What about the people?
Micro-foundations of open innovation in megaprojects

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Abstract

Megaprojects require substantial R&D activities involving many different organisations. Megaprojects are therefore an ideal setting for Open Innovation (OI), which favours risk-sharing, enables trustful collaboration, and facilitates the development of breakthrough innovations. OI has been widely studied at the organisational level, however far less attention has been paid at the individual level, including the motivations, costs and benefits perceived by the people involved in the innovation process. This paper aims to address this gap by studying the micro-foundations of OI in megaprojects and focusing on the experiences of people involved in university-industry co-supervised PhD projects. The paper provides two original contributions. Firstly, it contributes to the micro-foundations literature, by analysing the experience of university and industrial supervisors and PhD students involved in megaprojects. Secondly, it expands the OI literature by describing how the interpersonal interactions and the intentional knowledge spillovers promote innovation outside the original boundaries of the PhD project.

Keywords: Megaproject; Open Innovation; University-Industry; Micro-foundations; Cost-benefit;

Highlights

- The wide project network of megaprojects is an ideal setting for open innovation (OI)
- OI literature has focused on the organisational level, neglecting the experience of the people involved
- We study the micro-foundations underpinning university-industry collaboration in megaprojects
- We characterise the enabling/hindering factors of micro-foundations
- We investigate whether the personal benefits outweigh the costs in such collaborations

1 Introduction

Megaprojects are unique complex systems or infrastructure requiring substantial innovation during their planning, design, and delivery (Davies et al., 2009; van Marrewijk et al., 2008). Megaprojects are not only complex in technical terms but also in organisational ones, since they require large groups of organisations to coordinate their competencies and efforts to solve a complex problem and/or deliver a complex artefact (Merrow and Nandurdikar, 2018). The large project network, characterising innovation-development in megaprojects, makes an ideal setting to research open innovation (OI), a paradigm defined as "*a distributed innovation process based on purposively managed knowledge flows across organizational boundaries*" (Chesbrough and Bogers, 2014, p. 12) that focuses on innovation-oriented inter-organisational collaboration.

Even though the OI paradigm is in its maturity, its application in megaprojects has been scarcely studied. Indeed, according to an enquiry on Scopus in February 2020[1], only three journal articles deal with OI and megaprojects, and only one (Worsnop et al., 2016) explicitly takes a project management perspective. Wornshop et al. (2016) show that the length, complexity, and availability of financial and human resources unlock specific forms of OI practices for megaprojects that would not be implementable in regular projects. For example, the design and delivery of a primary school (a regular project) usually lasts a few months/years, its project delivery organisation is relatively simple, and there is little scope for innovation since technologies are available off-the-shelf and design and construction are composed of standard activities for contractors. On the contrary, the design of a new aircraft (a megaproject) can take decades and requires substantial R&D in several different scientific disciplines. A plethora of heterogeneous organisations (private firms, research laboratories, universities, etc.) are involved over a megaproject life cycle and share knowledge, information, and resources.

In the context of OI in megaprojects, a key role is played by the collaborations between industry and university (Davies et al., 2014). Complementarities in equipment and experience (Messeni Petruzzelli, 2011), along with the cutting-edge know-how owned by the universities, make these collaborations particularly attractive to challenges requiring novel approaches (Belderbos et al., 2004; Hyll and Pippel, 2016; Lasagni, 2012). University-industry collaborations have drawn much interest in the OI literature focusing on technology transfer, intellectual property issues, commercialisation, performance, enablers and barriers at the organisational level (Ankrah and Al-Tabbaa, 2015; Mascarenhas et al., 2018; Perkmann et al., 2013). Remarkably, there is a paucity of studies looking at the individual level, i.e. studying the people involved in these collaborations and their experience, including their personal benefits, costs and motivations. The micro-foundational perspective offers a lens to study collaborations at the individual-level (Bogers et al., 2018).

[1] Query: (TITLE-ABS-KEY ("Open Innovation") AND TITLE-ABS-KEY ("mega project" OR "megaprojects" OR "large project" OR "major project")). The papers are (Mechant et al., 2012; Wognum et al., 2018; Worsnop et al., 2016)

The micro-foundations literature speculates that macro-concepts and macro-outcomes, (e.g. firm-level capabilities, performance, and strategies) need to be understood in terms of the underlying actions, interactions, and characteristics of micro-level entities (e.g., individuals) (Contractor et al., 2019). Notably, it is not only a matter of studying a phenomenon at the individual level, but also of understanding "*the unique, interactional, and collective effects that are not only additive but also emergent*" (Barney and Felin, 2013, p. 4). A micro-foundational perspective is ideal to study university-industry collaborations (Al-Tabbaa and Ankrah, 2019), which usually involves person-to-person interactions (Perkmann et al., 2013) and recently received attention in project studies (Bredillet et al., 2018). In social science journals in general and management journals in particular, more and more papers take a micro-foundations perspective. However, this perspective is vastly ignored in project studies, with the article by Bredillet et al. (2018) being a notable exception. Remarkably, project studies have a long history of analysing projects and megaprojects through an organisational perspective, but being projects delivered by people, the micro-foundations perspective is also relevant for the advancement of project studies.

This paper deals with two tightly linked gaps in the body of knowledge: firstly, OI is under-researched in megaprojects and, secondly, the vast majority of research in OI is focused at the organisational level rather than at the individual level, consequently often neglecting the roles, motivations, and outcomes of the people involved in those organisations. Therefore, the aim of the paper is studying the micro-foundations of OI in megaprojects focusing on the people experiences in university-industry collaborations. More specifically, the following research questions are addressed:

RQ1 Which micro-foundations underpin university-industry collaborations in megaprojects?

RQ2 To what extent are personal costs balanced by personal benefits for the people involved in university-industry collaborations in megaprojects?

RQ3 Which factors enable or hinder the micro-foundations of university-industry collaborations in megaprojects?

To address the three research questions, this article analyses university-industry co-supervised PhD projects dealing with the decommissioning of the nuclear infrastructure in the UK. Decommissioning projects and megaprojects involve substantial R&D and bring together a plethora of different stakeholders. The article takes the experiences, at an 'individual level', of industrial supervisors, academic supervisors, and PhD students involved in co-supervised PhD projects as the unit of analysis. Leveraging PhD programmes such as the UK "Centre for Doctoral Training" (CDT) and the PhD projects sponsored by the UK "Nuclear Decommissioning Authority" (NDA), people collaborate on PhD projects according to the OI paradigm. Such PhD projects are exemplary of "OI" even though they have not been characterised by this terminology (or recognised as such) by the stakeholders involved. The three research questions enable the identification of patterns and practices that can be useful to promote OI in megaprojects in different sectors.

2 Literature review

The literature review is organised as a conceptual funnel. Starting from the wider perspective of megaprojects and innovation in megaprojects (Subsection 2.1), the review then focuses on the relevance of OI as an enabler of innovation (Subsection 2.2), then 'funnels down' to the peculiar characteristics of OI in university-industry collaborations (Subsection 2.3). The latter sub-section also explains how PhD projects can catalyse the collaboration between university and industry and lower the existing barriers.

2.1 Megaprojects

Megaprojects are *"temporary endeavours (i.e. projects) characterized by: large investment commitment, vast complexity […], and long-lasting impact on the economy, the environment, and society"* (Brookes and Locatelli, 2015, p. 58). There is an intrinsic complexity in planning and delivering megaprojects. Levitt et al. (2017) defined the complexity of the project in terms of difficulty, result, variability, non-linearity and non-governability of the project. Baccarini (1996) and Bakhshi et al. (2016) referred to the organisational complexity. More holistically, according to Merrow and Nandurdikar (Merrow and Nandurdikar, 2018) complexity has three dimensions: scope, organisation, and shaping.

Examples of megaprojects include space missions, building nuclear reactors, finding a cure for deadly diseases, etc. All these megaprojects require innovation from both a "what is it delivered" perspective (the hard science point of view that entails the technological challenges), and from a "how is it delivered" perspective (the social science point of view that studies the impact on stakeholders) (Aaltonen et al., 2019; Davies et al., 2014; He et al., 2019). The delivery of megaprojects requires a substantial amount of R&D from a technical and managerial perspective (Levitt and Scott, 2017). Indeed, the planning and delivery of megaprojects face several challenges: Boateng et al. (2015) underlined the tendency to make rough estimates; Brookes et al. (Brookes et al., 2017) discussed the tensions created by the long-time involved in planning and delivering megaprojects, other authors (Eweje et al., 2012; Invernizzi et al., 2017; Wang et al., 2017) dealt with the impact of the social responsibility of megaprojects.

Davies et al. (2015) seminal work on innovation in megaprojects proposed that the systematic management of the innovation process could improve the performance in planning and delivering megaprojects. Innovation in a megaproject can be driven by ideas, learning, and practices from other projects and industries. The client can use the contractual processes to encourage contractors and suppliers to develop new ideas and innovative solutions (Davies et al., 2009). Scholars also investigated how to integrate innovation in megaprojects (DeBarro et al., 2014), the learning process across megaprojects (Brady et al., 2014), and the risks and the uncertainties associated with innovation itself (Jussila et al., 2016; Locatelli and Mancini, 2010).

There is a growing awareness of innovation in megaprojects in the literature and in the last few years, scholars have investigated salient aspects of the topic. Sergeeva and Zanello (2018) looked at the role of innovation champions in leading and promoting innovation in megaprojects; Lehtinen et al. (2019) investigated how actors, fostering long-term innovations, lead to value creation in megaprojects; while Rottner (2019) leveraged a NASA megaproject to study how institutional, organisational and occupational boundaries relate to innovation. Despite this growing body of literature, the point made by DeBarro et al. (2015) is valid today: the literature does not establish a systematic strategy to generate and manage innovation in megaprojects. There is an incentive to create innovation-oriented partnerships with the main suppliers, users, universities, institutions and other stakeholders, providing new products and services on time and in the budget (Davies et al., 2016). This observation underlines the importance of combining the OI paradigm to the project management practices to reduce the uncertainties and to manage the risks associated with a megaproject (Lakemond et al., 2016).

2.2 Open Innovation

The OI paradigm describes the phenomenon according to which firms increasingly draw ideas, knowledge and competencies from outside their organisational boundaries, and use their own capabilities to purposely support external organisations and draw benefit from this (Chesbrough, 2003). OI leverages the theory of absorptive capacity, which is defined as the capability to acquire, assimilate, transform and exploit external knowledge (Cohen and Levinthal, 1990). Absorptive capacity is critical to draw benefit from others' know-how and enhance the focal organisation's innovation capabilities and performance (West and Bogers, 2014). Absorptive capacity can be characterised in terms of two distinct sub-capacities: the 'search' (or 'scan') capacity, which describes the capability to find the most useful external sources of knowledge among the many available; and the 'integrative' capacity, which describes the capability to incorporate the knowledge coming from external partners into the internal innovation process (Ahn et al., 2016; Arbussà and Coenders, 2007). Ahn et al. 2016) found that firms' openness (i.e. a measure of propensity to collaborate and share) positively influences both their search and their integrative capacities, which, in turn, positively influence their performance. In turn, as observed by Fosfuri and Tribo (2008), absorptive capacity improves as an organisation becomes more experienced in R&D collaborations.

Such collaborations can involve different types of stakeholders (e.g. users, suppliers, universities, competitors, etc.) having specific cultural characteristics, peculiar processes, often different goals and interests. On the one hand, such differences can promote fruitful complementarities; on the other hand, they expose the collaborating organisations to challenging interactions, which may achieve unsatisfactory results (Brunswicker and Chesbrough, 2018; Chesbrough and Brunswicker, 2014; Tucci et al., 2016). The OI literature has thoroughly examined the characteristics of collaborations with specific partner categories, such as users (Baldwin and von Hippel, 2011; Keinz et al., 2012), suppliers (Wynstra et al., 2001), competitors (Ritala, 2012), and universities (Segarra-Blasco and Arauzo-Carod, 2008). Users can leverage their experience with the focal firm's products and services, contributing to their innovation activities (Keinz et al., 2012). Suppliers may contribute to cut development costs and increase product value (Wynstra et al., 2001). Competitors can participate in the implementation of new technological standards in the market (Dahlander and Gann, 2010). Universities' cutting-edge knowledge makes them particularly important partners when the focal firm aims to develop a radical innovation (Belderbos et al., 2004; Hyll and Pippel, 2016; Lasagni, 2012).

Even though the OI literature has traditionally focused on organisation-level analysis, recent studies have been starting to address the OI "human side" (Ahn et al., 2017; Al-Tabbaa and Ankrah, 2019; Bogers et al., 2018; Ryan et al., 2018), which comprises the individual-level factors that enable OI. The study of such individual-level factors takes the lead from the micro-foundations movement that "unpacks" collective concepts by determining their proximate causes or explaining their outcomes at a lower level than the phenomenon (Felin et al., 2015). The university-industry collaboration has been among the first to be investigated from an individual-perspective, even if studies in the project management setting are recent and limited, with the notable exception of (Barnes et al., 2006). Perkmann et al. (2013) collected and organised previous studies to offer an overall perspective on the individual, organisational, and institutional factors fostering academic engagement and commercialisation. The next subsection describes the characteristics of university-industry collaboration and of the individual-level factors underlying it.

2.3 University-industry collaboration

Globalised competition and technological challenges induce firms to search for radical innovations that could support them in gaining competitive advantage. As observed by Felin and Zenger (2014), while the solution of relatively simple problems can be researched by independent actors, complex and ill-structured problems, require the building of theories describing the interaction between the various design choices. Sometimes the organisation, whose purpose it is to address such a complex and ill-structured problem, may lack the competencies to identify a theory underlying the phenomenon and need the support of theory-building organisations, such as universities. Furthermore, universities may provide firms with a perspective on cutting-edge technology and guide them to adopt or adapt it to their needs. Therefore, universities are increasingly engaged in collaboration activities with industry (Ankrah and Al-Tabbaa, 2015; Guerrero et al., 2019) that aim to develop innovation and create wealth (D'Este and Patel, 2007) and create one of the most popular and effective types of OI (Greco et al., 2015). In many cases, university-industry collaborations are funded or even triggered and coordinated externally, for instance in the case of publicly-funded joint research projects that favour technology transfer and tackle societal challenges (Al-Tabbaa and Ankrah, 2019).

Universities draw multiple benefits from such collaborations, including obtaining access to alternative sources of funding, research ideas from industrial environments, field-testing, and practical application of their research (Ankrah et al., 2013; Ankrah and Al-Tabbaa, 2015; Franco and Haase, 2015; Guimón, 2013). In turn, firms collaborating with universities can compensate for the limits of their in-house R&D, benefit from university-based technologies, access public funding and incentives, gain access to university facilities and complementary know-how, and facilitate the recruitment of skilled human resources (Ankrah and Al-Tabbaa, 2015; Guimón, 2013; Lee, 2000; Perkmann and Walsh, 2007).

Universities and firms can collaborate formally and/or informally (Striukova and Rayna, 2015). They may pursue joint research projects, sign agreements for the licensing of intellectual property, promote human mobility and training programs, participate in expert groups, etc. University-industry collaborations can have a short-term nature, as in the case of contract research, patenting and licensing agreements, or a long-term nature, which may determine the establishment of focused structures such as university-industry consortia, research parks, and incubation centres (Guimón, 2013). Fabrizio (Fabrizio, 2009) observed that the "*enhanced access to university research enjoyed by firms that engage in basic research and collaborate with university scientists leads to a superior search for new inventions and provides advantages in terms of both the timing and quality of search outcomes*" (p. 1). According to Koschatzky and Stahlecker (2010), longer-term collaborations are more strategic and open-ended, and may, therefore, have more innovative outcomes. In turn, Perkmann and Walsh (2007) suggested that, under the OI paradigm, the interactions between university and industry have become relationship-intensive rather than casual or short-term. Messeni Petruzzelli (Messeni Petruzzelli, 2011) observed that the existence of complementary technological competencies and long-lasting relationships between university and industry are important success drivers of the collaboration.

Too often, universities, industries and policymakers do not fully exploit the synergies that could arise by working together. Universities are sometimes branded as "ivory towers" uninterested in the practical implications of their research activities, but a growing number of "entrepreneurial scientists" are challenging this view by collaborating closely with practitioners (Lam, 2010). In turn, practitioners may ignore the latest developments in science and end up re-inventing the wheel or repeating the same mistakes. The causes of misalignments between academics and practitioners include cultural differences, the issue of intellectual property protection, and the different incentives in disseminating the research results (Ankrah and Al-Tabbaa, 2015; Vick and Robertson, 2018), which can hinder the collaboration between them (Muscio and Vallanti, 2014) and which may be addressed by nurturing trust (Bruneel et al., 2010). However, while extensive research has been conducted on the outcomes and hindering factors of university-industry collaborations, the study of the relationships between the individuals involved in such collaborations has been underdeveloped in literature. Very recently, micro-foundations studies have started to address this gap in literature, researching on the individual-level drivers of technology transfer (Al-Tabbaa and Ankrah, 2019), of firms' capability for explorative innovation (Ryan et al., 2018), and of academic engagement and commercialisation (Perkmann et al., 2013), while Tartari and Breschi (2012) observed that the fear of losing academic freedom was the most relevant hindering factor for university-industry collaborations.

One particular type of university-industry collaboration is suitable to study the micro-foundations underlying it: co-supervised PhD projects. Indeed, the sponsoring and joint supervision of PhD project is gaining momentum and connecting universities with other organisations (Thune, 2010). The term "industry", in this paper, is intended with an extensive meaning to include organisations such as private companies, non-departmental public bodies, government-owned entities etc. A co-supervised PhD student has both an academic and an industrial supervisor, closely linking researches with the engaged company (Kihlander et al., 2011). PhD projects with an industrial involvement pull the academic and industrial supervisors out of their comfort zone and encourage them to appreciate their counterparts' perspective while lowering organisational and cultural barriers (Kunttu et al., 2018). Indeed, PhD students are key developers of knowledge and innovation in collaborative research projects (Thune, 2009). The academic supervisor has the overall responsibility for the PhD student, while the industrial supervisor meets the PhD student and supports his/her learning and personal development (Sundström et al., 2016). PhD students can support the collaboration between university and industry, reducing the uncertainties in innovative activities, encouraging knowledge transfer and therefore creating a base for collaborations. Therefore, PhD students are positioned to mediate between stakeholders, balancing their expectations (Kitagawa, 2014). Perkmann and Walsh (Perkmann and Walsh, 2007) argued that inter-organisational relationships could benefit from human mobility, and exemplified the case of firms sponsoring PhD project. Megaprojects, in particular, are an ideal setting for a study because their complexity and challenges to develop new ideas, technologies, and organisational practices (Davies et al., 2014), require new skills and management techniques (Levitt and Scott, 2016).

3 Method

This section describes the methodology adopted to achieve the research aim of the article. Subsection 3.1, describes the context of the study; Subsection 3.2, presents the unit of analysis; Subsection 3.3, discusses the data collection; while Subsection 3.4 explains the data analysis.

3.1 Research context: innovation in decommissioning megaprojects

Decommissioning megaprojects are novel, complex, time-consuming, and expensive projects requiring substantial innovation. While humans have accumulated thousands of years of experience in the construction of large complex infrastructure (ranging from the Egyptians pyramids, Roman aqueducts, and gothic cathedrals) the decommissioning of infrastructure is a problem that is becoming more important. Over the last few decades, with the end of life of nuclear reactors, oil rigs, and chemical plants, the challenges of dealing with dismantling an infrastructure, managing the waste, and restoring the environment have emerged. These new challenges call for the development of new technologies (e.g. robots to manipulate toxic waste), processes (e.g. to safely store nuclear waste) and even novel ways to engage people, e.g. to deal with the loss of jobs coming from closing a facility (Invernizzi et al., 2017). Decommissioning megaprojects are therefore an ideal setting for studying innovation. In nuclear decommissioning projects, the traditional challenges of megaprojects are exacerbated, prompting the need to innovate, as presented in Table 1.

Table 1 also links innovation challenges with the stakeholders that need to collaborate to deliver nuclear decommissioning megaprojects and programmes successfully. In particular, the paper is set in the context of UK nuclear decommissioning, influencing factors being the availability of information (secondary data and the possibility to collect primary data) and both the relevance and the number of megaprojects in the sector. The best way to understand the scale and complexity of UK nuclear-decommissioning megaprojects is to refer to the official declaration of the UK government on its official website (GOV.UK, 2019) *"The 2019 forecast is that future clean-up across the UK will cost around £124 billion spread across the next 120 years[…] Based on the best data now available, different assumptions could produce figures somewhere between […] £99 billion and £232 billion."* In the UK, 17 nuclear sites are owned by the NDA, a non-departmental public body, responsible for cleaning up these sites "*safely, securely and cost-effectively with care for people and the environment*". Among these sites, Sellafield accounts for 75.6% of the entire budget (GOV.UK, 2019). The Sellafield site includes five nuclear reactors, nuclear fuel storage ponds and waste silos, nuclear fuel fabrication and reprocessing plants, and a fleet of nuclear waste storage facilities.

Altogether, the relevance of the decommissioning field, the availability of information and the familiarity of the authors with the field, makes the UK nuclear decommissioning megaprojects an ideal context for the research.

Common challenges in Megaprojects	Example of specific challenges in nuclear decommissioning megaprojects	Typical innovation required in nuclear decommissioning megaprojects	Relevant stakeholders involved in the innovation process
Development of new technologies and processes (e.g. space missions, new drugs, new high-speed ICT technology, etc.).	Safe management of radioactive and toxic materials arising from decommissioning. Environmental challenges, which arise when attempting to restore the site to its previous condition.	Development of new technologies and processes to deal with the unique chemical and physical nature of radioactive waste. Test the safety and security of these new processes and develop operative guidelines for application on the site.	Regulation experts and site managers who typically have a hard science background. Scientists dealing with "hard science" such as chemistry or physics. Highly specialised workforce in public and private laboratories. PhD students whose research focuses on hard scientific challenges, such as the development of a new process to deal with a certain type of waste.
Dealing with complex economics, financing and management (e.g. to raise billions of USD to fund the construction of a single infrastructure, the management of a complex and international project network, etc.).	Project management, economic and financial challenges, that arise since decommissioning costs are in the order of billions of USD and keep increasing, while often insufficient provision was made for decommissioning and waste management.	Development of new algorithms for project cost estimation. Identification of success factors in the planning and delivery of these projects. Definition of new funding strategies and criteria for funding allocation/prioritisation of projects.	Operation managers and project managers for both customer organisations (site owners and licensees) and contractors. Management consultancy companies. Scientists dealing with social science (e.g. project management academics). PhD students whose research focuses on social science challenges, such as the development of a new benchmarking process or an algorithm for cost estimation.
Dealing with difficult sociological and ethical decisions (e.g. the displacement of people caused by a new dam, the development of the atomic bomb, etc.)	Social and ethical challenges, which arise from a decommissioning workforce working themselves out of a job and local communities losing a major employer. Current and future generations having to bear the cost of decommissioning, while the benefits provided by the infrastructure were exploited by past generations.	Development of tools and guidelines to manage the early retirement of the nuclear workforce. Development of business models to provide jobs for the local community. Development of a communication strategy to engage and gain the support of internal and external stakeholders.	Operation managers and project managers of existing facilities. Experts and scientists dealing with human resources management, psychology, marketing, business development etc. PhD students whose research focuses on social and ethical aspects, such as those described before.

Table 1 – Linking common challenges in Megaprojects, to the specific challenges of nuclear decommissioning, the innovation required and the stakeholders involved. Extended from (Invernizzi et al., 2019, 2017)

3.2 Unit of analysis

As presented in Table 1, the planning and delivery of nuclear-decommissioning megaprojects involve access to virtually all R&D fields, both hard science (such as chemistry, geothermal, electronics) and social science (such as project management, economics, anthropology). The UK government and the NDA recognise that the skills, expertise, and resources needed to address nuclear-decommissioning can be found in UK universities and other relevant organisations. Over the years, several initiatives to promote collaboration among these organisations in an OI perspective have been promoted.

Two popular programmes are the NDA PhD projects and the Centres for Doctoral Training (CDTs), but other PhDs are funded through other mechanisms, including some directly funded by Sellafield Ltd, or by other industries and research organisations. CDTs are sponsored by UK research councils (i.e. the UK government) and involve a group of UK universities in delivering a four-year doctoral training programme to a minimum of 50 PhD students, over five cohorts (EPSRC, 2018). Each CDT targets a specific area of research, such as sanitation in developing countries, or, as in this case, nuclear decommissioning. CDTs are awarded to universities on a competitive basis, and a key success factor for winning these large grants is to show the heavy involvement of industrial partners, government bodies, and other relevant stakeholders. Funds are also provided to support the secondment of PhD students in these organisations (EPSRC, 2018). The PhD projects sponsored by the NDA involve the annual sponsorship of 5-6 PhD students on a research topic selected by the NDA. Each PhD student works on the research project for 3-4 years in his/her university under the supervision of an academic and an industry expert (either from the NDA or from another relevant organisation). The PhD student is also invited to liaise with several stakeholders such as the NDA, contractors, local communities and international organisations. By sponsoring PhD projects, the NDA can access tangible and intangible resources in universities and other research centres, and increase its network.

Such PhD projects are a great example of inter-organisational collaborations and catalyse OI by favouring fruitful interactions between scholars and practitioners, overcoming the hindering factors that often affect university-industry collaborations (Kunttu et al., 2018; Thune, 2010). They are an ideal case to investigate OI for several reasons:

- They are a representative case of structured OI practice in megaprojects;
- They explicitly promote long-term ties between scholars and practitioners, representing a best practice in leveraging OI through university-industry collaboration; and
- They explore the peculiarities of a megaproject from an OI perspective, paving the way to future projects.

All these different programmes have slightly different characteristics, however, they share a basic structure bringing together three key people: the PhD student, the academic supervisor (from a UK university) and an industrial supervisor (e.g. from the NDA, Sellafield Ltd or another organisation). As emerged from the literature, there is a consolidated body of knowledge describing both megaprojects and OI at the organisation-level, while a paucity of studies has focused on the individual level. Therefore our unit of analysis has been designed to address this gap in knowledge. The unit of the analysis are the experiences of the PhD students, academic and industrial supervisors involved in these sponsored PhD projects. The concept of experience will be unpacked looking at the motivations, interpersonal relationships, benefits and costs experienced at the individual level by the three categories of people involved in the PhD projects.

3.3 Data collection

Primary data was collected using semi-structured interviews (Qu and Dumay, 2011) based on a questionnaire specifically prepared for this purpose (Table 2). The questionnaire was sent to the interviewees as an attachment to the invitation to participate in the research. Thus, the interviewees had the time and full information to decide whether they wanted to participate in the research or not. The interviewees were selected through purposive sampling (Palinkas et al., 2015) to balance the mix between PhD students, academic and industrial supervisors. A total of 28 interviews were conducted between September 2018 and January 2019. The authors interviewed 14 PhD students, which correspond to as many PhD projects, 8 industrial supervisors, 5 academic supervisors, and the manager of some of these PhD programmes. Some academic and industrial supervisors had been involved in multiple PhD projects. The interviews ranged from 16 minutes to 53 minutes and lasted an average of 28 minutes. Table 2 shows the semi-structured questionnaire questions, linking them with their purpose and the research question they aim to address.

Purpose	Semi-structured questionnaire questions
General information on the interviewee	1. How are you involved in the decommissioning of the Sellafield site?
Micro-foundations underpinning university-industry collaboration [RQ1]	2. Which were your motivations to start supervising/participating/etc. in the PhD project? 3. How were you linked with the academic/industrial/both institution before the beginning of this PhD project? (Long-lasting relationship vs occasional vs never involved?)
Benefits and costs at the individual level [RQ 2]	4. Which benefits did you expect before starting the PhD project? 5. Which benefits did you achieve/are you achieving at the end/during the development of the PhD project? 6. What did you learn during your involvement with the PhD project? From whom? 7. What do you think is/will be the impact of the PhD research on the decommissioning project? 8. Which costs/investments did you expect before starting the PhD project? 9. Which costs/investments incurred/are incurring during the development of the PhD project?
Enabling and hindering factors [RQ 3]	10. Which do you think are the best practices of this kind of PhD project? 11. Which do you think are/have been the barriers to the success of this PhD project? 12. To what extent do you think sponsoring multiple PhD projects could be applied outside the NDA/NNL/Sellafield scheme?

Table 2 – Questionnaire items and their purpose

3.4 Data analysis

After the permission for recording was granted, the interviews were recorded, transcribed and analysed through thematic analysis (Braun et al., 2012; Dixon-woods et al., 2005). Thematic analysis *is "a qualitative research method that can be widely used across a range of epistemologies and research questions. It is a method for systematically identifying, analyzing, organizing, describing and reporting themes found within a data set"* (Nowell et al., 2017, p. 2). Thematic analysis is a highly flexible approach that can be modified for the needs of many studies, providing a rich and detailed account of data. It is also a useful method for examining the perspectives of different research participants, highlighting similarities and differences, and generating unanticipated insights. Additionally, thematic analysis is useful for summarising key features of a large data set, as it forces the researcher to take a well-structured approach to handle data, helping to produce a clear and organised final report (King, 2004).

The first step of the analysis was transcribing the interview recordings. During a familiarisation process that involved repeated listening to the recorded interviews and reading of the transcripts, emerging data was noted and listed as preliminary codes. To ensure consistency, all the preliminary coding activity was performed by one of the authors, who – for each interview and each of the answers to the semi-structured questionnaire questions – synthesised relevant quotes using keywords (e.g. PhD04 sentence "*There is a significant pay cut to me. So, I get paid quite a lot less than I used to get paid*" was labelled as *salary* in the question 9, Table 2). Such quotes and the linked keywords were then discussed and amended in the team. Subsequently, such keywords were aggregated into preliminary categories (e.g. the *salary* keyword was merged with the *time* keyword into the *life investment* category), which allow for the refinement and assignment of descriptive data to synthesised information (Olawale et al., 2015). This step has been an iterative process that involved looking through data, recurring sub-themes and searching for associations (Olawale et al., 2015). A sense-making narrative was created by leveraging such categories for each of six identified main themes: 1. Motivations of the participants; 2. Interpersonal ties; 3. Personal benefits; 4. Personal costs; 5. Enabling factors; and 6. Hindering factors.

The next section presents the results of the thematic analysis. Confidentiality is assured through the replacement of the interviewees' names with the codes: IndSup##, for industrial supervisors; AcaSup## for academic supervisors; PhD## for PhD students. Similarly, organisations' names and brands were coded with Org##, research program names with Prog##, and locations with Loc##.

4 Results

This section summarises the key results that emerged from the thematic analysis. The results have been organised according to the six themes. For each theme, the perspectives of the interviewees are presented.

4.1 Motivations of the participants

There are multiple motivations for scholars, practitioners and students to participate in the PhD projects. As expected, learning is a motivating factor for both PhD students and supervisors. PhD students are attracted by the specific nuclear-related topics that they expect to study (e.g. PhD07 was attracted by the opportunity to understand radiation science, chemistry and electrical engineering better). As well, academic and industrial supervisors expect to learn from one another, especially on topics outside their main area of expertise. As confirmed by IndSup05, "*it's really good for keeping up to speed with developments on what is going on in academia rather than just focusing on nuclear industry things".*

Professional development is also seen as a powerful motivation for PhD students since they often end up working in the industry or academia. Also, supervisors see opportunities for their professional development since "*the opportunity to attend [conferences] as a co-author […] raises your profile and again allows you to chat with other industrials who are working in your field*" (IndSup05).

In terms of funds, academic supervisors are keen to bid for PhD projects, since other grants opportunities are more challenging (the application is longer and the success rate lower). Securing research grants is often a requisite for the career advancement of UK academics.

Some of the interviewees are also motivated by the socio-economic impact since there is an interest to address the environmental problems associated with nuclear-decommissioning megaprojects and improve its economic performance. IndSup04 confirmed: "*I understand that we must reduce the cost of decommissioning otherwise I think sort of the prospect for the nuclear sector is not great*", while AcaSup02 observed that *"it's obviously a big societal, environmental benefit to clean up the waste and decommission these legacy sites".*

4.2 Interpersonal ties

Only a few of the PhD students liaised with the nuclear industry before starting the project, whereas the majority had links with academia. Conversely, almost every academic supervisor had previous professional ties with the nuclear industry. Similarly, several industrial supervisors had prior professional ties with academia. Nevertheless, in most cases, previous ties were weak, stemming from consultancy and small tasks (for academic supervisors and PhD students) or university-related projects and lectures (for industrial supervisors). This is effectively explained by AcaSup02 "*The links were not necessarily PhD project related, there were some consultancy links and some small programs of work that we used to develop the relationship but when I started the relationship was pretty weak, to be honest. So, we did a lot of initial consultancy with Org03 to sort of provide evidence of our skills […] so, the PhDs didn't start straight away*" and by IndSup06 "*I used to look after the Org01 direct research portfolio, I was there at the university [...] so, I managed the Org01 direct research portfolio previously and that was the university program so, I've been involved in university-related projects for quite a while*".

Such weak ties demonstrate the importance of these PhD projects, since they may end up in long-lasting professional relationships. In this vein, IndSup02 emphasised the value of "*having this professor or that teacher or that head of school or someone whom you can actually use at a later date for a purpose that is not necessarily directly linked to that PhD portfolio*".

4.3 Personal benefits

The interviewees offered an overview of the benefits achieved thanks to the funded PhD projects. PhD students benefited from expanding their network of contacts, obtaining more freedom and flexibility in terms of working hours, attending conferences, gaining access to laboratories and to the Sellafield site (difficult to access otherwise), publishing articles, and obtaining professional training. PhD students learned from their supervisors who were experts in the nuclear fields but, more interestingly, also from their peers, postdocs and colleagues, as highlighted by PhD10. Employment opportunities are also good: "*one of the parts of the submissions for the new CDT which was great was the employment rate of the previous CDT and how many of those postgraduates end up working in the industry or going on to further academic role, [...] 90% of the people going through this system are still in the system, in advanced level*" (AcaSup05).

Academic supervisors learned from their PhD students, "*because the students can drive a lot of knowledge" (*AcaSup02), but also from the industrial supervisors, "*the good thing about the industry people is that they have a lot of information buried away that you might read […]. So, I mean that's useful, get into knowing their problems is useful, getting into understanding solutions to those problems and generic solutions that can apply across a range of problems*" (AcaSup04). Academic supervisors also benefit from their published articles, which have a positive effect on their career and their university's reputation. Networking leads to relevant collaborations and "*get you known in the industry, and if the contacts are the right contacts, it will get your technology adopted*" (AcaSup03).

PhD projects may also support access to extra funding "*we've got an Innovate UK grant for a lot of the [...] techniques developed from PhDs and postdocs*" (AcaSup04). PhD students also acknowledged the development of additional skills (i.e. self-managing and self-confidence).

Industrial supervisors acknowledged that they have learnt from PhD students, for instance, from a methodological perspective, but also from other supervisors. IndSup06 affirmed, "*I think the PhD process has to fit in within the overall open innovation portfolio program and it's about making sure you can access the good ideas and realising the good ideas don't just come from internally, they come from externally as well*". From the industry perspective, there were reputational benefit through access to academic expertise and writing on scientific journals: "*you can get to meet the academics at the labs at the universities, and you get chances to have conversations with them about other things that might be applied to our issues, and you get to meet other PhD students you aren't supervising, it might be of interest*" (IndSup05). Access to each other's facilities and equipment is also particularly advantageous, because "*the universities have got the equipment that we don't have access to here*" (IndSup05).

The findings suggest that the benefits of a PhD project-driven university-industry collaboration do not necessarily coincide with tangible outcomes for the involved organisations (e.g. patents or new products) but, in most circumstances include the less tangible intermediate outcomes of the research and "contribution to knowledge". Intermediate outcomes can be new knowledge, ideas for opening new areas for research, or development of personal skills, which may be of use for future researches and projects.

4.4 Personal costs

The aforementioned personal benefits often come at a cost. PhD students may need to spend time and money commuting or moving to another country, with personal cost related to leaving family and friends. Furthermore, they usually receive a lower salary than their peers in the industry and, in certain cases, work longer hours.

Similarly, several industrial supervisors argued that the effort needed to supervise the PhD student is heavier than expected. This is exemplified by IndSup07, who states that "*there is a slight mismatch between the amount of funding available and investment that is required. Nevertheless, we are doing this in the first place. And if there was no funding at all, it just wouldn't happen. So, I'm very grateful to NDA for what they do provide*". Furthermore, most academic supervisors agreed that the time spent with the PhD student was more than expected. To explain the phenomenon, AcaSup01 confirmed "*mostly because the topic was very good, the person, the PhD student was very good and she wrote tons of stuff that needed to be reviewed*", while AcaSup02 observed, "*some students require* *more or less time depending on where they are in their PhD, initially, there's a lot of time to make sure they're sort of okay with the project*". AcaSup02 also described the time cost related to the location of collaborators, "*there's large time-cost: […] we have to go to Org002 to present results at least once a month or once every couple of months or whatever for 4/5 different projects […] and that's when the time can start to hurt to my perspective*".

4.5 Enabling factors

There was general agreement from interviewees for several enabling factors that emerged from the interviews. Supervisors need to be adequately motivated and have competences relevant to support their PhD student. As stressed by PhD07 and PhD14, having motivated supervisors is "*actually very useful*" because they feel supported and "*always have someone to rely on*". IndSup06 also observed, "*you need to make sure that the industrial supervisor has relevant technical knowledge, so he needs something that that person is interested in, that he has the knowledge, you need some alignment there*".

From both the PhD students and the industrial supervisors' perspective, the exposure of students to the industrial environment is heavily recommended. PhD08 emphasised the importance of spending time on-site and "*speaking with people every day who was on plant or on-site is very important because sometimes there are some problems that you didn't consider […] you see that they have a totally different approach*". PhD12 underlined the importance of "*getting involved in what other people are doing in the industry and understanding how all the projects and how all the researchers are interlinked*". IndSup03 interestingly observed that "*the students are based full-time in Loc01, [...] we give them access to our engineering rig, and we have much closer supervision of their activities on them. That works really well [...] these students know more about why they're doing their research than most other students. So, if you were to go and talk to students […] at the university, they would typically have some idea about the industrial challenge that they've tried to address, but quite often they will have something a bit wrong, […]. It doesn't happen at all when we talk to the people that we're working with, in the Prog01.*"

Additionally, the engagement of scholars and practitioners is seen as a major best practice. IndSup04 explained "*it's really that working together [industry and academia] and having good discussions and constant dialogues that I really think makes the scheme successful and gives us the maximum chances of success*", while IndSup06 revealed, "*there are other feeds, we're not just relying on these PhDs, we've got to engage with other academics, other programs and it's all feeding into that*". Good relationship among the supervisors is a key success factor, "*[the industrial supervisor], very knowledgeable, can tell you the right things in the right moment, can introduce you to other* *people*" (AcaSup01). Purposeful and frank university-industry interactions are fundamental because "*it's really important that the industry tells academia what its challenges are, what its needs are*" (IndSup04) and "*we must always listen to one another, and I think the beautiful thing about industry-academic projects is that parties learn from one another. And we start to learn and speak each other languages. [...] So, I think listening is really important*" (AcaSup03).

A further key enabling factor is a long-term perspective that allows a new project to build on the work of a previous PhD project. IndSup04 explains "*then maybe after the PhD you might [...] have another 3 years project to develop the technology further, but we need funding maybe from a customer, from someone like Org03 or another nuclear company*". Similarly, according to AcaSup05 "*what I think of a PhD project, it's usually an area that I want to know more about, and I probably want to know more about it because I want to take it further*." AcaSup02 observed that having continuous funding from industry to propose further PhD projects is very useful, "*because* [*Org03]* *liked what happened on the PhD and then saw more questions they wanted answering, they want to fund more specific research in ongoing thing*".

PhD projects are reviewed and the satisfaction of the PhD students surveyed, as "*one of the things that we do and actually work quite well is that every year [Org02 submits] a survey of all of the students to ask for feedback and to tell us like what work can we do, what works well, what doesn't work well and so on. And overwhelmingly that feedback is over 90% positive*" (IndSup02).

4.6 Hindering factors

According to the interviewees, this type of PhD project is not exempt from aspects that can hinder their success. PhD students observed that having multiple supervisors can be an obstacle to their work, feeling like they are "*doing two projects, […] a project for the academic and a project for the industry people*" (PhD13), so "*it's really important that they [the supervisors] are on the same page*" (PhD07). Furthermore, they have too few institutional chances to meet with other PhD students and share experiences, as "*most of the PhDs don't speak to each other, [...] the time [in the annual meeting] was too short […] to understand which the problems in all PhDs were*" (PhD02). Similarly, IndSup04 observed, regarding the annual meetings organised within the project "*one day is always a challenge to get an understanding of what everyone's doing*", suggesting that more meetings would be of help.

Several PhD students complained about the interaction dynamics with the industry side "*when [PhD students] come into the industry they have to deal with so many other people, it becomes very difficult to navigate in this*" (PhD07) so "*sometimes there is like a gap between what [the PhDs] think is very important and what [the industry people] think*" (PhD08) and "*it makes collaborating pretty* *much impossible and working together is quite difficult as well*" (PhD13). Also, academic supervisors perceive difficulties in the interaction with industry, "*understanding whom to speak to, to get the PhD students heard, to get the information out of academia into the industry is really difficult*" (AcaSup02). AcaSup04 remarked the importance of prepared industrial supervisors "*when you got somebody who's prepared [...] it makes a huge difference, I mean sometimes industry allocates people who are in charge of university interactions [...] and technically they're not ready*". AcaSup05 reported the negative aspects of industrial supervision "*it's like a small group of discussion with progress; there's no real interaction because the academic supervisors don't go to those meetings. […] that's all about project reporting; and also from the industrial side, there's no clear understanding of what is the real supervision*". Several industrial supervisors consider too little the time allocated to interact with their PhD student "*the actual amount of money available from the Org001 in terms of contact time is really not quite enough"* (IndSup03), while "*often I will put in extra hours to answer emails and correspond and think about things which I'm not really being paid to do*" (IndSup07).

In addition, the data and facilities needed by the PhD students were not always granted, or clearance was difficult to obtain, with negative repercussions on their research activities "*the industry had all the labs and all the equipment I need, but basically, they wouldn't let me in their lab. I never really got a proper answer for why I'm not allowed to go into their lab. Also, they would have tried to charge me for using their lab even though they're funding the project themselves*" (PhD13). The issue of accessing facilities is associated with the extremely hazardous and confidential nature of the megaprojects, which also hinders the communications among the individuals (e.g. cybersecurity in plants impedes the use of many widespread videoconference tools).

Intellectual property is also an issue since data confidentiality can hinder the publishing activity deriving from the PhD project. AcaSup01 explained "*a company […] could put an embargo on your thesis, prevent you from publishing [...] for 5 years and therefore the thesis was examined, but only certain examiners could do it, and nothing could be published off it for 5 years*", while AcaSup05 added "*if the industry is fully funding the PhD, it owns [all the intellectual property] and would have rights to exploit it. Now the problem comes when most of the models are partly funded, for example, Prog002, where 2/3 comes from the university, and 1/3 from industry and you have to agree on the sharing of IP*".

5 Discussions

The vast majority of megaproject literature takes an organisational perspective, where stakeholders are usually organisations. Even when discussing citizens and local communities, the focus is on those people as a group, not on the single person (Di Maddaloni and Davis, 2018; Wang et al., 2017). Only a few papers focused on individuals, typically project managers or decision-makers (Eweje et al., 2012; Flyvbjerg, 2006). Paradoxically even if megaprojects are 'done by people for the people' there is a lack of studies about the personal motivations, benefits and costs for people. More generally, the perceived experience of the people participating in the megaproject has been vastly ignored. Addressing this gap in knowledge is a key contribution of this paper.

The aim of this paper is studying the micro-foundations of OI in megaprojects focusing on the 'people' experiences in university-industry co-supervised PhD projects. Figure 1 summarises the key results. This section, by leveraging the literature review and the findings, discusses relevant implications to theory and practice. In particular, Subsection 5.1, Subsection 5.2, and Subsection 5.3 discuss respectively the implications related to RQ1, RQ2 and RQ3.

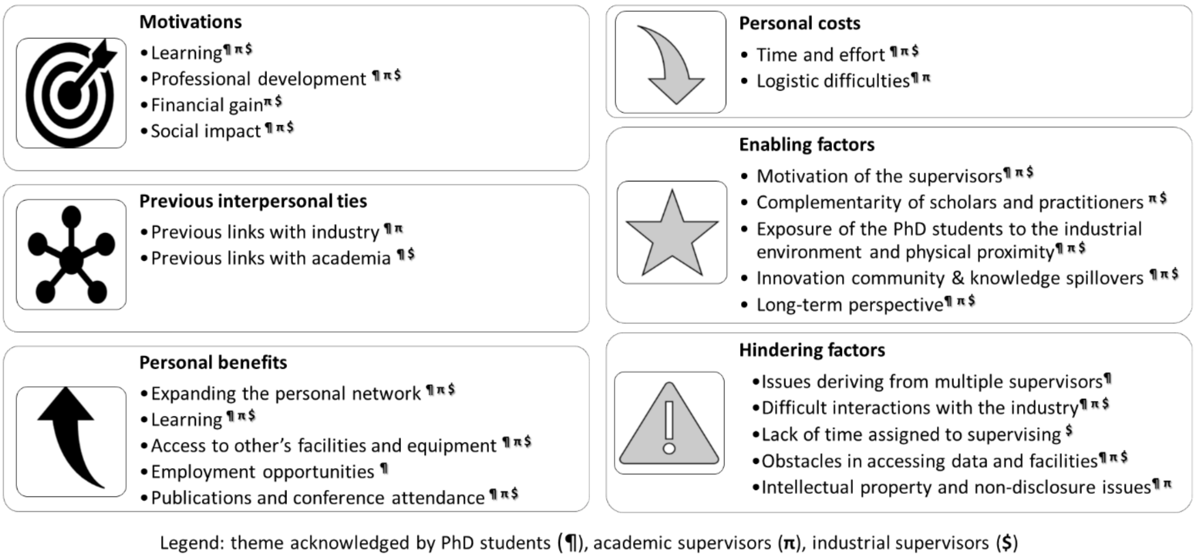

Figure 1 Key findings from the empirical research

5.1 The micro-foundations underpinning university-industry collaboration in megaprojects (RQ1)

Industrial PhD projects are usually associated with studies shaped following the needs of a company (Kihlander et al., 2011). They often aim to reduce uncertainties in innovative activities and to encourage the knowledge and skill transfer between University and Industry (Kitagawa, 2014). The findings showed that the individual-level factors underpinning university-industry collaboration are twofold: the achievement of personal – intangible and tangible – benefits, and the pre-existence of interpersonal professional links.

Firstly, individuals in each of the three categories under investigation anticipated opportunities for personal and professional development that originally motivated them to submit a proposal for a PhD project and consequently start the university-industry collaboration. From an utilitaristic perspective, PhD projects allowed access to financial resources with limited effort with respect to other public funds (e.g. research projects sponsored by the European Union). Such resources were particularly useful to give the supervisors the chance to work on an innovative topic of joint university-industry interest. Even though time was sometimes underestimated by the supervisors in the first place (as aspect discussed in the next subsection), winning the grant would allow them to justify their involvement in the specific research activity in the first place. Furthermore, some interviewees were also fascinated and somewhat excited, by the opportunity to address topics of great social relevance within the nuclear decommissioning challenge.

Secondly, weak interpersonal ties (Granovetter, 1977) between scholars and practitioners were important to engage in such PhD projects. While weak ties have been considered problematic for transferring knowledge in previous studies (Billington and Davidson, 2013), this research shows that they act as prerequisites to enable knowledge transfer through PhD projects, since, in most cases, the knowledge transfer would not have been possible without them. From an absorptive capacity perspective, the discussed weak ties enable the stakeholders' 'search' capability (Ahn et al., 2016), allowing them to identify suitable partners to start a research project of mutual interest. Weak ties are likely to have an impact also in the more general definition of joint university-industry collaborations, consistent with recent findings on pre-existing interpersonal relationships (Al-Tabbaa and Ankrah, 2019). Indeed, Al-Tabbaa and Ankrah found that pre-existent relationships between individuals were more important than pre-existent relationships between the respective organisations.

5.2 The personal benefits outweigh the costs in university-industry collaboration in megaprojects (RQ2)

The people involved in the PhD projects achieve multiple and diverse benefits, including the development of new knowledge, capabilities, and relational capital, as well as the achievement of new professional opportunities. Responding to our RQ2, the feedback gathered from the interviewees suggests that personal benefits largely outweigh the costs. Hereafter, we discuss the observed benefits and costs in view of the literature.

One straightforward individual-level benefit comes from the mutual learning that occurred during the collaborations, this finding is consistent with the expectations from the literature (Bogers, 2011). PhD students have the opportunity of experiencing an industrial context, differentiating them from typical research doctorates, as also observed by Cardoso et al. (2019). Their engagement encourages them (and their supervisors) to work outside their comfort zone, shaping the learning process as acknowledged by Pittaway (2007). Consistent with Ankrah et al. (Ankrah et al., 2013), industrial supervisors engage with cutting edge research and access complementary know-how, in part through the PhD students' capability to produce and transfer knowledge, which was also described by Thune (Thune, 2009). Academic supervisors gather access to practitioners' know-how and can apply their research results in practice, creating an 'impact', which is considered a particularly important outcome in British academic sector. The knowledge gathered by the academic supervisors includes information relevant to teaching (Lee, 2000), as well as information on industry problems, feedback from industry, and information on industry research as described by D'Este and Perkmann (D'Este and Perkmann, 2011). From an absorptive capacity perspective, the people involved in the PhD projects can learn from the approaches and routines of others and gain from the diversity of their knowledge. Therefore, they accrue their 'integrating' capability (Ahn et al., 2016; Arbussà and Coenders, 2007), and are more capable of making sense of other people' knowledge and integrate it with their own.

The people involved also draw benefits in terms of professional ties and professional development. This result confirms the positive effect of externally-driven university-industry collaborations on the social capital of the subjects involved (Al-Tabbaa and Ankrah, 2016; Al-Tabbaa and Ankrah, 2019). Long-term collaborations are related to interpersonal ties, that over the years can establish trust between universities and industries (i.e. inter-organisational trust) and reduce organisational barriers (Bruneel et al., 2010; Fitjar and Gjelsvik, 2018; Mcevily et al., 2003; Messeni Petruzzelli, 2011; Santoro, 2001; Sjöö and Hellström, 2019). Oliver et al. (2019) also observed that organisational issues and the lack of experience in university-industry collaborations, reduce trust and, consequently hinder the overall project's outcomes. Both supervisors and PhD students benefit from opportunities for professional development by accessing experts and decision-makers. In a climate of mutual trust, the interaction between people from different organisations becomes a source of creativity (Lazzarotti et al., 2016). The above-mentioned individual benefits contribute to the success of the PhD projects under analysis, adding further evidence to the literature exploring the role of self-interest in social sciences (Miller, 2001; Smith, 1776).

With respect to costs, the PhD projects prove time-expensive for all the people involved, and occasionally logistically complex, due to the need to meet in person and visit sites. For some PhD students recruited overseas there is also the "emotional cost" of leaving families and managing long-distance relationships. While the distance factor has obtained much attention in the university-industry collaboration literature on geographic proximity at the organisation-level (e.g. Crescenzi et al., 2017; Hong and Su, 2013; Laursen et al., 2011), to the best of our knowledge the weight of time investments and distance at an individual level has been under-researched.

5.3 Enabling and hindering factors of the university-industry collaboration micro-foundations (RQ3)

This study identified several enabling factors of the university-industry collaboration micro-foundations. Moreover, the study suggested some practical implications applicable to megaproject stakeholders aiming to develop similar PhD projects.

Strong personal motivations facilitate the effectiveness of both academic and industrial supervision. In the investigated OI scheme, the supervisors have mainly mentioned intangible personal benefits. Therefore, it is important to involve people in supervisory roles with personal interests in innovation. This confirms earlier studies about incentives to engage in OI activities (Antikainen et al., 2010; Enkel and Bader, 2016; Franco and Haase, 2015; Razak et al., 2014).

PhD students need supervisors with different theoretical, methodological and technological competencies. For the PhD students, with both industrial and academic supervisor involved in the megaproject, this is promoted by the diversity of the supervisors' backgrounds. Such diversity is a success factor for innovation projects (Padilla-Meléndez et al., 2012). The complementarity of such competencies and their partial overlapping promotes mutual understanding as described by Messeni Petruzzelli (Messeni Petruzzelli, 2011).

PhD students need access to the facilities and technologies of the organisations and institutions involved in the PhD project. Visiting the megaproject site is critical to understand the context, interact with experts and appreciate the obstacles related to the applicability of the research. Accessing critical resources such as laboratories, data, competencies is a necessary condition for successful collaboration (Eisenhardt and Schoonhoven, 1996), therefore accessibility needs to be resolved at the very early stages of the PhD project, or better, secured by the academic supervisor before the project starts. The result recalls the literature on physical proximity and OI, which emphasises the importance of immediate comparisons and face-to-face interactions (Batterink et al., 2010; Mueller and Jungwirth, 2016). Regular meetings, conferences, and seminars promote a successful collaboration and nurture the personal relationships between the people involved in the PhD project. Frequent communications develop empathy and an understanding of personal needs and expectations (Al-Tabbaa and Ankrah, 2016). Knowledge transfer is unlikely to happen effectively when interactions are infrequent (Landry et al., 2007). It is necessary to have a broad range of interactions, both formal and informal to overcome misalignments (D'Este et al., 2007).

PhD students and their supervisors are nodes of a global network (Yuan et al., 2018). Their capability to scan such a network for the knowledge, data, and technologies they need for their research, as well as their capability to use such externally-sourced inputs, is in-line with Arbussà and Coenders view of absorptive capacity (Arbussà and Coenders, 2007). In line with the concept of innovation community, "*a network where everyone can propose problems, offer solutions, and decide which solutions to use*" (Pisano and Verganti, 2008, p. 6), the small number of people involved in a PhD project are able to leverage the strength of their wide scientific and/or professional network. In turn, the outputs of the PhD students' research are often shared – e.g. during scientific conferences, industry association meetings, articles, and reports - conveying knowledge spillovers that contribute to progress within and outside the original boundaries of the megaproject. In this context, spillovers are intended to reach a variety of stakeholders including policymakers and other organisations dealing with comparable megaprojects. Furthermore, the outcomes of PhD projects often become inputs for new PhD projects, representing a spillover that helps to build the knowledge base needed to address the goals targeted by the megaproject.

A long-term perspective is essential to stimulate the development of not only the right answers but also the right questions. Several authors have emphasised the importance of long-term collaborations between industries and universities (Ankrah et al., 2015; Geisler et al., 1990; Striukova et al., 2015). Indeed, planning multi-years collaborative research projects stimulates successful research outcomes by enabling a better understanding of the overall project context. PhD projects require a minimal budget with respect to the underpinning megaprojects; however, they can be critical to the development of constructive, long-term relationships between the key stakeholders that need to join forces for the overall success of the megaprojects, both in the short and long run (Turner et al., 2012).

The vast literature on OI and university-industry collaboration at the organisation-level has identified several hindering factors, which were effectively systematised in seven classes by Ankrah and Al-Tabbaa (Ankrah and Al-Tabbaa, 2015): "(*1) Capacity and Resources; (2) Legal Issues, Institutional Policies and Contractual Mechanisms; (3) Management and Organisational Issues; (4) Issues relating to the Technology; (5) Political Issues; (6) Social Issues; and (7) Other Issues"* (p.9). Our results are consistent with many of them, including the difficulties in accessing data and facilities (1), in the interactions among the subjects involved (3), infrequent physical interactions (7), and the management of the intellectual property (2, 4).

With respect to the interaction difficulties and restricted access to data, the key issues are the nature of nuclear decommissioning megaprojects and the sensitivity of the information, leading to communication difficulties due to cybersecurity and clearance restrictions to the industrial facilities. However, this is true also for non-nuclear megaprojects since the access to data and sites pose security and/or safety issues and need to be carefully planned. In fact, while a simple project (e.g. the construction of a primary school) does not require a great deal of secrecy or access to extremely sensitive information, the situation is different for megaprojects due to their complexity, national relevance, and the multitude of organisations involved. Furthermore, industrial supervisors are usually very busy professionals, and their timely and long-lasting involvement is not guaranteed. This kind of hindering factor can be overcome with more resources (usually time) allocated to extend the industrial supervisors' participation in the PhD projects. This time needs to be negotiated in advance with the line managers. The findings have shown that supervisors are not always aware of their commitments toward academic-related goals, such as the completion of the dissertation in the agreed number of years and the collaborative dissemination of research results.

Regarding the management of intellectual property, our findings have confirmed its problematic nature. The conflicts generated by intellectual property issues identified in the interviews are typical of university-industry collaboration (Ankrah and Al-Tabbaa, 2015; Siegel et al., 2004) and OI in general (Barchi and Greco, 2018). If a private organisation is funding the PhD project, it usually owns the IP developed and has the right to exploit it, but when the projects are partially funded by academia, government and industry, alternative legal agreements are needed upfront. Consistently with Tartari et al. (2012), we found conflicts over the timing of disclosure of the research, which frustrated some of the interviewees.

Unlike Tartari and Breschi (2012) findings, this article did not find evidence of fears over loss of academic freedom, in the investigated sample, due to the interaction with industry, save aspects related to confidentiality. Multiple factors can explain this difference. Firstly, our interviews took place a decade after Tartari and Breschi's research, a time horizon during which academics have become much more open and less suspicious towards the industry. Secondly, patterns for British academics may be different with respect to the Italian ones, who were targeted by Tartari and Breschi. Thirdly, the megaproject context attracts scholars and practitioners that are very interested in collaborating with each other, despite the difficulties, which may not be the cases of the sectors investigated in the previous study.

6 Conclusions

Megaprojects are an important area of project studies and represent the ideal setting to foster innovation because of their complexity and budget. Therefore, there is a growing interest in innovation management in megaprojects, especially in the OI context (Davies and Brady, 2016; Dodgson et al., 2015; Worsnop et al., 2016). A relevant but under-researched OI practice in megaprojects involves university-industry collaboration, which is defined as the interaction between higher educational system (e.g. universities) and industries, with the aim of exchanging tangible (e.g. materials, equipment or funds) and intangible (e.g. technology, knowledge or data) resources (Ankrah et al., 2013; Ankrah and Al-Tabbaa, 2015; Tartari and Breschi, 2012).

This paper adopts a micro-foundations perspective to analyse the experiences of PhD students, academic and industrial supervisors involved in PhD projects developing innovations in megaprojects. The micro-foundations perspective shifts the unit of analysis from the organisations and the network of organisations (a traditional perspective in project studies) to the people involved in the project (a topic that has received far fewer attentions).

The findings show the importance of individual learning and personal development, which are among the main drivers for the development of knowledge and technology within collaborations (Bogers, 2011). Moreover, it emerges that several benefits of participating in the PhD collaborations do not necessarily coincide with the final outcomes, nor need necessarily to have a tangible form (e.g. patents or products). Most of the benefits identified in the interviews take the form of intangible intermediate outcomes, including new knowledge gained, novel ideas for opening new areas for research, or the development of personal skills. These PhD projects can pave the way for future researchers, and favour long-lasting university-industry relationships. Indeed, successful collaborations between organisations need to share a certain level of similar competencies and capabilities (Messeni Petruzzelli, 2011) which is a trade-off with the diversity of organisational backgrounds, a critical success factor for innovation projects (Padilla-Meléndez et al., 2012). This tension shows how the development of valuable innovations requires different and complementary capabilities, skills and culture, which in turn foster the absorptive capacity enabling organisations to explore external sources of knowledge, adapt to environmental changes and increase the degree of innovation (Teece et al., 1997; Zahra and George, 2002).

As a contribution to theory, this paper has revealed how OI is fostered by university-industry collaborations in the context of megaprojects with the direct involvement of scholars and practitioners, and the indirect involvement of other people professionally linked to them. The PhD projects under investigation have shown that the implementation of OI in megaprojects is not without difficulties, for instance, due to the confidentiality of information and access to sites. Still, such PhD projects are considered to carry a positive final benefit/cost balance at the personal level. Moreover, the paper shows how taking a micro-foundations perspective can contribute to project studies shifting the interest from organisations to people.

The contribution to practice is the description of the enabling and hindering factors for organisations involved in co-supervising PhD projects in megaprojects. The research identifies the expected pay-off for the person involved, e.g. higher qualifications and career progression (for PhD students), grants and publications (for academic supervisors) or personal development (for all the individuals involved). The research shows how prior interpersonal ties (e.g. between supervisors) are a positive element to achieve innovative outcomes and an even broader network. These existing links promote the interpersonal trust that tends to increase over time through long-lasting collaborations, ultimately leading to inter-organisational trust too. This can reduce the likelihood that partners will act opportunistically and support the alignment of objectives of the different stakeholders during the PhD projects and also in future projects or collaborations.

Leveraging the results of this research, relevant practical recommendations can be suggested to organisations willing to replicate the idea of sponsored PhD projects:

- Provide appropriate and timely support for accessing data, information, facilities, and overall know-how;
- Establish frequent communications about the progress and directions of the collaboration between the key people involved in PhD supervision (at least on a monthly basis);
- Clearly frame the project context (i.e. scope and requirements) to maintain project alignment, in other words clearly defining what is in the scope and what is not, and adequately manage scope changes; and
- Nurture long-term relationships and long-term collaborations by creating formal and informal meetings.

The article has limitations that need to be acknowledged. Firstly, the results are exploratory in nature, and future researches could explore more in-depth the generalisability of these findings and attempt to elaborate on them. Secondly, the study focuses on a specific sector (nuclear decommissioning) and a specific country (the UK), and future research could explore different PhD projects in other sectors in the context of projects and megaprojects.

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