In what extent firms and universities contribute to new knowledge co-development and unknown exploration through U-I collaborative Ph.D. programmes?**

[3] "*There is a need for more insight into the firms' perspective on the involvement of students and Ph.D.'s in research partnerships, as most research discusses the academic perspective only*" (de Wit-de Vries et al., 2018, p. 15).

In order to answer those questions, first we reviewed in the literature on U-I collaborative Ph.D. what would be the different research strategies of those projects. Second, we analysed what were the different forms of those collaborations.

2.3. U-I collaborative projects main R&D objectives:

As reported by some qualitative study, one of the main goal of a U-I collaborative Ph.D. project would be producing knowledge regarding products or processes for the involved firm. Indeed, Borrel-Damin & al. (2015) in a longitudinal qualitative study in Europe, reported that most firms considered that the core benefits of U-I collaborative Ph.D. programmes was the development of new knowledge leading to new product development. In those cases, industrial partners were mainly facing a specific industrial issue that they were willing to solve through the Ph.D. (Gustavsson et al., 2016) or asked for the validation of a Proof or concept that they have already completed (Schartinger et al., 2006). The research topics were then mainly restricted to tangible product (Granata and Dochy, 2016). This orientation towards products was also often reported as a limit regarding the possibilities of new academic knowledge development by students or academic supervisors. Indeed, as students have industrial responsibilities regarding the product or process development, they could lack of time to perform in-depth academic research (Slaughter and Campbell, 2002) or the relevant testing procedures that might be not suitable regarding firm project schedules (Grimm, 2018; Malfroy, 2011).

Nevertheless, scholars also presented case studies for which projects undertook through U-I collaborative Ph.D. were mainly dedicated to the development of knowledge with less direct commercial goals. In those cases, firm's motivations were associated to new competences creation and retention through the development of new knowledge

(Gustavsson et al., 2016). Those research projects undertook through U-I collaborative Ph.D. were also devoted to enhance firm's absorptive capacity capabilities (Cohen and Levinthal, 1990; Thune, 2009) and to assess scientific possibilities relevant for the firm technological landscape (Fleming and Sorenson, 2004). Finally, we also found rare evidences of U-I collaborative Ph.D. projects that aimed to develop new knowledge in a very explorative context with high risk of failure. Indeed, Harryson & al. (2007) reported how U-I collaborative Ph.D. projects were managed to address very exploratory projects in a dedicated spin-off companies from a large manufacturer of high-end audio products. Through a college of experts, they were assessing new explorative projects which would have not been considered in more classical new product development ways due to short-termism and timelines oriented of the firm's R&D divisions. In this spin-off, they were selecting a few projects that met both firm's long-term strategy and that encompassed high academic challenges. Harryson & al. (2007) acknowledged how this mechanism favoured innovative new knowledge creation and creativity, leading to exploration of new research areas.

Then, we propose the following taxonomy for U-I collaborative projects research strategy:

PROJECTS R&D STRATEGY	**DEFINITION**
Product / process improvement	U-I collaborative Ph.D. projects dedicated to develop new academic knowledge directly embedded to a pre-existing product or process of the firm.
New competences enhancement	U-I collaborative Ph.D. projects dedicated to develop new academic knowledge that aim to strengthen new competences areas for the firm
New innovation area exploration	U-I collaborative Ph.D. projects dedicated to the development of new knowledge associated to the investigation of new innovation areas with high-level of academic research challenges

Table 2 – U-I Collaborative Ph.D. projects - R&D strategy types

2.4. The shaping U-I collaborative Ph.D. forms – contracting out or collaboration

Many scholars reported that U-I collaborative Ph.D. projects were dedicated to knowledge transfer, mainly from academia to industry. Indeed, firms can access to cutting-edge-scientific knowledge (Grimm, 2018; Lambert, 2003; Schartinger et al., 2006) and Ph.D. students are then considered as "*primary vessels of knowledge transfer*" (Thune, 2009, p. 637). Ph.D. students are then able to develop the relevant skills allowing (1) discussions with the academic community through papers submitted in conferences, journals and informal networking with other researchers and (2) discussions with the practitioner's community through involvement in the company. The students are then translating academic knowledge in a language that the company would be familiar with (Kihlander et al., 2011). Indeed, as they are bridging academic and practitioner communities, scholars named those students either "*agent of change*" (Butcher and Jeffrey, 2007) or "boundary spanner" (Salminen-Karlsson and Wallgren, 2008).

Scholars also reported that a couple of projects where merely devoted to the co-development of new knowledge through more collaborative approaches (ie. beyond a logic of knowledge transfer). As two distinct communities are absorbing knowledge and giving it meaning and value in their own particular ways, the collaborations could favour new original knowledge co-development (Gertner et al., 2011). In particular, the academic partner can benefit from the collaboration through having access to in-depth data regarding the firm and the industry sector or gaining insights regarding issues encountered by the industry. Those can open new research areas (D'Este and Patel, 2007; Gustavsson et al., 2016). Harryson et al. (2007) showed how the high level of commitment between the parties allowed them to explore very new academic and industrial research areas.

We then illustrated in table 3 below the two main collaboration mode types.

COLLABORATION MODES	DEFINITION
Knowledge transfer & absorption	The collaboration is focusing on transferring existing knowledge from one community (most frequently academic) to the other through the Ph.D. student and to develop new knowledge associated to the "adaptation" of the knowledge being transferred to the community.
Knowledge co-development	The collaboration is focusing on transferring and co-developing new knowledge through commitment and high-level interactions between the two communities.

Table 3 – U-I Collaborative Ph.D. projects – Collaboration mode types

3. DEVELOPPING A METHODOLOGY TO EXPLORE U-I COLLABORATIVE Ph.D. PROJECTS MAIN ARCHETYPES:

3.1. A Case study: the "CIFRE" French programme for U-I Collaborative Ph.D.:

In this exploratory study, we relied on an original dataset of U-I collaborative Ph.D. performed through the French programme "CIFRE" supported by the French National Association for Research and Technology (ANRT) on behalf of the French Ministry of Higher Education and Research. The *Industrial Convention for Research Training*[4] (*Convention Industrielle de Formation à la Recherche*, CIFRE) is a State regulated programme that give the ability for a firm[5] relying on French law to hire a Ph.D. student through a research collaboration with a public research laboratory. The 3-year collaboration has to conduct to a Ph.D. dissertation for the Ph.D. student. Through the programme, the ANRT grant a subsidy of 14,000 € for the 3-year duration of the project to the firm that hire the Ph.D. student through a permanent or temporary contract of 36 months (with a minimum wage of 23,484 € / year).

[4] Authors' translation

[5] It can also be an association or a State organization

The Ph.D. student is also registered in a public research laboratory. Finally, the research laboratory and the firm are also committed by a collaboration agreement (ie. a contract) that are negotiated between this two parties and including financial and intellectual property terms. The figure below illustrate the engagement between the parties (Figure 1).

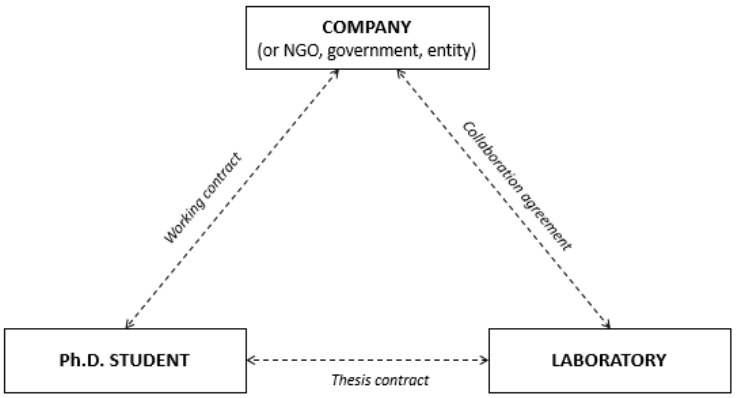

Figure 1 – CIFRE U-I Collaborative Ph.D. scheme

The CIFRE programme was established in 1981 and aims both at (1) strengthening exchanges between public research laboratories and firms, associations and other State organisations and (2) favouring Ph.D. graduates insertion is their professional careers by supporting their professional experiences. 1,450 CIFRE were allocated in 2018 showing the attractiveness for the programme. It represented 9% of financed Ph.D. in France and 6.5% of all the Ph.D. cohort in France in 2017 (Cour des Comptes, 2018). In particular, one key role for ANRT is reviewing that the research project of the U-I collaboration is in adequacy with the established policy and is suitable for a research project undertaken by a Ph.D. student in a 3-year timeframe. In this exploratory study, we had access to an original data set of 90 collaboration contracts between laboratories and firms with their associated research projects.

3.2. Exploitation of U-I collaboration contracts to identify project R&D goals and forms:

The collaborations agreements are not based on a pre-existing templates: laboratories and firms are able to write the contract that suit best their respective needs and goals. We proposed here a dedicated methodology to test and expand our framework regarding U-I collaborative Ph.D.' R&D strategies and knowledge production forms through a sample of collaborations agreement. We relied on the following methodology steps:

STAGES	NAME	CONTENT
1	**Variable identification**	To identify patterns and relevant contents in collaboration agreements (and associated appendixes) giving insights regarding the initial framework for U-I collaborative Ph.D. This phase is performed on a first set of 20 contracts.
2	**Framework validation & enrichment**	To expand the initial framework based on the previous analysis and develop associated coding scheme to each category in order to perform a complete analysis on a larger set of data.
3	**Data set double coding**	To code each collaboration agreements (and associated appendixes) of the data set according to the established coding scheme. Two persons are separately coding the data set to insure coding consistency.
4.	**Descriptive statistics**	The complete data set including the new coding scheme is analysed according to the enrich framework

Table 4 – Methodology stages

4. CIFRE U-I COLLABORATION PH.D. COLLABORATIVE AGREEMENTS ANALYSIS: VARIABLE IDENTIFICATION, FRAMEWORK ENRICHMENT AND CODING:

4.1. Variable identification:

The collaboration agreements between the laboratories and the firms are in many cases composed of (1) the core contract and (2) the appendixes including the scientific & technique appendix and if available the financial appendix. On a first set of 20 collaboration

agreements, we identified the following relevant categories to give insight to our initial framework. Our results are presented in table 5.

COLLABORATION AGREEMENT PART	SUB-SECTION	TYPE OF DATA	DERIVATED DATA FOR THE RESEARCH	INSIGHTS CATEGORIES
Core contract	**Partners profiles**	Company name, address and identification (SIRET)	Type of company (SME / Large firm)	Meta-data (inc. type of company)
		University / School name, address and identification	N/A	Meta-data
		Laboratory name, address and identification	Discipline(s) names # of discipline(s)	Meta-data
	Ph.D. student works	Time spend in the laboratory vs. company facilities	% time spend in the laboratory vs. company facilities	Forms of collaboration
	Intellectual Property	Commercial exploitation of research results / Property of research results	Type of IP contract (Shared / Exclusive)	Forms of collaboration
Scientific & technique appendix	**Summary of research project**	Text (variable length from 1 section up to 10 pages)	Research strategy (Product-Process / New competencies / Exploration)	Research strategy & Forms of collaboration

Table 5 – Categories of analysis

4.2. Framework validation & enrichment:

Based on table 5 we performed robustness checks of our initial framework. Indeed, collected information helped us to test the relevance of the framework. We noted that all categories of the initial framework were covered through the usage of the defined categories. In particular, we choose to refine the collaboration forms category to integrate the fact that in some cases, the Ph.D. student were involve almost exclusively by one party only. We defined this situation as “outsourcing of knowledge development” due to the particular form

of this relationship. In particular, we introduced a double logic: (1) outsourcing when the Ph.D. student is almost exclusively in the laboratory and (3) embedded Ph.D. when the Ph.D. student is almost exclusively in the company facilities.

Following this modification, we were able to define specific criteria for our coding scheme. Criteria, definition and supportive examples are provided in table 6 below.

TYPE	CATEGORIES	CRITERIA	DEFINITION	EXAMPLES[6]
COLLABORATION MODES	**Outsourcing of knowledge development (or embedded Ph.D.)**	- Time spend in laboratory ≤ 10% or ≥ 90%; - and/or exclusivity on the IP rights; - and (or if other elements are not available) elements are confirmed in research project scientific and technique appendix.	The collaboration is focusing on developing new knowledge exclusively by one party only through a research project with implication for the other party.	"*3 – Sharing of the researcher time. The researcher is sharing its time between the company and the laboratory: 66% [name of the firm - anonymised] and 34% [name of the company – anonymised]*" (contract 8314-02) "*5.4.1. [name of the company – anonymised] has an exclusive industrial and commercial exploitation right in its domain on results, new and modified software*" ' (contract 8314-02)
	Knowledge transfer & absorption	- Time spend in laboratory (10% to 90%); - Shared intellectual property rights; - and research project scientific and technique appendix specified that the academic partner possess the core part of the original knowledge that will be transfer & developed through the collaboration.	The collaboration is focusing on transferring existing knowledge from one community (most frequently academic) to the other through the Ph.D. student and to develop new knowledge associated to the "adaptation" of the knowledge being transferred to the community.	*"7.2.1. – Commercial exploitation. The parties have an exclusive direct and indirect exploitation right […]. For direct or indirect exploitation, the party that exploit or that supervised exploitation will give to the other party a remuneration of for which nature and calculus mode will be defined […] by taking in account the quote-part relatively to its contribution*" (contract 00529) "*The Ph.D. employee of the firm will spend 75% of its time in the laboratory and 25% in [name of the company – anonymised]" (contract 00529)*
	Knowledge co-development	- Time spend in laboratory (10% to 90%); - Shared intellectual property rights; - and research project scientific and technique appendix not specified that one party possessed the core initial knowledge, it is broadly shared between the parties.	The collaboration is focusing on transferring and co-developing new knowledge through commitment and high-level interactions between the two communities.	"The Ph.D. student will spend : (1) 33% of its time in laboratory *[name of the laboratory 1 – anonymised], (2) 33% of its time in laboratory [name of the laboratory 2 – anonymised], 33% of its time in company facility [name of the company – anonymised]" (contract 2015-0681)* "*Theoretical study and implementation in real condition of a probabilistic methodology of failure calculus through a couple of real or virtual experiences giving partial information on the studied product*" *(contract 2015-0681)*

[6] Author's translation

Research strategy	**Product / process improvement**	- The product or service that constitute the core scientific project is explicitly cited in project scientific and technique appendix and have already been developed by the industrial partner.	U-I collaborative Ph.D. projects dedicated to develop new academic knowledge directly imbedded to a pre-existing product or process of the firm.	"*The objective of this research work included in this CIFRE thesis is to identify with an high degree of certainty a user in a distance teaching platform to deliver the required course certification […] this approach will be developed and adapted for the platform already developed by [name of the company – anonymised]" (contract 2015-1126)*
	New competences enhancement	- There is an identified and unique discipline involve in the project ; - The literature review of the scientific and technique appendix is dedicated to a clear, detailed and precise research question based on a particular and existing discipline.	U-I collaborative Ph.D. projects dedicated to develop new academic knowledge that aim to strengthen new competences areas for the firm	"*Consequently, to design a fast access protocol capable of dynamically switch from MAC relay to […] appears as a high level technical challenge*" "*This protocol need to be integrated in the existing ecosystem with a minimum of changes implications in the other well studied and established layers. Then, this Ph.D. thesis will include a practical dimension that constitute to the testing of this protocol in real conditions* […]." (contract 2015-0816)
	New innovation area exploration	- The project is explicitly cited as "high-risk" or "very theoretical" or "exploratory" ; - and/or it is a transdisciplinary research project ; - and/or more than one is laboratory involved	U-I collaborative Ph.D. projects dedicated to the development of new knowledge associated to the investigation of new innovation areas with high-level of academic research challenges	"*Theoretical study and implementation in real condition of a probabilistic methodology of failure calculus through a couple of real or virtual experiences giving partial information on the studied product*" "*In order to do the planned works, our approach is considering the data as random, inaccessible or fluctuant*". (contract 2015-0681)

Table 5 – Categories of analysis

4.3. Coding a complete data set of 90 collaborative agreements:

We performed the coding scheme on a complete dataset of 90 collaboration agreements. Each contract was double coded by two authors of the research team to ensure consistency of the data. When authors got different results in terms of R&D Strategy and Collaboration mode, each contract was checked conjointly by the two authors in order to define the adequate code according to the defined coding scheme.

Due to the fact that there is not any common template for the parties to enforce collaboration agreement and because some agreement terms referred to not available framework agreement between laboratories and the company, some pieces of information were missing. Finally, only 78 (ie. 87% of the original dataset) were successfully coded.

5. EXPLORATORY RESULTS:

5.1. Descriptive statistics:

The studied sample of 78 collaborative agreements were mainly covering projects in engineering sciences (47%) – including mechanical science, material sciences, etc. – and computer sciences (26%) as well as author disciplines for which details are available in Appendix. The sample is containing large firm (58%) and SMEs (40%) and one case of governmental organisation. More details regarding the composition of the dataset are available in the Appendix.

According to our analysis on this case study, co-development is the mainly used collaboration mode by the parties for their U-I collaborative Ph.D. research projects (table 7). It was including almost half of the projects in the sample (ie. 48.7% of cases). Furthermore, outsourcing situations for which the research works were mainly performed in the university

facilities by the Ph.D. student and the academic supervisor's team, were the second most common mode of collaboration (ie. 26.9% of cases). Transfer & absorptive capacity and embedded Ph.D. were the least common modes of collaboration with respectively a share of 14.1% and 10.3% of the projects' sample.

	Co-development	Embedded Ph.D.	Outsourcing	Transfer & absorptive capacity	***Total***
Collaboration mode	38 48.7 %	8 10.3 %	21 26.9 %	11 14.1 %	78 100 %

Table 7 – Collaboration mode

According to our analyses regarding the R&D strategy associated to the U-I collaborative Ph.D. projects (table 8), around half of them were focusing on enhancing a new competence in an identified and existing research fields with research interests for both the firm and the academic partner (ie. 52.6%). Nevertheless, it has to be highlighted that there is still an important part of highly innovative and explorative projects (21.8%) as well as projects focusing on tangible product or services already defined by the company before the beginning of the U-I collaborative Ph.D. (ie. 25.6%).

	New competences enhancement	New innovation area exploration	Product / process improvement	***Total***
R&D strategy	41 52.6 %	17 21.8 %	20 25.6 %	78 100 %

Table 8 – R&D strategy

It has also to be noted that the respective share of SMEs and large firms for each of the two variables (R&D strategy and collaboration mode) do not seem to show significant

divergence at this stage (see. Appendix for more details). Nevertheless, the size of the sample would need to be improve through additional projects investigations to satisfy statistical robustness checks on the company size effects.

5.2. Identification of U-I collaborative Ph.D. archetypes:

We performed a cross-analysis of the two variables: R&D strategy and Collaboration Mode. Results are available in table 9. Adequate statistical tests were performed in order to insure results consistency.

R&D Strategy	*Collaboration Mode*				***Total***
	Co-development	Embedded Ph.D.	Outsourcing	Transfer & absorptive capacity	
New competences enhancement	21 26.9 %	2 2.6 %	9 11.5 %	9 11.5 %	41 52.5 %
New innovation area exploration	14 17.9 %	0 0 %	2 2.6 %	1 1.3 %	17 21.8 %
Product / process improvement	3 3.8 %	6 7.7 %	10 12.8 %	1 1.3 %	20 25.6 %
Total	38 48.7 %	8 10.3 %	21 26.9 %	11 14.1 %	78 100 %

$\chi^2=28.733 \cdot df=6 \cdot$ *Fisher's p=0.000*

Table 9 – R&D strategy & collaboration mode

We showed that there are archetypes of research strategy and collaboration modes in the context of U-I collaborative Ph.D. research projects:

- When parties were collaborating in order to improve an already existing product or process in the company through the research project, in many cases the industrial partner were either outsourcing the problem solving to the university facilities

(**archetype 1**) or favoured the presence of the Ph.D. student almost full time in its facilities (**archetype 2**);

- When parties were collaborating to develop new identified competences through the improvement of the associated scientific state-of-the-art, the collaboration were mainly based on co-developing the scientific and industrial content of the R&D project between the two parties (**archetype 3**). Outsourcing or transfer were also utilized somehow by the parties to perform those tasks ;
- When parties were collaborating in order to investigate new high-end exploratory scientific fields, they were using almost exclusively a co-development mode (**archetype 4**).

6. DISCUSSIONS:

In this paper, we asked what would be the different archetypes of U-I collaborative Ph.D. in terms of R&D contribution and in what extent firms and universities contributed to new knowledge co-development and unknown exploration through those programmes. We developed here an exploratory methodology to define (1) what would be the R&D strategy pursued by firms and academics in U-I collaborative Ph.D. and (2) what would be their collaborations modes. It appears that four main archetypes emerged through our exploratory analysis regarding a sample of 78 collaborative agreements. We discussed here their logic and implications.

If the project was focusing on performing problem-solving tasks, the parties mainly agreed that it would be performed by one party only – either academic (archetype 1) or firm (archetype 2) – with limited direct interactions between them during the project. It has to be highlighted that those two archetypes only represent 20.5% of the projects in our sample and

it contrast with previous analyses. Indeed, some studies predicted that those projects would represent the most part of U-I collaborative Ph.D. due to the fact that (1) firms would have more bargaining power to influence the relationship toward their product development (Assbring and Nuur, 2017; Slaughter and Campbell, 2002) or (2) due to cultural differences between what each party is calling "research" (Bruneel et al., 2010; Malfroy, 2011). It has to be emphasised that due to the review process of R&D projects submitted at the ANRT to apply for U-I collaborative Ph.D. agreements, only high-level scientific projects suitable for a Ph.D. student 3-year contract would be validated[7]. Indeed, each proposal is reviewed regarding (1) the capacity of the firm to accompany the scientific training of the Ph.D. student and its financial robustness to perform the planned works and (2) the scientific quality of the research project through the engagement of the parties and their adequacy to perform the dedicated project. Those elements could help to explain why archetypes 1 & 2 are not highly represented in the sample as only problem-solving oriented projects without challenging scientific implications would have not been satisfying CIFRE agreement criteria. Then archetypes 1 & 2 would then encompassed projects for which the parties could justify that one of the party perform a major part of the works. Further investigations are needed to dig into those situations but it could be notably explained by the possession of costly required scientific or technical materials by one of the party or by the fact that a PoC testing or a product validation would face very high-level scientific challenges.

The third archetype of collaboration was focusing on projects aiming at developing a new identified competences with technical and scientific implications for both parties, through a co-development mode. This archetype represented 26.9% of the U-I collaborative

[7] Cf. ANRT website for the dedicated procedure.

Ph.D. in our sample: this high magnitude is aligned with Thune and Børing (2015) and Gustavsson et al. (2016) findings regarding U-I collaborative Ph.D. objectives. In those cases, partners were developing and/or transferring new knowledge related to an already existing research discipline for which the laboratory is experienced and the knowledge is relevant regarding firm's industrial challenges. In order to perform those tasks, co-development of the knowledge is required to insure that the knowledge would benefit to both parties. Finally, archetype 4 concerned research projects that aim at exploring new scientific fields with high level of unknown and for which the works were performed through the co-development of new knowledge by the parties. This archetype represented 17.9% of the projects while to our knowledge, previous studies have not mentioned this type of projects in U-I collaborative Ph.D. contexts with the only exception of a case study reported by Harryson et al. (2007) in the audio industry. The fact that an highly explorative strategy were associated with a co-development scheme has nevertheless been documented in the literature on U-I collaborations (Cassiman et al., 2010; Vega-Jurado et al., 2017)

As a result, it appears in this exploratory study that U-I collaborative Ph.D. research projects performed through the French CIFRE scheme were mainly based on the co-development of new knowledge related to industrial challenges that mainly go beyond a simple problem solving logic regarding the firm's products or services. Indeed, those projects were mainly shaped following a logic of double – impact (Plantec et al., 2019): co-developing knowledge related to high-end scientific challenges in existing or new disciplines and in a same timeframe, supporting firm's innovation capacity through an increase of unknown exploration capacity. It has to be highlighted that the high level of commitment between the parties in U-I collaboration that is required to co-develop new knowledge has been reported in the

literature as a rare case due to a couple of cultural and institutional barriers (Antonioli et al., 2017; Bruneel et al., 2010; Galán-Muros and Plewa, 2016; Santoro and Bierly, 2006). In particular, McCabe et al. (2016) built a taxonomy of U-I partnerships: “deep collaborations” referred to situations for which the industrial partner is involved in both practical and analytical aspects of research activities along with the academic partner. This type of collaboration echoes in particular archetypes 3 & 4. Authors, through a qualitative study in Australia, demonstrated that usually “*there is a celling to coproduction of knowledge*” (McCabe et al., 2016, p. 23) due to lack of joint decision making regarding the scientific content of the project. It can be explained by a lack of legitimization of the industrial partner to participate in those decisions. In the French CIFRE case and through our limited and exploratory sample, the surprisingly high share of archetypes 3 & 4 would constitute a support for further research on what would be the institutional conditions that favour this situation. In particular, a couple of mechanisms could be deeper analysed. First, the fact that the CIFRE programs favoured previous discussions between the academic and the industrial partner before the application for U-I collaborative agreement to the ANRT with a dedicated focus on the research projects that has to be written and validated by the partners. In particular, it could favour co-production mode due to the fact that research programs are build “with” the industrial partner and not “for (Van de Ven, 2007, 2018). Second, the fact that the ANRT is reviewing the consistency of the research projects from the academic side through a blinded review with another academic specialised in the discipline support projects with high scientific challenges. Third, the fact that parties are engaged in a 3-years projects could avoid short-termism more associated with problem-solving on firm’s new product developments.

Nevertheless, some limits of this exploratory study would also have to be overcome by further research in order to deeper investigate those elements. First, there is a need for an increase of the research projects included in the sample in order to increase robustness of the statistical analysis, more granular investigations of particular elements (eg. amount of the financial transfer regarding the type of collaboration mode or strategy, IP strategy, etc.) and analysis of the differences between SMEs and large firms that seem for instance to give unintended results in terms of the very close behaviour between those two types of firms. Second, the developed methodology could benefit to further improvement in particular in order to extent exploitation possibility with other U-I collaborative Ph.D. programs such as those in Denmark, Germany or England or even U-I collaboration. Third, those archetypes were built based on the U-I collaborative Ph.D. collaboration agreements between the laboratory and the firm which constitute a situation *a priori* of the collaboration. Investigations would be needed to insure that the willingness of the collaboration that is reported in those contracts are representing adequately the situation *a posteriori*. Four, further study would considered cross-checked those elements with other databases in order to review the impact of each archetype for example in terms of number of published academic publications and associated ranking or innovativeness or patent databases in order to assess technological impact.

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9. APPENDIX:

9.1. Scientific disciplines included in the sample:

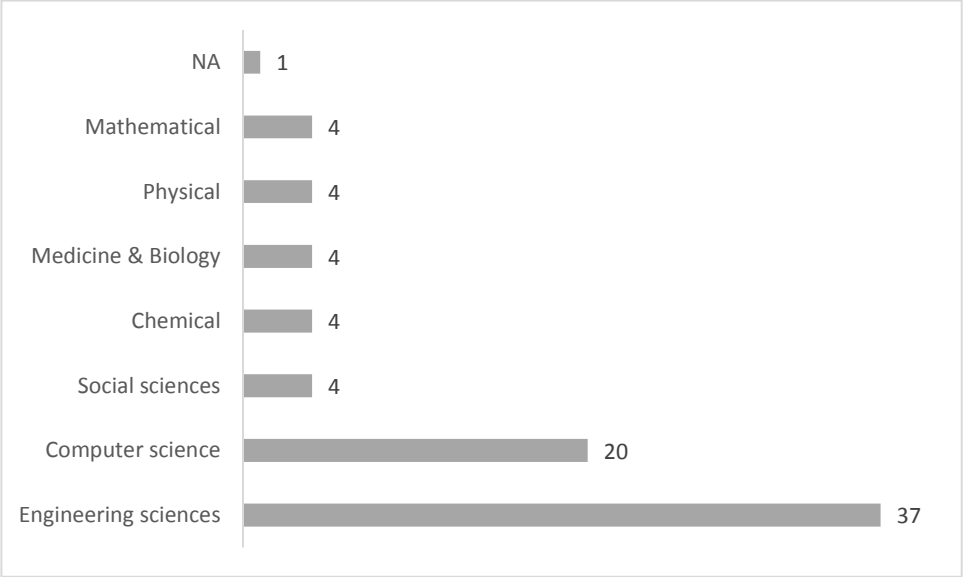

Figure 2 – Scientific disciplines of the U-I Collaborative Ph.D. projects in the sample.

9.2. Type of firms & collaboration mode:

Company type	*Collaboration Mode*				***Total***
	Co-development	Embedded Ph.D.	Outsourcing	Transfer & absorptive capacity	
Government	1 100 %	0 0 %	0 0 %	0 0 %	1 100 %
Large firm	23 50 %	6 13 %	11 23.9 %	6 13 %	46 100 %
SME	14 45.2 %	2 6.5 %	10 32.3 %	5 16.1 %	31 100 %
Total	38 48.7 %	8 10.3 %	21 26.9 %	11 14.1 %	78 100 %

χ^2=2.544 · df=6 · Fisher's p=0.851

Table 10 – Type of firms and collaboration modes

9.3. Type of firms & R&D strategy:

Company type	*Collaboration Mode*			***Total***
	Discipline	Exploration	Product	
Government	1 100 %	0 0 %	0 0 %	1 100 %
Large firm	27 58.7 %	11 23.9 %	8 17.4 %	46 100 %
SME	13 41.9 %	6 19.4 %	12 38.7 %	31 100 %
Total	41 52.6 %	17 21.8 %	20 25.6 %	78 100 %

χ^2=5.363 · df=4 · Fisher's p=0.194

Table 11 – Type of firms and R&D strategy